A methodological framework for developing the structure of Public Health economic models

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- Young Operational Research Society Conference, Exeter, April 2013 (Key note oral presentation for the Health Stream);
- Health Economics Study Group (HESG), Warwick, June 2013 (Paper presented by another participant with subsequent author clarification and discussion).

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List of Abbreviations

AHP	Analytic Hierarchy Process
CATWOE (Mnemonic)	Customers (people benefiting within the system), Actors (people performing the tasks in the system), Transformation (the core activity of the system), Weltanschauung (or worldview – the objective of the system and its underlying beliefs), Owner (the person with the power to approve or cancel the system) and Environment (external factors which may impact upon the system eg. legal rulings)
DES	Discrete event simulation
HTA	Health Technology Assessment
LYG	Life Year Gained
NICE	National Institute for Health and Care Excellence
NHS	National Health Service
PAM	Purposeful activity model
PDG	Programme Development Group
PMM	Performance Measurement Model
PSA	Probabilistic Sensitivity Analysis
PSM	Problem structuring method
PSS	Personal Social Services
QALY	Quality-adjusted life year
SACS	Sociology and Complexity Science
SODA	Strategic Options Development and Analysis
SSM	Soft Systems Methodology
WHO	World Health Organisation

Abstract

Mathematical models are frequently used to assess the cost-effectiveness of Public Health interventions to improve allocation of scarce resources. Public Health interventions tend to operate within dynamically complex systems and require broader considerations than clinical interventions. Inappropriately simple models and lack of justification may lead to poor validity and credibility, resulting in suboptimal allocation of resources. A conceptual modelling framework is a methodology that guides modellers through the development of a model structure. This research aims to answer the question; 'What might a conceptual modelling framework for Public Health economic evaluation comprise and what could its potential be to improve model quality?' Such a framework does not currently exist.

The framework was informed by: (a) two literature reviews of the key challenges in Public Health economic modelling and existing conceptual modelling frameworks; (b) qualitative research to understand the experiences of modellers when developing Public Health economic models and their views about using a conceptual modelling framework; and (c) piloting a draft version of the framework within a diabetes prevention project. Evaluation was via theory-based analysis and a focus group of modellers.

The conceptual modelling framework comprises four key principles of good practice and a proposed methodology. The principles are; (1) a systems approach to Public Health modelling should be taken; (2) developing a thorough documented understanding of the problem is imperative prior to and alongside developing and justifying the model structure; (3) strong communication with stakeholders and members of the team throughout model development is essential; and (4) a systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling. The conceptual modelling framework is described within the thesis.

Evaluation suggested that the framework, which could be used for good practice, reference and education, could improve model quality if disseminated in an accessible form. Future research recommendations include use within different case studies followed by further evaluation and development of methods for modelling individual and social behaviour drawing upon Sociology, Psychology and Public Health.

Chapter 1: Why a formal conceptual modelling framework might have the potential to improve the quality of Public Health economic model structures

1.1 Chapter outline

The research question addressed within this thesis is ‘What might a conceptual modelling framework for Public Health economic evaluation comprise and what could its potential be to improve model quality?’, where ‘quality’ is defined as part of the research. There is no agreed definition of a conceptual modelling framework,[1] which is also developed as part of the research; however the preliminary definition is taken to be ‘a set of principles and methods which facilitate the development of a qualitative description of a quantitative model.’ Section 1.2 describes the study aim and objectives and Section 1.3 explains the rationale for the research. Section 1.4 describes my academic and philosophical position and Section 1.5 sets out the approach taken within the research. Section 1.6 outlines the structure of the thesis.

1.2 Aim and objectives of the study

The aim of this thesis is to develop a conceptual modelling framework which has the potential to improve the quality of Public Health economic model structures. The objectives are:

- To identify and explore key challenges within Public Health economic evaluation by reviewing what other researchers have exposed within the literature.
- To specify the way in which existing conceptual modelling frameworks might help within Public Health economic evaluation by exploring the literature across a broad range of disciplines.
- To provide an analysis of modellers’ views about the way in which Public Health economic models are currently developed and the benefits and barriers of conceptual modelling frameworks.
- To assess critically the use of the draft conceptual modelling framework within a case study assessing the cost-effectiveness of interventions for diabetes screening and prevention.
- To produce a conceptual modelling framework document that can be used by modellers to help them develop Public Health economic model structures.
- To evaluate the framework via focus group analysis and theory-based evaluation.
- To make recommendations around future research and use of the conceptual modelling framework developed.

1.3 Rationale for the thesis

In order to describe the rationale for the thesis, background information about health economic modelling, methods for dealing with uncertainty, the discipline of public health and conceptual modelling, is required. These are each described below.

1.3.1 Health economic modelling

Worldwide there are insufficient resources to meet the demand for healthcare.[2] This means that decisions are required about which healthcare resources should be funded and which should not. In many countries including the UK, rather than making *ad hoc* decisions based upon non-explicit and selective information, a rational and coherent framework is used for making these decisions, with an aim of maximising the health gains of society according to the available budget.[3] Health economic evaluation attempts to provide such a framework by comparing the differences in costs and outcomes between alternative options in order to help decision makers make choices between competing priorities.[2] Health economic evaluation is now well established within the UK and worldwide.[3]

<u>Types of economic evaluation</u>

The predominant type of economic evaluation within applied healthcare research is cost-effectiveness analysis.[3] The origin of cost-effectiveness analysis is said to be within Operational Research where a unidimensional health-related objective function is maximised within a set of budget constraints by identifying and valuing all healthcare interventions.[3] However, due to the large number of permutations of healthcare interventions and settings, and the continuously changing nature of healthcare, this theoretical approach is not practically possible. As such, simple decision rules have been developed for comparing two or more alternatives for a specific population within a particular setting. This approach involves employing a threshold to represent the estimated opportunity cost (the monetary value of the health foregone) of healthcare interventions displaced by new, more costly interventions to assess whether the benefit of the new intervention is greater than the interventions being displaced, assuming a fixed budget constraint.[4] The outcome measure most commonly employed within cost-effectiveness analysis is the incremental quality-adjusted life year (QALY) gained.[3;4] Cost-effectiveness analysis is the recommended approach for economic evaluation by the UK National Institute for Health and Care Excellence (NICE). Within England and Wales, the generally accepted threshold for a healthcare intervention to be considered to be cost-effective is £20,000 - £30,000 per incremental QALY gained.[5]

Cost-benefit analysis is an alternative approach, which requires both resource use and consequences of an intervention to be expressed in monetary amounts. This is usually estimated by valuing the willingness to pay of individuals for a health gain or for avoiding a disbenefit.[3] This can be assessed via a survey, known as contingent valuation, or it can be estimated based on trade-offs which have previously been made between outcomes and money.[6] Under Kaldor-Hicks criterion, interventions must result in sufficient benefits such that the people who benefit could in theory compensate the people who lose out and as a result of this compensation no individuals are made worse off (taking into account both costs and outcomes).[3] Whilst a cost-effectiveness analysis in economics is associated with extra-welfarism which aims to maximise health by choosing all medical procedures which are more cost-effective than a certain threshold, cost-benefit analysis is grounded within welfarism which aims to maximise overall welfare subject to a budget constraint.[3] This means that healthcare interventions would be compared with all other goods. Given the scope of Public Health interventions and associated outcomes, a cost-benefit analysis may be considered theoretically superior,[7] however there are practical issues associated with monetary valuation of outcomes.

Another form of economic evaluation is cost-consequence analysis, where relevant costs and outcomes in multiple dimensions are presented separately rather than being combined.[2]

Mathematical models

Very commonly, mathematical models are used as a vehicle for undertaking economic evaluation.[2] This is because trials, particularly of Public Health interventions, would require large sample sizes and a long follow up period in order to be able to fully capture the costs and outcomes of the interventions. Mathematical models use mathematics to represent the parts of the real world and the relationships between those parts that are perceived to be of interest to those individuals who are assessing a particular problem.[8] This means that the level of abstraction is dependent upon the purpose of the model. Mathematical models can be used for economic evaluation to estimate the differences between the costs and outcomes of alternative interventions by simplifying complex realities, synthesising evidence from a wide range of sources and extrapolating short term data over the long term. Within these models, judgements about what is relevant for inclusion within the model and how relationships within the model should be represented are required. A model in health economic evaluation usually includes information about the relevant disease natural histories, current service pathways, the resources required and the health outcomes of the affected individuals. Models are intended to be simplifications of reality and we usually have imperfect data upon which to develop the model. This means that there are always uncertainties associated with the model structure and inputs, and hence with the model results. It is important fully to describe the level of uncertainty within the model results so that decision makers can understand the risk of making an inefficient and possibly irreversible decision. In addition, a description of which aspects of a problem are uncertain helps decision makers to consider where areas of further research may be of most value in reducing decision uncertainty.[3]

1.3.2 Methods for dealing with uncertainty

Uncertainty within a health economic model can be classified into parameter uncertainty, methodological uncertainty and structural uncertainty.[9;10]

<u>Parameter uncertainty</u>

The conventional approach for addressing parameter uncertainty is via the use of probabilistic sensitivity analysis (PSA) which involves the characterisation of uncertainty surrounding all model parameters using appropriate statistical probability distributions.[11] This uncertainty is most commonly propagated through the model using Monte Carlo simulation over a large number of samples to assess the likelihood that a given policy option is optimal.[11] However, current approaches to PSA do not account for methodological or structural uncertainty.[12]

<u>Methodological uncertainty</u>

Methodological uncertainty relates to methodological choices such as the perspective of the analysis, the discount rate and the valuation of health outcomes. NICE, which produces Public Health guidance within England and Wales, uses a Reference Case in order to standardise decisions around modelling methodology.[5] This reflects the broad technical value judgements of the decision making body. Key features of the Reference Case for Public Health economic evaluation are that: a cost-effectiveness analysis should be undertaken as the primary analysis (cost-utility where possible), with a cost consequence or cost-benefit analysis as a secondary analysis; costs should be based upon a public sector perspective; outcomes should include all health effects on individuals; a QALY has the same weight irrespective of the characteristics of the population; all costs and health effects should be discounted by an annual rate of 3.5%; and the comparator should be interventions routinely used in the public sector, including those regarded as best practice.[5]

<u>Structural uncertainty</u>

Structural uncertainty relates to whether all relevant processes are represented in the model, that is, what is included and excluded and how the relationships between inputs and outputs are captured.[13] In mathematical terms, given a function $f(p_1, p_2, \ldots p_n) + \varepsilon$, where p_i is a parameter and ε is an error term, structural uncertainty relates to which p_is to include within the model and the specification of the function 'f'.[10] Examples of structural uncertainty are which diseases should be included within the model, how to represent the disease natural history, which service pathways are relevant and how to model the relationships between intermediate outcomes and long term outcomes. Decisions about model structure are to some extent dependent upon the availability of evidence. If the model structure is inadequate then the PSA may provide misleading results in terms of the estimated mean result and/or the extent of the uncertainty around the results. Despite this, structural uncertainty has received the least attention in terms of methods development.[12]

Methods for dealing with structural uncertainty

Uncertainty around the most appropriate model structure may be dealt with retrospectively following model implementation by expressing the impact of uncertainties upon the model results and/or prospectively by considering the process through which decisions are made around the conceptualisation, structuring and implementation of the model.[14] The former of these aims to characterise uncertainty, whilst the latter aims to reduce uncertainty and understand where areas of uncertainty remain. Since in principle most structural uncertainties are fully or partially reducible, prospective methods are likely to be useful to decrease the probability of making an inefficient policy decision. The approach most commonly employed for handling structural uncertainty within health economic evaluation is scenario analysis, which involves assessing the impact of alternative structural assumptions upon the model results in turn. However, scenario analysis does not capture the combined uncertainty within the model results. Moreover, there are no formal methods for choosing the initial model structures or which structures to vary within the scenario analysis.

Recent methodological attention on structural uncertainty has focussed on variants of model averaging approaches, either at the whole model level or at the individual structural assumption level.[10;12;15] This approach essentially reduces to a process of converting structural uncertainty into parametric uncertainty by building alternative structures into the model and ascribing elicited probabilities to each structure so that standard approaches to analysing probabilistic uncertainty can then be used.[11] Resource and time constraints mean that it is not practical, or necessarily helpful, to ensure that all possible model structures (which may each require a number of different parameters to be specified) are implemented and ascribed appropriate probabilities. As for scenario analysis, currently there are no methods for determining a set of plausible model structures to incorporate within the analysis.

Strong *et al.* have recently developed a discrepancy approach; an alternative method which helps the modeller decide which structural assumptions are important during implementation of the quantitative model.[16] It does this by comparing intermediate model outcomes with available data and applying some discrepancy term to describe the error. However, this approach is in its infancy and the process of capturing structural choices as discrepancies is poorly understood.

Importantly, a fundamental flaw with all of the existing approaches for handling structural uncertainty is that there are no prospective methods for choosing and justifying appropriate model structures for the analyses.[17] Within this thesis it is argued that in order to handle structural uncertainty appropriately, prospective methods for understanding the decision problem and choosing appropriate model structures should be developed.

In 2010 within a study of avoiding and identifying errors in Health Technology Assessment (HTA), Chilcott *et al.* found that there were no formal methods for developing the model structure of health economic evaluations which were systematic or transparent.[17] Two conceptual modelling frameworks have been developed since 2010 when this research began: (1) by Kaltenthaler *et al.* (which I was involved in developing); and (2) by a working group of the International Society for Pharmacoeconomics and Outcomes Research (ISPOR).[14;18] This highlights the timely nature of this work. Both of these frameworks were developed for the economic modelling of clinical interventions and thus the structural development of Public Health economic models continues to be based upon *ad hoc* methods which are highly dependent upon the modeller and the stakeholders, as well as the decision problem.

1.3.3 Public health

Public Health has been defined as 'the science and art of preventing disease, prolonging life and promoting health through the organised efforts and informed choices of society, organisations, public and private, communities and individuals'.[19;20] More specifically, according to Green and Hiatt,[21] in order to prevent morbidity and early mortality by influencing behaviour and by protecting others from harmful behaviours, the objectives of the discipline of public health are to:

a) Identify, measure, monitor, and anticipate community health needs;
b) Formulate, promote and enforce essential health policies;
c) Organise and ensure high quality, cost-effective public health and health care services;

d) Reduce health disparities and ensure access to healthcare for all by improving the health of the poor and disadvantaged;
e) Promote and protect a healthy environment;
f) Disseminate health information and mobilise communities to take appropriate action;
g) Plan and prepare for natural and man-made disasters;
h) Reduce interpersonal violence and aggressive war;
i) Conduct research and evaluate health promoting / disease preventing strategies;
j) Develop new methodologies for research and evaluation;
k) Train and ensure a competent public health workforce.

Within Public Health, it is known that certain changes in diet or lifestyle will impact upon disease incidence; however much less is known about why people behave the way that they do and how to change the public's behaviour, and little is known about maintaining modified behaviour.[21;22]

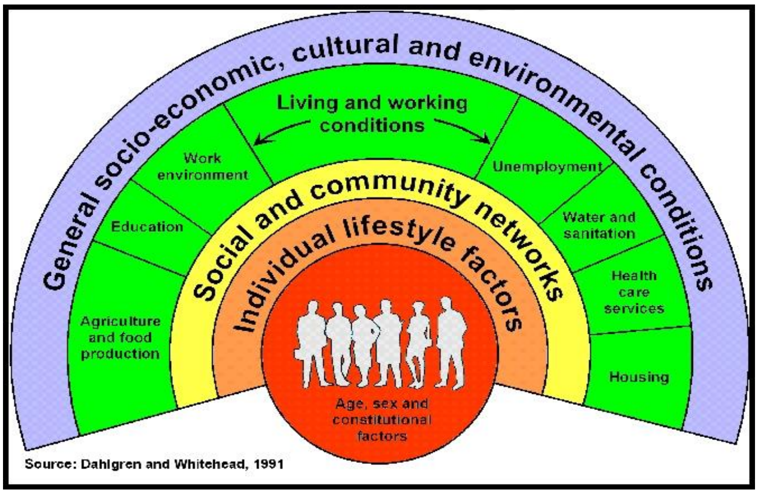
<u>Social structure</u>

Social structure is the result of billions of individual actions (human agency) which create patterns of behaviour.[23] However, society is more than the sum of the individual actions of the people within it, because there is inevitable interaction between the actions of individuals with each other, and with their social structure. The exact nature of this interaction is debated; however most sociologists agree that this relationship is complex and that, to some extent, people's behaviour will affect their social structure and at the same time their social structure will affect their behaviour.[24] Thus society is an entity in itself, which constrains and organises human behaviour without the conscious intent of the individual.[24-26] Different mechanisms act upon disease at the social level to the individual level.[27] At the social level, health is affected by the influences of social patterning, whilst at the individual level, behaviour and biology are causally linked to disease. It would therefore be insufficient for Public Health interventions to aim to modify individual behaviour, without consideration of the social structure, or to ignore the interaction between the individual and social level when assessing the effectiveness and cost-effectiveness of the interventions. The factors of social structure that impact upon health are known as the social determinants of health.

<u>The determinants of health</u>

The determinants of health have been classified in many different ways, but they tend to include individual, community and population level influence upon health. Perhaps the most well known is that of Dahlgren and Whitehead, shown in Figure 1.1,[28] reproduced with permission.

Figure 1.1: Determinants of health



Within Figure 1.1, the age, sex and constitutional (i.e. hereditary) factors in the centre are generally predetermined; however the remainder of the factors within the diagram are potentially modifiable. Other classifications of the determinants of health are briefly reviewed within Chapter 3.

Health inequalities and inequities

Health inequalities are differences between the health of groups of individuals, which may be unrelated to policy,[29] whilst health inequities are defined by the WHO as 'unfair and avoidable or remediable differences in health among population groups defined socially, economically, demographically, or geographically'.[30] It has been shown in the UK and in many other countries that there is a correlation between socioeconomic status and health, known as the social gradient.[31;32] This is the case for almost every disease.[33] The social gradient has become steeper over the last forty years.[34] This is because people with a higher socioeconomic status tend to benefit more from Public Health interventions than people with a lower socioeconomic status, thus improving average health across the population generally steepens this gradient.[32] It is therefore important that Public Health aims to tackle the challenges posed by the social gradient.[32;35] The relationship between socioeconomic status and health is complex and debated amongst social epidemiologists, involving material, psychosocial, behavioural and biological factors. Very little is known about how socioeconomic status directly influences biological factors.[36] Some researchers take a psychosocial perspective, suggesting that the perception of lower socioeconomic status causes stress which impacts upon health,[37] whilst others take a materialist position whereby lack of resources impacts upon health directly and psychosocial factors play a smaller role.[38] Other theories try to integrate these factors with behavioural and/or biological factors.[35;39]

The life course

It is important to understand the impact of time and timing upon the relationships between the determinants of health and the impacts of Public Health interventions when measuring and estimating outcomes. Complex behaviour generally takes time to modify and behaviours may be reinforced over the lifetime of the individual (i.e. a positive feedback loop may occur where an intervention leads to behaviour modification and the result of this leads to further similar behaviour modification) if the intervention is targeted at an appropriate time in a person's life course.[40] The concept of feedback loops within Public Health systems are explored in more detail within Chapters 2 and 3. Kelly *et al.* suggest that interventions may be most effective at specific points in the life course.[40] Within the NICE behaviour change guidance, examples provided of this are leaving school, entering the workforce, becoming a parent, becoming unemployed, retirement and bereavement.[22] This life course approach aims to understand how the social determinants of health impact on all stages of life from child development to adulthood.[40]

Complexity of Public Health systems

Public Health is generally associated with greater complexity than systems within which clinical interventions operate; thus my research focuses upon Public Health economic evaluation. Within assessments of clinical interventions, it is generally the disease and the impact of the intervention upon that disease which needs to be understood. Within Public Health economic evaluation, in addition to this, it may also be necessary to understand the relationship between the determinants of health / health inequities and behaviour and how that is affected by the intervention (as discussed above). As a result, the scope of the system involved may not be easily defined. The causal relationships associated with many Public Health interventions are shown in Figure 1.2 below and an example of the complexity of a Public Health system is demonstrated within the Foresight obesity map,[41] reproduced with permission in Figure 1.3. Further discussion of the complexity of Public Health systems and the implications of this for modelling is provided within Chapters 2 and 3.

Current approach to Public Health economic model development

Guidelines and checklists for good modelling practice have been developed for health economic models.[42;43] These allow modellers to review a model and check **what** has been done, but they do not describe criteria by which to judge each requirement or describe **how** models might be developed. For example, Phillips *et al.* suggest that 'all structural assumptions should be transparent and justified. They should be reasonable in the light of the needs and purposes of the decision-maker.'[42] The aim of the checklist is not to describe how to develop structural assumptions, nor are the criteria for the assumptions being ‘reasonable’ defined. Similarly, the NICE Public Health methods guide describes what to present, but does not provide methods for choosing model structures. Assumptions about the appropriateness of approaches for modelling clinical interventions may not always be questioned for economic modelling of Public Health interventions. Therefore, not only is there a limited understanding of the complexity of Public Health for which no formal methods for developing the model structures currently exist, but there may also be a lack of awareness for some modellers that the assessment of many Public Health interventions is a different type of problem which requires new ways of thinking for developing the model structure. A framework for developing Public Health economic model structures may help to guide modellers.

Figure 1.2: Causality for Public Health interventions

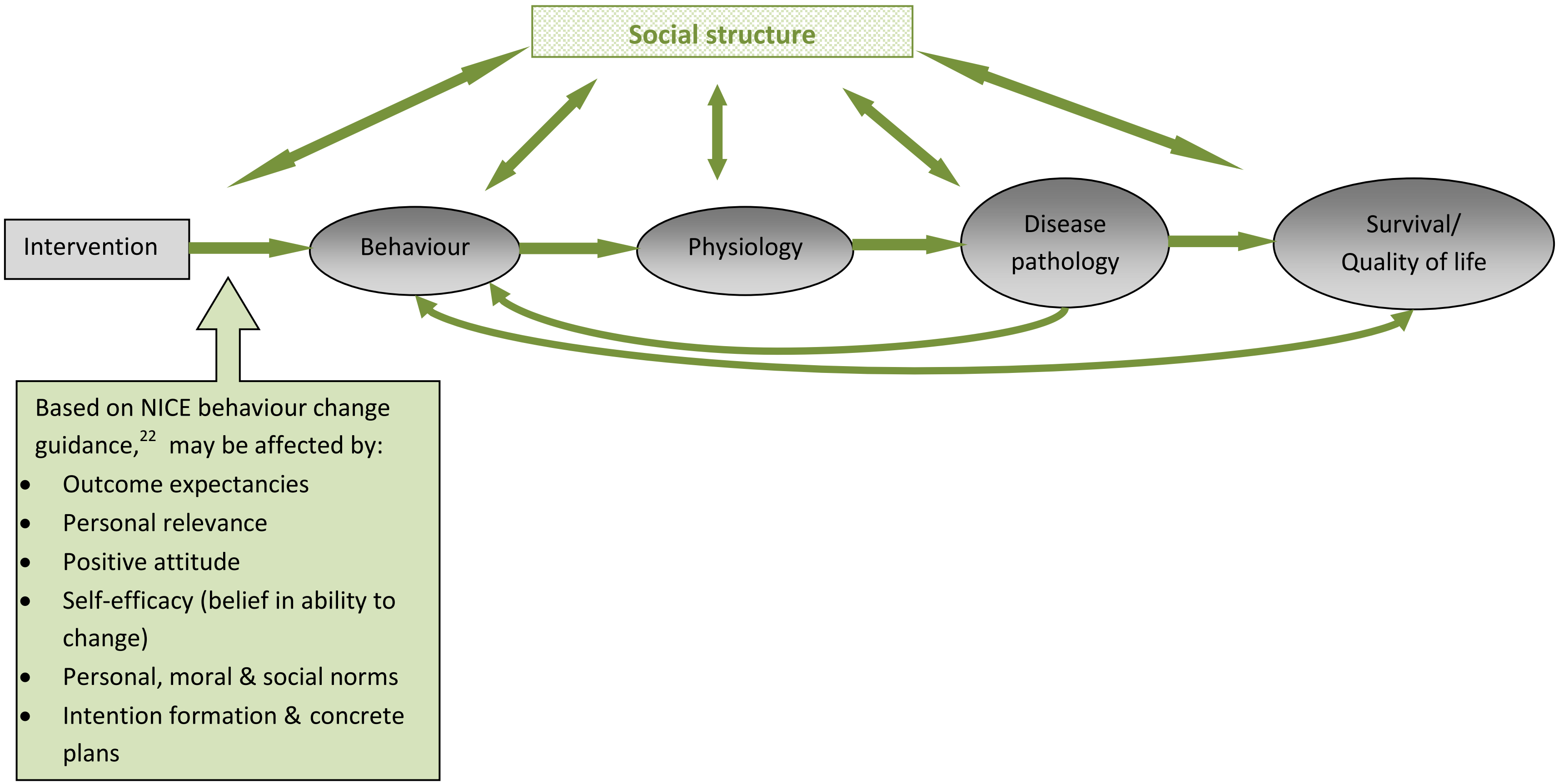
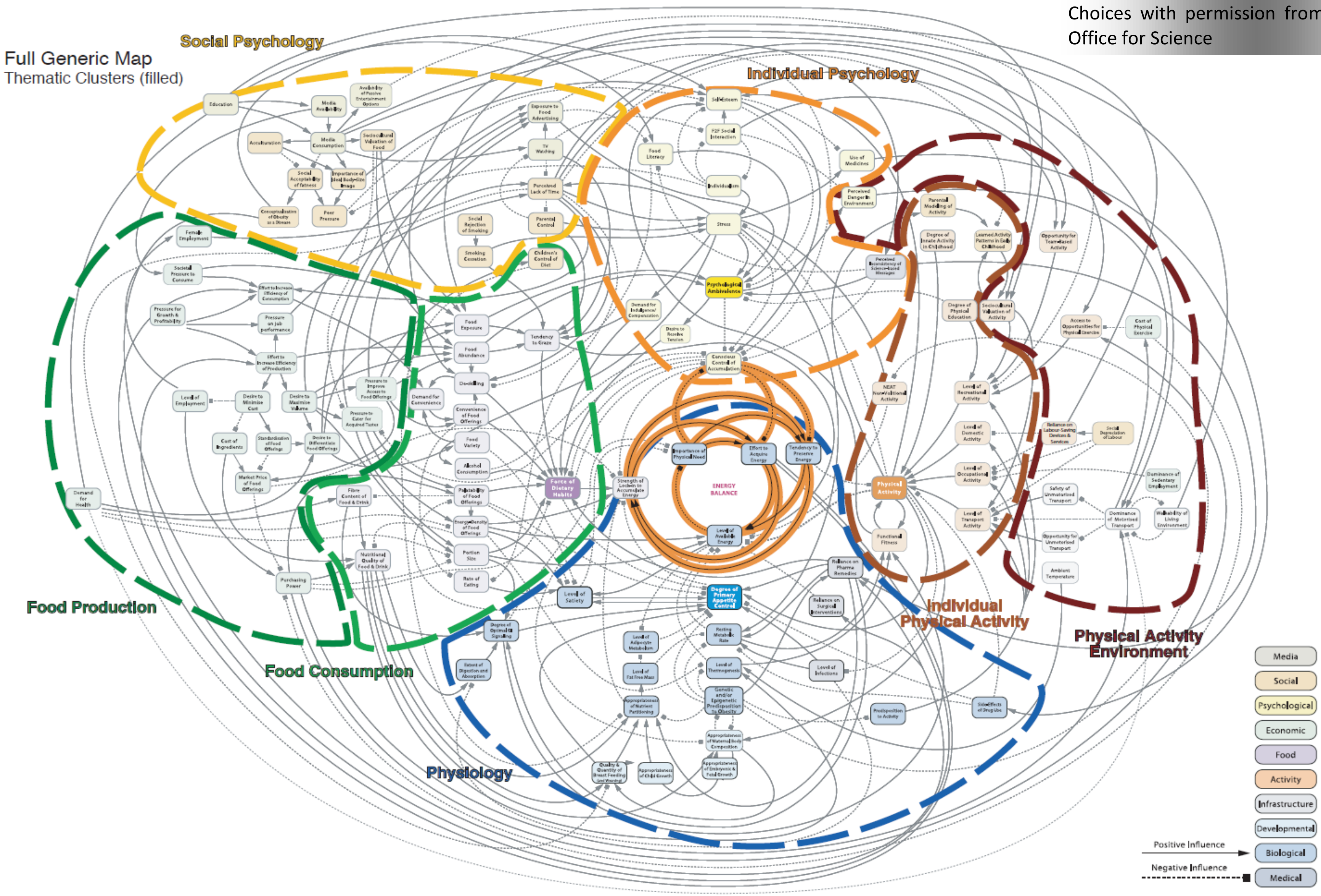


Figure 1.3: Foresight obesity map[41]

Reproduced from Tackling Obesities: Future Choices with permission from Government Office for Science



1.3.4 Conceptual modelling

Conceptual modelling is broadly the abstraction of reality at an appropriate level of simplification for the problem;[44] however there is currently no single agreed more comprehensive definition. This is explored further within Chapter 4.

<u>Current practice</u>

In 2010, a qualitative research study was published by Chilcott *et al.* about avoiding and identifying errors within health technology assessment models. One of the major findings was the large amount of variability within the model development process between modellers, particularly in conceptual modelling.[17] Conceptualising the problem (in some form) is an inevitable *a priori* process in order to develop a mathematical model; however within the Chilcott study some modellers suggested that they did not make a distinction between conceptualisation and implementation of the quantitative model, and of those that did, the process and level of documentation varied.[17] By undertaking conceptualisation and implementation in parallel, there is no basis for justifying the structure of the final model.[14] Modellers within that study suggested that written documentation may consist of the proposed model structure, assumptions, a diagram or sketch of the model design and/or clinical / disease pathways, memos, representative mock-ups to illustrate specific issues in the proposed implementation model and/or written interpretations of evidence.[17] The variation in defining a conceptual model is likely to be due to the paucity of literature around the process of model development within health economic modelling. For example, key health economic evaluation textbooks do not describe the conceptual modelling process,[2;3] and the conceptual modelling process is not considered within systematic reviews of Public Health economic evaluations undertaken to date.[45-48]

<u>The need for a conceptual modelling framework</u>

Importantly, within the study by Chilcott *et al.* approximately 70% of the discussion about elements which might contribute towards errors in decision making focused upon the conceptual modelling process.[17] Conceptual modelling is the first part of a modelling project, which guides and impacts upon all other stages. This means that if this is done poorly, all subsequent analysis, no matter how mathematically sophisticated, is unlikely to be useful for decision makers.[49]

Some literature describes conceptual modelling as an ‘art’ rather than a science, and hence the skills need to be developed by experience.[1] This may be true to some extent since subjective judgements are central to the development of model structures. However, Forrester states that any worthwhile venture emerges first as an art, and as such the outcomes are special cases and are poorly transferable, but that this can then be transformed into a science by understanding the foundations of the art, making it more useful to new situations.[50] If one takes this view, this would suggest that conceptual modelling is treated as an 'art' because the methods are in their infancy, rather than because conceptual modelling truly should be an 'art'. In the context of the defence field, Pace suggested that modeller professionalism could be improved by the development of conceptual modelling frameworks.[51] Several researchers have suggested that domain-specific frameworks are required, due to the difficulty in specifying a generic conceptual modelling framework.[1;52]

Benefits of a conceptual modelling framework

Based upon the book by Robinson *et al.* titled 'Conceptual Modeling for Discrete Event Simulation', some of the key benefits of a conceptual modelling framework may be: (i) improved model requirements (which may include improved understanding of the problem and the development of an appropriate model scope); (ii) improved credibility (i.e. stakeholder acceptance of the model) both by stakeholder involvement and clear documentation when developing the model structure; (iii) improved model validity (i.e. developing the right model) by facilitating the specification of appropriate structural assumptions; (iv) improved model verification (i.e. developing the model right) by providing a method for comparing the quantitative model with the intended structural assumptions; (v) guidance for testing alternative options; and (vi) clear model documentation which may facilitate independent validation and verification and model reuse.[1] A conceptual modelling framework may also facilitate the characterisation of structural uncertainties by understanding which areas remain uncertain and how, and as such helping to identify where primary research may be valuable. Consequently this primary research should help to reduce structural uncertainty within future models by providing evidence describing the relationship between factors where it was previously weak. The benefits of a conceptual modelling framework will be considered in further detail as part of the literature review of conceptual modelling frameworks in Chapter 4.

Model complexity

One of the key issues for consideration when developing a model is the level of complexity incorporated. The idea of parsimony has frequently been recommended in the context of model development.[18;44] Although there is wide agreement that a model should be as simple as possible in theory, practically there are limited methods for helping the modeller decide upon the level of complexity within the model. A conceptual modelling framework could help modellers to make decisions about the complexity of the model structure within Public Health economic evaluation.

1.4 Academic and philosophical position

My academic background and position

My academic background is in Mathematics and Operational Research, with Health Economic experience gained through application of these. Thus, my conceptual modelling framework has been developed with Operational Research at the core. However, the research reported in this thesis is inevitably at the intersection of a range of disciplines including Operational Research, Public Health, Health Economics, Econometrics, Psychology and Sociology, and these have been investigated and embraced throughout the development of the framework for this work. Whilst my academic background is in quantitative research, qualitative research has been undertaken as part of this thesis and I have developed my skills in this area.

My applied research experience in this area led to the identification of a perceived requirement for a conceptual modelling framework and thus at the start of this research I had a strong belief that this is an important gap. This has shaped my research question. I have endeavoured to be open to the possibility that a conceptual modelling framework may not be useful for all circumstances, and this has been discussed within the evaluation (see Chapter 8). I am examining the research question from the perspective of a health economic modeller which is consistent with my intended audience of the thesis. However, I am aware that my research experience may impact upon my interpretation of the data (see my ontological position below).

Paradigms

There are many different ways of thinking about a problem. In *The Structure of Scientific Revolutions*, Kuhn offers a way of dealing with these different perspectives.[53] Kuhn's central organising concept is paradigm. He argues that a paradigm is a set of agreed practices followed by groups of researchers, usually for some time period within a sub discipline within a broader disciplinary community. Within a paradigm there are shared preconceptions which in turn influence the methods for the collection of and the interpretation of evidence. These paradigmatic methods and processes often constitute the taken for granted assumptions of the sub discipline. For individuals who are very familiar with a particular sub-discipline, the paradigm is often assumed to be reality itself. This in turn means that evidence which does not fit with these shared preconceptions is likely to be rejected. Kuhn observed that this rejection will continue until such a point when not only is the evidence incompatible with current assumptions but also the adherents to the old ways of thinking no longer exert power over journal publication, control of grant awards and the appointment of new staff. At that point a new social order emerges and a paradigm shift occurs; the ways of thinking are revised.[53]

Our understanding of any topic at any point in time is constrained by the current paradigm. For example, our understanding of medicine employs a particular paradigm, within which in Western societies we expect to be healthy well beyond middle age.[54] Within the discipline of Public Health, several paradigm shifts have occurred from God being responsible for disease, to 'bad air', to germ theory, to the current paradigm that disease can be understood in terms of multiple risk factors.[55] These current broad assumptions within Public Health may also be contested.[56] The process of relating factors causally within a model is another example and this research is placed within the current paradigms associated with Public Health and causality. Throughout the research I will endeavour to identify the assumptions that I make as a researcher about data collection and analysis and the degree to which this may influence the inferences and conclusions made (see *reflexivity within the thesis* section over page).

<u>My ontological position</u>

A key philosophical issue within this work is around what reality is, since we are trying to understand and represent key aspects of reality. Ontology is about the nature of the world and what we can know about it.[57] There are three main ontological stances, although there are a number of variations around these. A realist stance argues that reality exists independently of people's beliefs and understanding, and that there is one true reality. A materialist stance also claims that reality exists independently of people's beliefs and understanding and that there is one true reality, but that it is defined by material aspects of the world such as physical or economic things. In contrast, an idealist stance argues that reality is constructed through human understanding and as such there are multiple realities.[57] There is no agreement about which ontological stance is the most appropriate or correct. Within this work, a subtle realist perspective is employed; which is a type of realism influenced by idealism, in that whilst it is assumed that there is one true reality, it is only knowable through human understanding and socially constructed meanings.[57] This Kantian position means that I may interpret data differently to another researcher, although the same methods should not generate contradictory conclusions between researchers. In the context of modelling, a subtle realist perspective means that it is important to share and question the assumptions of modellers, decision makers and other stakeholders so that our human understanding tends towards reality.

<u>My epistemological position</u>

Epistemology is about ways of knowing and learning about the world.[57] It may be argued that there are two main epistemological stances; positivism and interpretivism.[58] A positivist stance assumes that the results of the data analysis are objective, and independent of values, 'knowledge' and views, and as such objective methods of analysis are considered to be appropriate such as hypothesis testing.[58] Quantitative researchers often take a positivist perspective although they may recognise that aspects such as research design may affect the results of the research. In contrast, many qualitative researchers suggest that qualitative data analysis cannot be completely objective and that it is likely to be affected by the perspectives of the participants as well as the researcher's values, 'knowledge', views and research interests.[57] This is an interpretivist perspective and it is the perspective taken within this research. For example, participants may have different opinions about a social issue and within interview transcripts the researcher is likely to only analyse data that is relevant to the research question. I view health economic modelling from an interpretivist perspective since it is dependent upon subjective assumptions and values. However, it is worth noting that some people regard the results of these quantitative models as if they are an objective tool, thus taking a positivist stance in their interpretation.

Combining qualitative and quantitative research

Some researchers have suggested addressing research questions, where relevant, using pragmatic multi-methodology approaches, rather than being overly concerned by the philosophical positions of each approach.[57] However, other researchers have argued that multi-methodology approaches should be limited to using methods from the same epistemological stance since combining methods from different stances ignores the philosophical underpinnings of each of the research methods.[57] There is still no agreement about this, even between mixed methodologists.[57]

Qualitative analysis is generally associated with an inductive approach which involves looking for patterns from observations to generate theory, associated with an interpretivist epistemology. Quantitative research is generally associated with a deductive approach, which is consistent with a positivist epistemology, where a hypothesis is proven or disproven, when making generalisations from qualitative data.[57] Mason suggests that it could be argued that all research employs both deduction and induction since if taking a deductive approach the initial hypothesis is likely to be based upon existing data, and if taking an inductive approach the research question is likely to be developed based upon existing theory.[58] This research uses both deduction and induction in that the initial research question is based upon relevant theory and developed further during the research.

Reflexivity within the thesis

Reflexivity is the idea that meaning from research within an interpretivist paradigm is developed based upon the complex relationship between the understanding of the participant and the researchers prior to the research combined with the additional meaning gained from the research.[59] Throughout the research I take a reflexive approach. Thus, for example, within the qualitative research described within Chapter 5, meaning is developed based upon my prior understanding, the initial understanding of the participants involved, plus the iterative process of developing and describing meaning throughout the data collection. This new meaning in turn impacts upon the participants' and my understanding subsequent to the data collection setting. It is therefore important for me to be aware of my impact upon the research and identify any assumptions and preconceptions that I have which may impact upon my interpretation of data.[59]

Conceptual modelling employs a reflexive process whereby modellers, decision makers and other stakeholders are continuously sharing and establishing meaning and assessing what to do based upon prior meaning and activity. This conceptual modelling process mirrors the learning process and development of this research. Stakeholders are defined for the purposes of this research as 'any person who might impact upon or be impacted upon by the system of interest'.

<u>Range of research methods and writing styles within the thesis</u>

Part of my learning within this thesis was about the use of different types of research methods. Several different research methods are employed throughout and different writing styles are used as appropriate for each of these research methods. The literature reviews are written in the third person so as to present a relatively objective analysis of the papers identified, removing as much of my personal opinion and perspective as possible. In contrast, the qualitative research is written in the first person so as to remain in line with the reflexive approach taken. The critical reflection of the draft conceptual modelling framework case study is also written in the first person and is intended to provide more of an exploratory perspective.

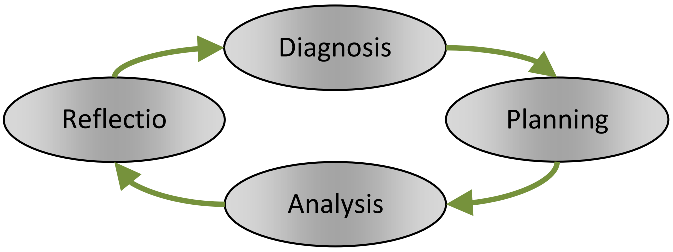
<u>The focus on the development of the conceptual modelling framework</u>

The Medical Research Council Guidelines for Developing and Evaluating Complex Interventions suggest that in order to understand whether an intervention is successful it needs to be developed, piloted, evaluated, reported and implemented.[60] These guidelines highlight the particular importance of adequate development and piloting work in order to lead to successful subsequent stages. I therefore focus upon the development and piloting of the conceptual modelling framework within this research. Full evaluation, reporting and implementation can be pursued within subsequent research following this work.

1.5 Approach taken

Throughout the thesis, a process of cyclical learning has been undertaken of diagnosis, planning, analysis and reflection as shown in Figure 1.4. My research question at the start of this work was 'What might a conceptual modelling framework for Public Health economic evaluation comprise and what could its potential be to improve model quality?' Following the research undertaken within Chapters 4 and 5, the research question was expanded to be clearer about the definition of 'quality'. The process of defining what the conceptual modelling framework would comprise was led by understanding how the framework might improve the quality of Public Health economic model structures. In addition, the conceptual modelling framework that has been developed is not intended to be a final unchangeable framework, but rather a starting point which can be continually revised following its use within different Public Health economic modelling projects and according to developments within other related research areas.

Figure 1.4: Cyclical approach to methods development



1.6 Thesis structure

The structure of the thesis is presented within Figure 1.5. Chapters 2-6 describe the methodological development of a conceptual modelling framework. The outcomes of the research presented within each of these chapters inform data collection and interpretation within multiple other chapters as shown within Figure 1.5, due to the cyclical approach to methods development taken. The exact way that each chapter feeds into each other is described within the relevant chapters.

Chapter 2 reviews the literature around the key methodological challenges within Public Health economic modelling in order to highlight key aspects of Public Health which may need to be considered within the model development process and to place my own research in the context of other research on Public Health economic modelling.

Chapter 3 considers, in more depth, some of the issues raised within the literature review in Chapter 2 where it was thought that further exploration would be useful. This involves consulting broader literature within the fields of complexity theory and systems thinking, Public Health, Sociology and

Psychology. It reflects upon what a dynamically complex system is and whether all Public Health systems are dynamically complex, the use of systems thinking for modelling such complex systems, it reviews the literature around the social determinants of health, and considers how models of Psychology and Sociology might be used to model behaviour within health economic models.

Chapter 4 presents a literature review of conceptual modelling frameworks. The aim of the review is to understand (a) what comprises existing conceptual modelling frameworks, in terms of the stages of model development considered, the level of detail provided, the definition of a conceptual model, the methods / methodologies recommended and the relationships between them, and the theory associated with the framework, and (b) the strengths and limitations of these frameworks, how they have been evaluated, and their potential application within Public Health economic modelling.

Chapter 5 describes modellers' experiences with developing the structure of Public Health economic models and their views about the benefits and barriers of using a conceptual modelling framework in order to facilitate the development of a useful conceptual modelling framework. The qualitative research methods employed are outlined, and the results of the analysis are described.

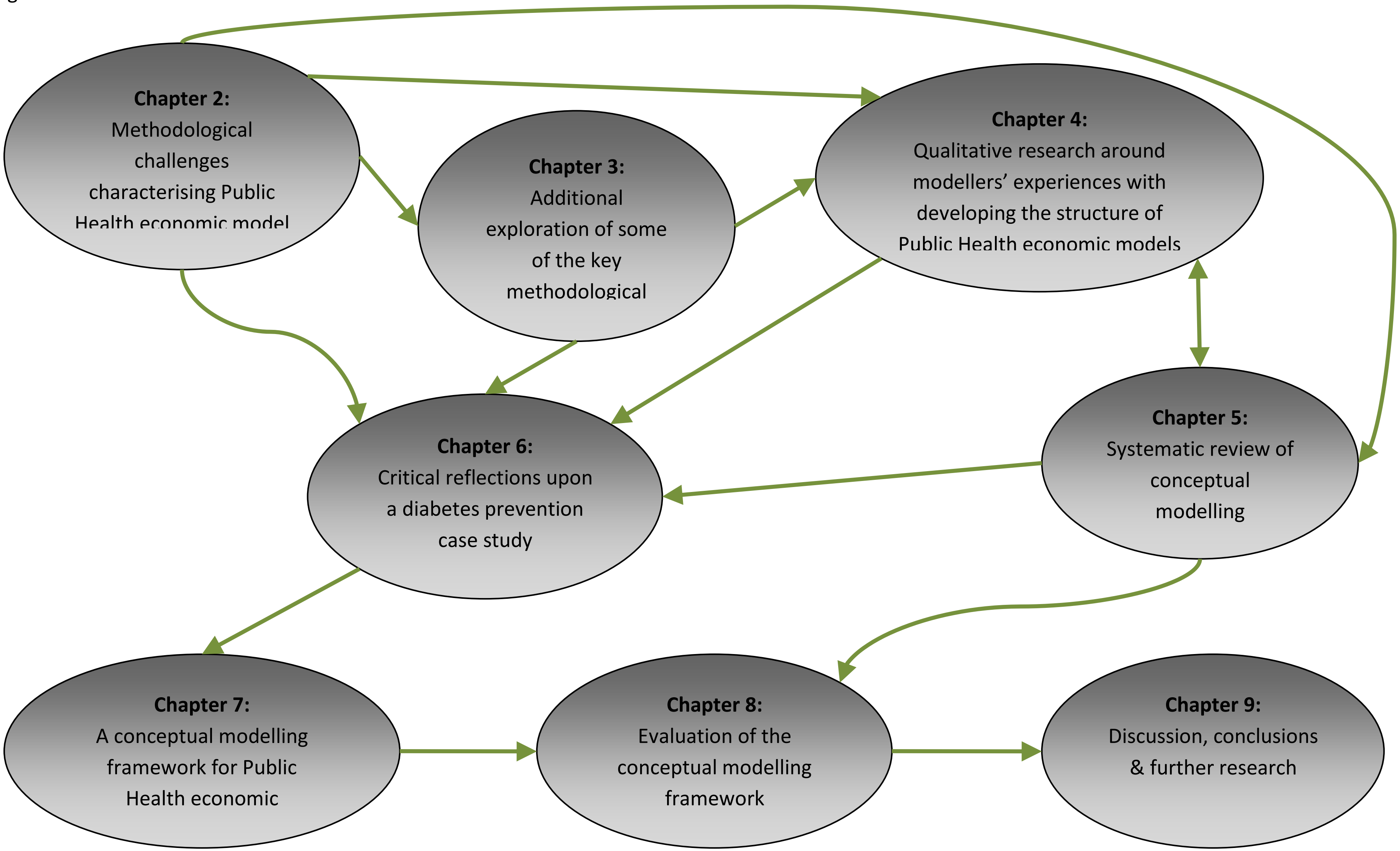
Chapter 6 describes my experience and critical reflections on the use of the draft conceptual modelling framework within a case study assessing the cost-effectiveness of prevention interventions for type 2 diabetes in order to further develop the framework.

The conceptual modelling framework for Public Health economic evaluation is described within Chapter 7, with justification for the methods presented based upon Chapters 2 - 6. An example to illustrate the methods is included using the diabetes case study described within Chapter 6.

Chapter 8 considers whether the research question has been addressed by (1) reflecting upon the theoretical basis of the conceptual modelling framework developed, including whether the framework might be associated with any negative implications for model quality, and (2) presenting the analysis of a focus group of modellers who provide their views on the utility of the framework.

Chapter 9 describes the contribution of each chapter of the thesis in the context of other research, with a particular focus upon the contribution of the conceptual modelling framework presented within Chapter 7. It also outlines the strengths and limitations of the research and the conclusions and further research recommendations.

Figure 1.5: Thesis structure



Chapter 2: Methodological challenges characterising Public Health economic model development

2.1 Chapter outline

A literature review of the key methodological challenges within Public Health economic modelling is presented. It aims to highlight key aspects associated with Public Health which may need to be considered within the model development process and to place my own research in the context of other research on Public Health economic modelling. Section 2.2 and 2.3 describe the methods and results of the review respectively. The review is divided into four key themes which were developed from the findings of the included papers; (A) inclusion of non-healthcare costs and outcomes; (B) the inclusion of equity; (C) multi-component interventions and complex systems; and (D) technical modelling issues. Section 2.4 provides a discussion of the review and Section 2.5 presents the implications of the review upon methods development.

2.2 Methods of review of key methodological challenges of Public Health modelling

The traditional Cochrane search aims to identify all studies that meet pre-specified inclusion and exclusion criteria.[61] Methodological reviews often require alternative search strategies which allow the scope of the search to develop as the reviewer's understanding of the methods increases,[62] with the aim of using the reviewing process to enhance understanding. Thus, for this review, papers were identified using an iterative approach to searching,[63] using a range of different search techniques described in more detail below. The inclusion and exclusion criteria developed as a result of the search is described within Section 2.3.

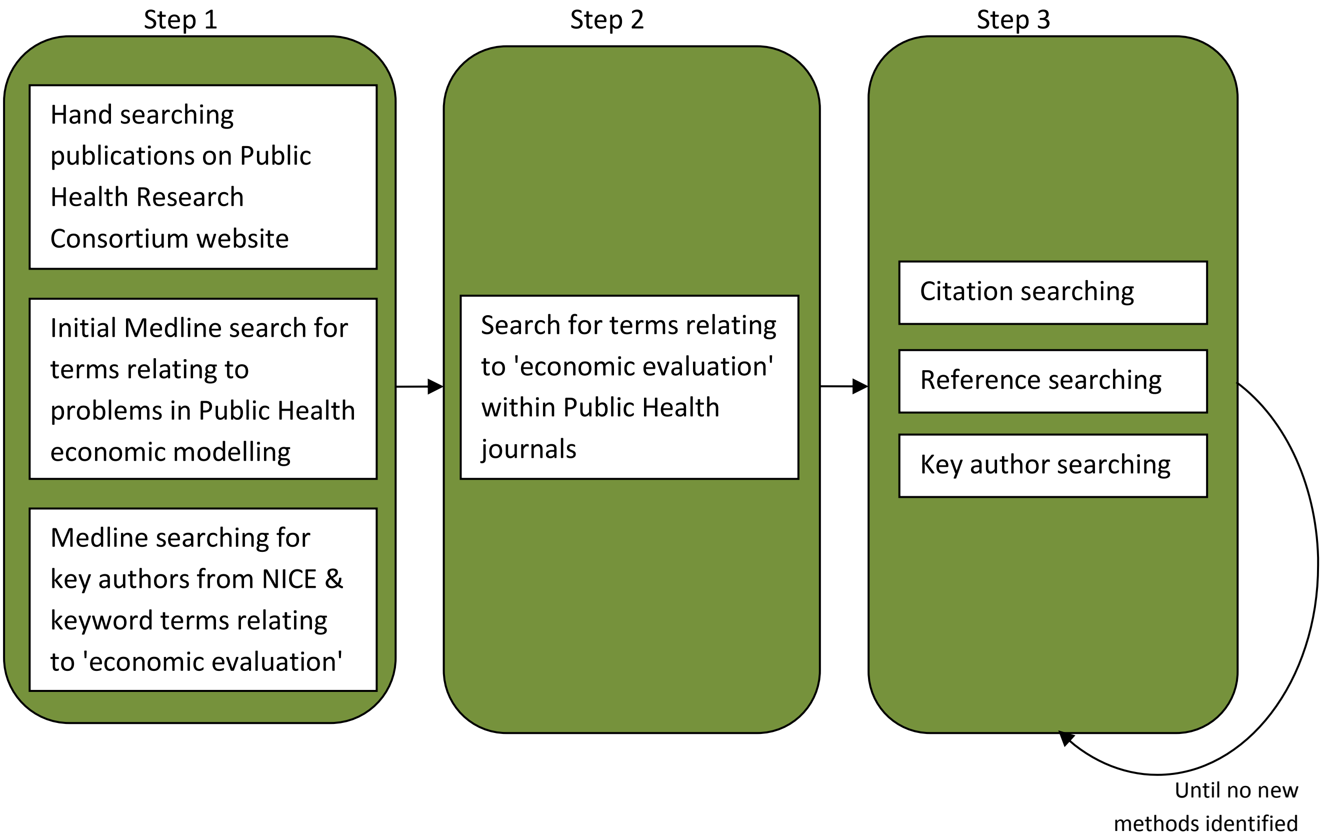
<u>Article identification</u>

In order to develop an initial understanding of potential methodological issues; (1) papers relating to economic evaluation resulting from the work of the Public Health Excellence Centre at NICE were identified by searching for key people from the website as authors in Medline; (2) the publications written by the Public Health Research Consortium, a collaboration between eleven UK institutions to strengthen the evidence base for interventions to improve health, were hand searched; and (3) a Medline search for terms relating to problems in Public Health economic modelling was undertaken. Due to the results of this step, key Public Health journals were subsequently searched (Journal of Public Health, European Journal of Public Health, American Journal of Public Health, International

Journal of Public Health) using search terms relating to economic evaluation. This was feasible due to the limited published data around Public Health economic modelling.

All of the retrieved literature was screened at title and abstract level for potential relevance, and the full paper was retrieved where insufficient detail was provided within the abstract to determine potential relevance. For those considered relevant to the review, citation searching, reference searching and key author searching was undertaken. The search was not limited to peer-reviewed publications if additional key information was presented within "grey literature" including relevant working papers and presentations from workshops and conferences. The process was repeated until theoretical saturation i.e. no new relevant material was identified. The search was undertaken in December 2010 and citation searching of the included papers was repeated in August 2013. Figure 2.1 shows the methods for the literature search. The search strategies are shown in Appendix A.

Figure 2.1: Methods for literature search



2.3 Results of review of key methodological challenges of Public Health modelling

Defining relevance resulting from the search process

During the search process, papers describing methods for valuing equity or health outcomes (as against the incorporation of these within a model) were not considered relevant because they related to parameterisation rather than model structuring.

The identified paper by Weatherly *et al.*[64] was based upon a more extensive report by Drummond *et al.*[48] and part of the report presented a systematic review of economic evaluations of Public Health interventions. The report identified and described the results of three other systematic reviews of Public Health economic modelling studies; West *et al.*,[45] Rush et al.[46] and McDaid and Needle.[47] The main limitations associated with the Public Health economic evaluations identified by the four systematic reviews were that many different outcome measures are used making comparison difficult, that the perspective adopted is often too narrow (i.e. health service perspective) and that many studies adopt a limited time horizon, all of which were identified by the included theoretical papers. Consequently, published case studies of economic evaluations within Public Health and these systematic reviews were not included within this review as it was considered that they were unlikely to offer any new methodological challenges. Thus studies defined as relevant for the review met the inclusion / exclusion criteria shown in Table 2.1 below.

Table 2.1: Review inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
A methodological paper on economic modelling in Public Health	Case studies of economic evaluations
	Methods for valuing equity or health outcomes (as against the incorporation of these in a model)
	"Grey literature" if the content is already published in a peer reviewed journal

Included articles

Eighteen articles identified from the search were considered to be relevant. A summary table of the included articles is provided in Appendix A. The articles have been divided into four categories which emerged from the review, shown in Table 2.2 below.

Table 2.2: Number of articles identified per category

Author (year)	Category			
	Inclusion of non-healthcare costs and outcomes	Inclusion of equity	Complex systems & multi-component interventions	Other modelling issues
Kelly *et al.* (2005)[65]	√		√	
Weatherly *et al.* (2009)[64]	√	√	√	
Claxton *et al.* (2007)[66]	√			
Mooney (2007)[67]	√			
Shiell (2007)[68]	√		√	
Smith and Petticrew (2010)[69]	√		√	
Anderson (2010)[70]	√		√	√
Cookson *et al.* (2009a)[71]		√		
Richardson (2009)[72]		√		
Shiell (2009)[73]		√		
Cookson *et al.* (2009b)[74]		√		
Plsek and Greenhalgh (2001)[75]			√	
Shiell and Hawe (1996)[76]			√	
Whitehead (2010)[77]			√	
Rickles (2009)[78]			√	
Rappange (2009)[79]				√
Total per category	7	5	9	2

A. Inclusion of non-healthcare costs and outcomes (7 articles)

Seven studies were identified which describe issues with identifying and including all relevant costs and outcomes.[64-69]

<u>Incorporating all benefits and risks of an intervention</u>

An opinion piece by Mooney suggests that it may be difficult for stakeholders to agree upon the benefits and risks associated with a Public Health intervention and as a result all relevant outcomes might not be included within economic evaluations.[67] For example, is a health promotion campaign successful if people are more informed but do not change their lifestyle? The author suggests that the 'costs' of necessary changes in lifestyle need to be considered (eg. the 'cost' of getting up at 6am to go to the gym). However, this opinion piece does not suggest methods for determining relevant costs and benefits.

Similarly, Shiell,[68] Anderson[70] and Smith and Petticrew[69] suggest that the cost-effectiveness of Public Health interventions may be underestimated if all health and non-health impacts of an intervention are not considered. Shiell suggests that whilst many costs and benefits cannot be or are difficult to measure within Public Health, it may not be appropriate to simply identify these outcomes qualitatively within the report (instead of including them within the quantitative analysis), as recommended by Drummond[2] for health technology assessments. This is because of the substantial impact they could have upon the model results within Public Health. He illustrates this with an economic evaluation of the walking school bus (eight children and two adults walking to school together) which was estimated to cost Aus $1 million per disability-adjusted life year gained when the analysts included only health benefits. However, this intervention was not designed solely to improve health and there are many non-health benefits of the intervention such as less traffic pollution and congestion and increased sense of community, which means that the analysis does not demonstrate the broader cost-effectiveness of the intervention. Smith and Petticrew suggest that Public Health economic modelling should focus upon broader outcomes such as 'happiness' as one way of attempting to capture these broader costs and outcomes.[69]

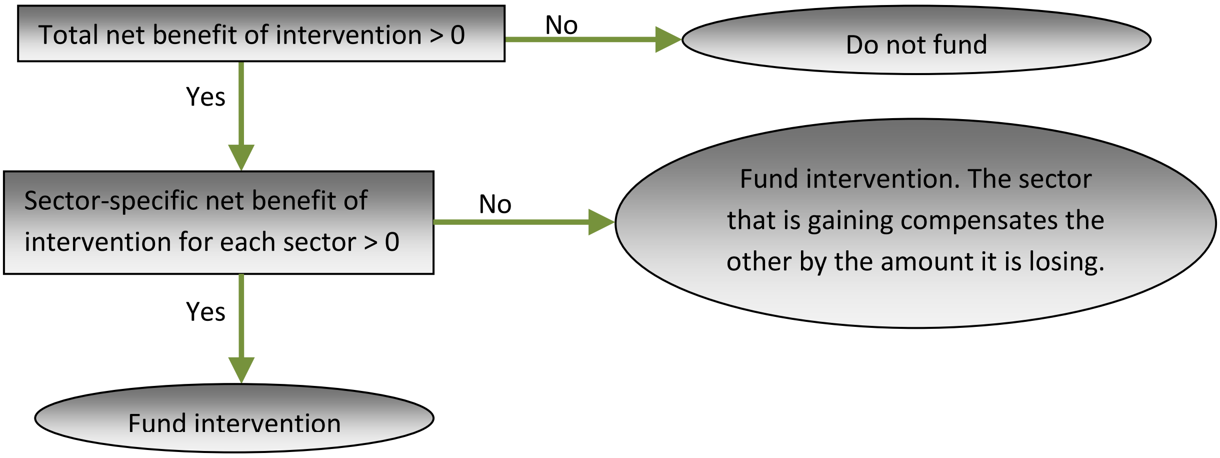
The QALY outcome measure

Kelly *et al.* and Weatherly *et al.* suggest that the QALY outcome measure may be insufficient for economic evaluations of Public Health interventions. This is because the QALY does not capture the mental and social outcomes associated with some Public Health interventions or non-health outcomes such as education or crime.[64;65] Both papers suggest a potential solution may be to undertake a cost-consequence analysis from the perspective of each sector as a supplementary analysis, as also recommended by Anderson.[70] However, there remain practical issues relating to the way in which decision makers should use this information to compare interventions, which are not addressed within these papers. Kelly *et al.* also suggest that discrete choice experiments (where the public rank different real-world scenarios based upon several dimensions) may have the potential to be used within Public Health intervention evaluation.[65] Discrete choice experiments could be used to provide a broader outcome measure than the QALY.

Compensation test for public sectors

Claxton *et al.* propose an alternative potential solution for the inclusion of intersectoral costs and benefits,[66] which is also referred to within the paper by Weatherly *et al.*[64] This involves estimating the net benefit of the Public Health interventions from all relevant sectoral perspectives and then applying a compensation test as shown in Figure 2.2.

Figure 2.2: Compensation test approach



Whilst this approach seems theoretically reasonable, the paper does not try to address the practical issues with this approach. Valuation methods, metrics and thresholds differ by sector and the cooperation of other sectors would be required for this approach to be feasible. A key issue, which is of particular concern to this work, is that there are no methods for identifying relevant intersectoral costs and outcomes for inclusion within the model. A more recent paper by Payne *et al.* around valuing the economic benefits of complex interventions agrees with Claxton *et al.* that healthcare maximisation is not a sufficient objective when costs and outcomes fall upon other sectors.[80] The authors outline several alternative approaches to capturing the broader outcomes of complex interventions and suggest that further methodological research is still required.

Summary

Seven papers all highlight a number of difficulties in defining relevant costs and outcomes for the evaluation. Only three of the six studies which have been identified suggest potential methods and all three of these studies are associated with practical issues.[64-66] All three of the suggested approaches attempt to present the results of the analysis in an alternative format in order to help decision makers understand where costs and outcomes are incurred. However, none of the papers explicitly focus upon how these costs and outcomes might be identified during the early stages of model development, nor do they consider recommending any communication with stakeholders to help to tackle these choices. This is the case even though all authors highlight that one of their key concerns is in identifying and including all relevant costs and outcomes. I would suggest that the presentation of alternative results is helpful only if relevant costs and outcomes have been incorporated within the analysis.

B. *Inclusion of equity (5 articles)*

The UK Government aims to both increase overall health and reduce health inequities as outlined within the 2010 Public Health White Paper.[81] In many cases these two objectives may require different interventions, and hence one could argue that there is a greater need to develop methods for including equity considerations within economic evaluations of Public Health interventions, as suggested by Kelly *et al*.[65] Five papers were identified by the review which discuss the incorporation of equity within Public Health economic modelling.[64;71-74]

Weatherly *et al.* suggest that the inclusion of equity is one of the four key methodological challenges within Public Health economic modelling, along with attribution of outcomes (i.e. quantifying the effectiveness of the interventions), measuring and valuing outcomes and inclusion of intersectoral costs and consequences.[64] However, there is no clear justification for the choice of the four methodological challenges outlined within this paper.

<u>Potential methods for incorporating equity</u>

Cookson *et al.* discuss the need for the explicit incorporation of equity within economic evaluation of Public Health interventions and suggest four potential methods for doing this.[71] This is followed by a series of responses by Richardson,[72] Shiell,[73] and the original authors.[74] The authors highlight that health inequity reduction is a key policy objective in the field of Public Health, yet whilst value judgements relating to equity are currently made, equity considerations are not typically addressed within economic evaluations. They suggest three types of equity consideration; (1) reducing health inequalities; (2) prioritising specific groups (eg. children); and (3) adhering to ethical rules or procedures. The authors suggest that society would be willing to pay more per QALY gained for certain groups such as children, the severely ill and the socioeconomically disadvantaged, than for other members of the population, although Richardson disputes this in his response.[72]

The four methods for considering equity within economic evaluations of Public Health interventions proposed by Cookson *et al.* are:

(1) The identification of relevant equity considerations and a review of existing literature around this to provide qualitative discussion around relevant equity issues;
(2) Quantitative analysis of key subgroup data from trials where available around the impact of the intervention upon health inequities;

(3) Estimating the opportunity cost of including equity considerations in terms of health foregone (i.e. the comparison of health foregone if adopting the equitable option with that of maximising health);
(4) Valuing health inequality reduction by quantitatively weighting health outcomes according to equity considerations.

Within their paper, Weatherly *et al.* also highlight options (3) and (4) as potential approaches,[64] which is likely to be due to the overlap of authors between the two papers. Cookson *et al.* suggest that any of these approaches would be worthwhile only in situations where a targeted Public Health intervention is not considered to be cost-effective, where there are multiple alternatives or where a population intervention is dependent upon behaviour which may differ for different groups. They conclude that it is not possible at this stage to specify the most appropriate approach and that testing of each is required.[71] The necessity for Cookson *et al.* to suggest approaches (1) and (2) above highlights to Richardson how underdeveloped equity considerations are.[72]

Shiell's response to this paper suggests that valuing the health inequality reduction associated with clinical and lifestyle interventions (i.e. 'downstream' interventions) is less worthwhile than undertaking primary research and modelling around the effectiveness of interventions tackling the social determinants of health (i.e. 'upstream' interventions).[73] Upstream interventions include health promotion interventions (eg. workplace health promotion interventions) and non-health sector interventions (eg. providing affordable housing). Shiell explains that downstream interventions are unlikely to reduce health inequities substantially, whilst upstream interventions have the potential to.[73] Richardson suggests that it may be more useful to think about the broader consideration of 'social objectives' rather than the trade-off between 'equity' and 'efficacy'.[72]

<u>Summary</u>

All of these papers highlight the importance of considering equity in some capacity within economic evaluations of Public Health interventions. There is currently no agreement over the most appropriate approach. Methods for valuing equity are considered to be beyond the scope of this work; however consideration of the social determinants of health inequities will be considered further within Chapter 3.

C. Complex systems and multi-component interventions (9 articles)

Nine identified papers describe the complexity of Public Health systems in the context of economic evaluation.[64;65;69;75-78;82]

Comparing complex systems with 'complex' interventions

Shiell *et al.* describe what is meant by a complex system and distinguish this from complex interventions.[82] The authors define a complex system as one which 'is adaptive to changes in its local environment, is composed of other complex systems and behaves in a non-linear fashion'. Thus the stock market would be an example of a complex system. They define a complex, or multi-component, intervention as 'built up from a number of components, which may act both independently and inter-dependently' as defined by the Medical Research Council.[83] Shiell *et al.* argue that whilst multi-component interventions are more difficult to evaluate, methodology for economic evaluation of multi-component interventions is not fundamentally different since it is not necessary to understand how the intervention works within an economic evaluation. They also state that MRC guidelines exist for evaluating multi-component interventions.[83] However, Kelly *et al.* suggest that from a policy perspective it is important for a model to address what aspects of an intervention make it successful or unsuccessful.[65] This is to help decision makers understand how different approaches may be used to overcome barriers to change and whether interventions may be generalisable in other settings. Kelly *et al.* suggest that this is important in terms of economic evaluation if part of the objective is to reduce inequities in health, where the impact on specific subgroups needs to be modelled (see Chapter 3 for further discussion of this).[65]

Shiell *et al.* argue that the evaluation of interventions within complex systems presents new methodological challenges and hence it is important to understand whether an intervention is being evaluated within a complex system.[82] The paper suggests that the usual approach to economic evaluation is to assume that the effects of an intervention can be assessed without considering the impact of the environment upon its effectiveness. This meant that the social structure and people's interactions with each other are not considered. However, this assumption will be inadequate within a complex system where feedback loops are important and aspects of the environment cannot be assumed to be constant. The authors suggest that economic evaluations of interventions within complex systems need to consider ecological theory (which relates human development to an ecological system), interactions between the interventions and their environment, non-linearity (that the effect is not proportional to the cause), multiplier effects (small changes in initial conditions can have large impacts upon the outputs), and the interaction between the intervention and subsequent behaviour.[82] Similarly, Plsek and Greenhalgh discuss the challenge of complexity in healthcare systems and suggest that the science of complex adaptive systems is appropriate for addressing this challenge.[75] This means modelling a system by considering the behaviour of the parts and the relationships between those parts, rather than taking a purely reductionist approach to science which breaks a system down into parts and ignores the relationship between those parts.[84] This is discussed in more detail in Chapter 3. Whilst the theory within both of these papers is logical, they do not go further to describe how the science of complex adaptive systems could be used or how the theory may be tested.

Anderson also suggests that some of the key reasons for Public Health economic evaluation being more challenging than Health Technology Assessment (HTA) modelling are due to the interventions being multi-component, with tailored, dynamic and evolving implementation which may be at the community / population level rather than the individual level.[70] He suggests that within Public Health there are long causal chains and the causal mechanisms may be social and behavioural as well as biological, and that heterogeneity may be important, making results of models of the 'average' person potentially meaningless.[70]

<u>Community interventions within complex systems</u>

Within another paper, Shiell and Hawe suggest that for interventions which have the community rather than the individual as the focus, the total impact of the intervention may be greater than the sum of the individual impacts.[76] This is because there may be additional community impacts such as empowerment (developing a sense of community and the knowledge, skills, networks and opportunities to improve future health of the community) and competence.[76] Therefore, if these broader community impacts are excluded, the cost-effectiveness of these interventions will be systematically underestimated by the methods employed. The paper suggests that the effects of community interventions will take longer to appear; however their effects are more likely to be sustained and these impacts need to be measured and included within economic evaluations. Shiell and Hawe suggest that the major challenge is in capturing community-level change as distinct from the aggregate outcomes of individuals. This relates to the idea of social structure described within Chapter 1. Similarly, Smith and Petticrew suggest that there is a need to focus on the effects of the interventions upon communities and populations, as well as on individual effects.[69] A response to this paper was published by Whitehead who argues that there are Public Health evaluations which have been undertaken using a macro-level analysis such as within tobacco control.[77] This response argues that it is the funders of Public Health economic modelling who encourage a micro-level approach rather than the analysts. Again, many issues are raised within these papers, but no potential solutions are provided.

Understanding causality within complex systems

Correlation is the linear association between two quantitative variables.[85] Causal relationships are such that a change in the value of one variable **causes** the value of another variable to change.[86] Two correlated variables may appear to be causally related, because changes in one variable appear to lead to changes in another variable, but there may be a third variable which is causing both of these effects. Rickles considers how causality is established within complex intervention research such as Public Health.[78] This paper does not consider methods of economic evaluation, but adds to the discussion about the key characteristics of Public Health modelling and hence was considered relevant to this review. Rickles quotes Hausman and Woodward to highlight the importance of the difference between causation and correlation in terms of the potential to affect outcomes: “When X and Y are correlated and X does not cause Y, one expects that when one manipulates X, the correlation will break down. By contrast, if X causes Y, one expects that for some range of values of X, if one is able to manipulate those values, one can thereby control the value of Y.” [78] The paper discusses the limitations associated with understanding causality within randomised controlled trials, observational studies and causal modelling. The author points out that within Public Health, understanding causality is more complex than within other health areas due to the risk factors, otherwise termed the ‘determinants of health’, often being social. This means that health outcomes are not only dependent upon characteristics of the individual, but also upon the social structure (see Chapter 1 for description of the social structure) and there is strong interdependence between the variables. The determinants of health are discussed in more detail in Chapter 3.

As in the papers by Shiell [82] and Plsek and Greenhalgh,[75] Rickles discusses the issue that a small difference in initial conditions may lead to widely different outcomes.[78] This means that it is important to understand the key variables for the occurrence of an effect, as also discussed by Kelly.[65] In this regard, Rickles suggests that effectiveness is difficult to estimate even with a randomised controlled trial, the recognised ‘gold standard’ for comparing two or more interventions. This is because trial participants are generally randomised according to variables (such as age and sex); however if not all variables that might impact upon the trial outcomes are controlled for, then the outcomes of the trial may be different to the outcomes within the population. Trials of Public Health interventions are likely to be too small to control for all relevant variables appropriately. The author discusses similar, amplified issues with observational studies. He also suggests that simulation studies do not provide a better solution to estimating causality since it is necessary to assume a causal structure to implement a simulation in the first place and it is not possible to know the unknown variables in the system which may have a large impact upon the outcomes. Again, the purpose of this paper is to highlight a research gap rather than to suggest new methodologies. Whilst they are all relevant issues, decision makers need to make policy decisions in the face of these uncertainties. The author does not consider the implications of this in terms of model development and validation. Being explicit about what is 'known' within a model provides a good starting point for understanding what is not known. In addition, there may be external data against which to validate a simulation model.

Weatherly *et al.* suggest that more use should be made of econometric methodology for analysing non-experimental data.[64] This includes techniques such as time series analysis, propensity score matching (a technique used to select individuals to form a control group with similar observable characteristics to those of the treatment group) and difference-in-difference techniques (comparing the treatment group before and after treatment and to some other control group to allow for the fact that there may have been effects other than the intervention effect over time). Similarly, Kelly *et al.* suggest that econometric analysis may be useful.[65]

<u>Summary</u>

These papers all suggest that Public Health interventions operate within complex systems. This has important implications for the development of the model structure and the science of complex adaptive systems is proposed for dealing with this; however none of these papers propose methods for model development. Due to the emerging importance of this issue for structural development of models, Chapter 3 expands upon the theory relating to complex systems.

D. Other modelling issues (2 articles)

A paper and a workshop presentation identified within the review discuss other modelling issues associated with Public Health economic evaluation.[70;87]

<u>Differences between modelling Public Health and clinical interventions</u>

Within a workshop presentation, Anderson suggests that there are two special cases in Public Health where modelling is well established; (1) vaccination programmes and communicable diseases, and (2) screening and surveillance programmes.[70] He suggests that for all other Public Health modelling, there are two widely divergent approaches being employed; "back of a fag packet" (i.e. very simple models) or “cerebral meltdown” (for example, the Foresight obesity system map[41]). A key gap implied here is justification for the level of complexity employed. Based upon another presentation from the same workshop, Anderson suggests that decision trees (cohort modelling approach outlining decisions and their possible consequences within a tree-like structure) and cohort Markov models (modelling approach describing all relevant health states and the probability of transitioning between them), which are typically employed within HTA, may not be adequate for Public Health modelling. Anderson explains that this is due to the non-discrete behavioural changes, the complex long causal chains and the requirement to simulate many health and non-health outcomes.[70] This is consistent with the literature showing that Public Health systems are complex.

Anderson succinctly describes some of the differences between Public Health and modelling clinical interventions in the context of HTA, summarised in Table 2.3. He highlights many of the issues which have already been raised by this review including the inclusion of non-healthcare costs and outcomes and the complexity of Public Health systems and interventions. In addition, Anderson highlights that in Public Health the population of interest, the starting point for the simulation and the care pathway may be less well defined. He suggests that due to all of these differences and the nature of the evidence within Public Health research, modelling should potentially be more exploratory, with results presented in terms of sensitivity analyses rather than a ‘base case’. As described within Chapter 1, such a retrospective approach alone is unlikely to be sufficient and could potentially benefit from methods for understanding the system and choosing relevant model structures in addition.

Anderson also suggests that modelling may be better used to explore the cost-effectiveness of individual components of interventions rather than the overall cost-effectiveness of Public Health interventions. However, this has the disadvantage of ignoring the complexity of the system being modelled, as discussed by other papers within this review,[65;69;75-78;82] and of underestimating the intervention effectiveness due to interaction effects.

Table 2.3: Differences between Public Health and clinical intervention models outlined by Anderson

Issue	Clinical interventions	Public Health interventions	Relation to other categories within review
Outcomes associated with intervention	Health	Health and non-health	Relates to 'Inclusion of non-healthcare costs and outcomes' section within review
Range of outcomes	Few key outcomes	Many different outcomes across sectors	
Scale of impact of intervention	Individual	Community / population	Relates to 'Complex systems and multi-component interventions' section within review
Causal mechanism of intervention	Chemical / biological / mechanical	Social and behavioural	
Role of context / boundary on intervention effectiveness	Low interaction with context	High interaction with context, leading to high heterogeneity – central estimate of analysis may have limited meaning	
Length of causal chain	Short causal chains	Long causal chains	
Complexity of intervention	Single component	Multi-faceted component	
Degree of standardisation of intervention	Pre-specified and static components	Tailored or dynamic and evolving implementation	
Entity	The patient with a specific disease	A population with risk factors but no specific disease	These issues have not been identified previously by review
Starting point for simulation	Diagnosis or failure of previous treatment	At any point in time	
Care pathways	Specifiable disease stages with clinical events	Difficult to define and variable between individuals	

<u>Accounting for future illness</u>

Rappange *et al.* suggest that the cost-effectiveness of Public Health interventions may be overestimated because the costs associated with future illnesses, which would not have occurred if the person had died at a younger age in the absence of the intervention, are not included within economic evaluations.[79] They suggest that illnesses which are prevented by Public Health interventions such as heart disease and cancer are later replaced by chronic diseases which generally affect older people, such as dementia. This is also an issue within economic evaluations of clinical interventions, although it is accentuated within Public Health economic evaluation due to the potential life years gained. The key argument for including future costs which are unrelated to the disease within the evaluation is that of internal consistency. Health utilities are obtained from the general population who are receiving healthcare interventions and thus the resource use associated with future life years is implicitly included within the QALYs gained.[88] One of the main arguments for the exclusion of future illness costs is a practical one in terms of the lack of comprehensive data over the long term and being unable to predict what conditions are likely to develop. In addition, it has been argued that it is politically inappropriate to include unrelated medical consumption during the additional life years gained and that since both healthcare and non-healthcare consumption costs would be incurred in these additional years, then both would need to be incorporated throughout the lifetime of the individual.[87] Currently the NICE methods guide states that the costs of future illness should not be included within economic evaluations, and hence they will not be considered within my methods development;[5] however these might be able to be incorporated within future research.

Summary

These papers describe some of the key differences between economic evaluation of Public Health interventions and clinical interventions, as well as consideration of whether models should account for future illness which is exacerbated within Public Health. It is suggested that modelling should be more exploratory within Public Health economic evaluation than for the assessment of clinical interventions.

2.4 Discussion

Methodological papers about Public Health economic modelling have generally only been published since the turn of the 21st Century and there is currently much debate around how to address the challenges as demonstrated by the many opinion pieces and response papers published. Economic evaluations within Public Health are generally different to economic evaluations of clinical interventions since they usually require the development of models of multi-component interventions with complex causal chains operating within dynamically complex systems, dependent upon the social determinants of health, as against models of simple interventions which generally do not depend upon human behaviour operating within relatively clear system boundaries. It is also often much less clear what a 'good' outcome of a Public Health intervention is. In addition, a key objective of Public Health is to reduce health inequities. Very few of the studies propose any methodology for dealing with the issues they raise, and of those that do, they generally focus upon alternative ways of presenting the model results. Whilst many of the papers highlight issues associated with understanding the problem and model scoping, none of them consider methods for this conceptualisation process. Anderson suggests there is a dichotomy, with some analysts developing very simple Public Health models and others developing highly complex ones.[70] These very different model structures are generally developed with limited justification for the level of complexity. A conceptual modelling framework for Public Health economic evaluation could provide methodology for helping the modeller choose an appropriate level of complexity.

2.5 Chapter summary and implications for methods development

This chapter reviewed the literature around the key methodological challenges within Public Health economic modelling. Key implications for methods development are that a conceptual modelling framework for Public Health economic evaluation would need to consider:

- The inclusion of non-health costs and outcomes;
- Equity;
- Methods for dealing with dynamic complexity;
- Analysis of poorly defined multi-component interventions impacting upon broad populations with no specific disease;
- Variable care pathways.

A review of existing conceptual modelling frameworks is presented within Chapter 4, one objective of which is to consider whether there are any existing frameworks meeting these requirements.

Issues requiring further exploration

The review suggests that a key methodological challenge relates to Public Health systems being complex. Current approaches tend to assume simple cause and effect when developing model structure, and do not consider the impact of feedback loops and unintended consequences upon other parts of the system. These are likely to provide inadequate representations of the problem. Given the importance of handling complexity within Public Health economic models, this is explored further within Chapter 3. Chapter 3 considers what a dynamically complex system is and whether Public Health interventions always operate within dynamically complex systems. The use of systems thinking for handling this complexity is also considered within Chapter 3.

Many of the key challenges raised within the review relate to the social determinants of health and health inequities, introduced within Chapter 1. This includes the dynamic complexity of Public Health systems, as well as equity issues and the inclusion of non-health costs and outcomes. Within the Public Health literature, the determinants of health and health inequities have been studied considerably in order to understand how policy might improve population health and health inequities. Thus Chapter 3 explores this literature in order to understand how it might feed into a conceptual modelling framework. Finally, the review suggests that human behaviour affects intervention effectiveness and thus the Sociology and Psychology literature are explored within Chapter 3 in order to understand how models of behaviour might be incorporated.

Chapter 3: Additional exploration of some of the key methodological challenges

3.1 Chapter outline

This chapter aims to review, in more depth, some of the issues raised within the literature review in Chapter 2 where it was thought that additional literature from other disciplines might be useful for methods development. This involved consulting literature within the fields of complex adaptive systems, otherwise known as complexity theory, systems thinking, Public Health, Sociology and Psychology. Section 3.2 reflects upon what a dynamically complex system is and whether all Public Health systems are dynamically complex, whilst Section 3.3 considers the use of systems thinking for modelling such complex systems. Section 3.4 reviews the literature around the social determinants of health which contribute to the dynamic complexity, as well as being important with regards to the inclusion of non-health outcomes and costs and the issue of equity. Finally, Section 3.5 considers how models of Psychology and Sociology might be used to model behaviour within Public Health economic models.

3.2 Complexity within Public Health modelling

A key challenge arising from the review within Chapter 2 is that of handling complexity. This section considers in more detail what a dynamically complex system is and whether Public Health interventions always operate within dynamically complex systems. It is mainly based upon my reading of two books; 'Complex Adaptive Systems' by Miller and Page[84] and 'Business Dynamics: Systems Thinking and Modeling for a Complex World' by Sterman.[89]

<u>What is a dynamically complex system?</u>

Dynamically complex systems have been studied within many different disciplines including Anthropology, Artificial Intelligence, Biology, Chemistry, Computer Science, Economics, Meteorology, Neuroscience, Operational Research, Physics, Psychology and Sociology. As such there is no standard definition, and there are many different perspectives and definitions for the same ideas.[84] However, the following aspects of dynamically complex systems are generally agreed upon across disciplines.

Interactions between elements are important

Bertalanffy describes a system as 'an entity which maintains its existence through the mutual interaction of its parts'.[90] For example, water is a system made up of hydrogen and oxygen, but it has different characteristics to both of its elements and this is due to the interaction between the elements. Complexity arises when the interactions between elements within the system and between the elements and their environment are important in defining outcomes, although the elements themselves do not need to follow complicated rules. The behaviour of the system may therefore be understood by learning about the behaviour of the elements within the system and their interactions.[89]

Characterised by feedback loops (non-linearity)

The dynamics of complex systems arise from the interaction between positive feedback loops (where an increase [decrease] in one factor leads to an increase [decrease] in another, which in turn causes the first factor to increase [decrease], which would lead to exponential growth [decay] if no other factors were present) and negative feedback loops (where an increase [decrease] in one factor leads to a decrease [increase] in another, which in turn causes the first factor to decrease [increase], which often leads to self-correcting behaviour).[89] The interaction between these feedback loops often produces counter-intuitive behaviour, particularly where there are long time delays between cause and effect, and hence makes it difficult for the human mind to be able to predict this behaviour.[89] Thus outcomes of complex systems are rarely proportional to the cause (i.e. they are non-linear).[89] If one aspect within a dynamically complex system is modified, it is inevitable that other parts of the system will be affected, both in terms of other elements within the system and in terms of the environment.

Variability is important, which may result in emergent behaviour

Variability between elements within complex systems is important since this may stabilise or destabilise the system.[84] For example, people may try to avoid busy roads each with different thresholds around how much traffic they are willing to travel within and this would lead to some of the people choosing different routes, thus eventually stabilising the system so that people travel on many different roads. Alternatively, a person cycling to work might cause one other person to cycle, which might just be sufficient to cause another person to cycle, which might just be sufficient to cause another person to cycle to work, and so on, thus destabilising the system so that the majority of people cycle to work rather than drive. Modelling the ‘average’ person would be misleading in these cases because it would not capture the emergent behaviour of the system.

Timing and time delays are important

The timing of events within dynamically complex systems is important.[84] Factors within the system change over time and the rate of change of different factors will vary. Outcomes may be affected by when particular events happen. Time delays within feedback loops mean that long term outcomes are often incorrectly predicted by policy makers due to the interactions between feedback loops, the limited learning cycles available as a result of changing policies and the difficulty of holding other variables within the system constant within trials for longer time periods.[89]

Characterised by self-organisation, dependent upon networks

In addition, space within dynamically complex systems may be important.[84] Each element within a system is only aware of some of the other elements within the system and its environment. Each element does not understand the behaviour of the system as a whole within a complex system and hence the system is said to be self-organising.[89] Elements may organise themselves so that elements with similar preferences group together.[84] An example of this is the social groups within society, discussed by Kelly *et al*.[40]

There may be unintended consequences of the interventions

Unintended consequences may occur as a result of policy makers not appreciating the impact of time delays, non-linearity, variability and social networks as discussed above. In addition, the outcomes of an intervention are often unanticipated because of the responses of other people within the system who the intervention is not aimed at and who have different aims to the policy makers.[91] An example is smoking companies trying to offset the impacts of anti-smoking campaigns.

No clear boundary around the system

Defining the boundary around a complex system is not trivial since the wider environment also impacts upon the behaviour of the system.[89] All systems are subsystems of a bigger system, and it is important to define the system of interest at a level where all important interactions between the elements for the purpose of the model are captured.[92] For example, a map of the local area is a subset of a map of the country, which is a subset of a map of the world; each of which have different purposes and hence different boundaries.

Elements adapt over time

Elements within a dynamically complex system may learn over time and change their behaviour accordingly.[89] Moreover, individual behaviours tend to reinforce one another through their interactions, such that the system as a whole is dependent upon the amount of strategic ability the individual agents have.[84]

These characteristics of a dynamically complex system are summarised in Box 3.1.

Box 3.1: Characteristics of a dynamically complex system

- Interactions between elements are important;
- Characterised by feedback loops (non-linearity);
- Variability is important, which may result in emergent behaviour;
- Timing and time delays are important;
- Characterised by self-organisation, dependent upon networks;
- There may be unintended consequences of the interventions;
- No clear boundary around the system;
- Elements adapt over time.

The characteristics of a dynamically complex system outlined within Box 3.1 are employed as the definition of a complex system within all subsequent analysis.

Public Health example: contraceptive services

A Public Health economic modelling project assessing the cost-effectiveness of interventions to encourage young people to use contraceptives and contraceptive services which I have previously worked on is described in order to illustrate dynamic complexity within a practical example. This example, hereafter described as 'Contraception project', will also be referred to throughout the remainder of the thesis. The 'Contraception project' was a project for NICE for which I undertook the modelling work in 2010. The decision makers' focus was around preventing unintended pregnancies rather than preventing STIs and the analysis took a public sector perspective. Interventions considered included school-based dispensing of contraceptives, advanced provision of emergency hormonal contraception and intensive case management to prevent repeat teenage pregnancy. Table 3.1 outlines why this is a dynamically complex Public Health system.

Table 3.1: Illustration of a dynamically complex system

Key aspects of a dynamically complex system as described within Box 3.1	**Contraception project example**
Interactions between elements are important	The rate of pregnancies and STIs is dependent upon the sexual interactions between people.
Characterised by feedback loops (non-linearity)	*Positive:* An unintended teenage birth is thought to be associated with an increased probability of the child having a disadvantaged background which is associated with unintended pregnancy in later life. *Negative:* Poor contraceptive use may lead to the development of a STI which may lead to better contraceptive use.
Variability is important, which may result in emergent behaviour	The decision of one person to use contraception might just be sufficient to encourage another person to use contraception and so on until there is a general change in attitudes and behaviour towards contraceptive use.
Timing and time delays are important	The time at which a person has a baby during their lifetime may affect outcomes. In addition, differences in socioeconomic outcomes may not be seen for a number of years.
Characterised by self-organisation, dependent upon networks	The sexual activity and contraceptive behaviour of young people is not centrally organised. The groups young people associate with will influence their sexual activity, their contraceptive use and attitude towards STIs and pregnancy.
There may be unintended consequences of the interventions	Encouraging young people to use intrauterine devices (IUDs) may decrease the number of pregnancies but increase the number of STIs. In addition, condom companies may increase advertising if the government were to advertise other forms of contraception.
No clear boundary around the system	Interventions to reduce initial disadvantage may have impacts in addition to reducing unintended teenage pregnancies such as decreasing crime rates.
Elements adapt over time	Young people may change their contraceptive use over time. For example, after having a STI a person may be more likely to use condoms in the future.

Which Public Health systems are dynamically complex systems?

It is important to understand which types of Public Health systems are dynamically complex in order to develop appropriate methods for model development for different Public Health intervention evaluations. It should be noted that the complexity of the model *per se* is not being contemplated at this stage; rather it is the complexity of the system upon which the model will be based which is being considered. Defining a 'system' for the purpose of relevance to an economic evaluation within Public Health is not trivial as it does not have clear system boundaries. Based upon the aim of economic evaluation as defined by Drummond,[2] a system in this context includes any persons, organisations or resources whose associated costs and/or outcomes are affected, directly or indirectly, by some intervention or its comparator(s). The system is therefore determined by the interventions being assessed. Thus, in order to understand whether all Public Health systems are complex, different types of Public Health interventions need to be explored.

A taxonomy of Public Health interventions

Previous research has attempted to understand and classify different types of behaviour change techniques and interventions.[22;93-95] The NICE guidance on behaviour change divides these interventions into policy, education or communication, technologies, and resources, and according to the population that is targeted and/or affected by the intervention. Table 3.2 below shows examples of interventions for the combination of these typologies.

Table 3.2: Typology of Public Health interventions with examples

	Individual	Community	Population
Policy	Workplace ergonomics	Cycle lanes	Cancer screening programmes
Education or communication	GP advice to reduce alcohol consumption	Community healthy eating classes	Campaign for quitting smoking
Technologies	Breathalysers for drivers	Vascular health checks in disadvantaged communities	Seat belt legislation
Resources	GP providing free condoms	Free leisure centre entry	Free nicotine replacement therapy

In order to understand whether each type of Public Health intervention operates within a dynamically complex system, each of the examples within Table 3.2 were assessed against the criteria for complex systems outlined within Box 3.1 in a similar way as is done within Table 3.1 for the Contraceptive project example. The result of this exercise was that all of these examples operate within dynamically complex systems. This suggests that most, if not all, Public Health interventions operate within dynamically complex systems.

Decision making within dynamically complex systems

The human brain is unable to fully understand dynamically complex systems and people tend to think in terms of simple cause and effect and use heuristics (or 'rules of thumb') to estimate outcomes.[96] Moreover, if there is one cause that can explain an effect, people often stop searching for alternative causes.[96] This means that decision makers will not necessarily be choosing the optimal decision due to the simplifications they may have made about the system. This is known as bounded rationality.[97] In addition, it is more intuitive for people to attempt to treat the symptom of a problem, than treating the underlying cause[96]; for example preventing teenage pregnancy rather than initial disadvantage. It is therefore important to develop tools which can help us to understand these complex systems for Public Health economic modelling.

Additional types of complexity

Within Public Health economic modelling there could be considered to be three levels of complexity; the first relates to the complexity of the system being modelled as discussed above, the second relates to the complexity of the model, whilst the third relates to the complexity of the decision making process (i.e. having multiple stakeholders). The conceptual modelling framework should aim to address all three levels of complexity. Methods for judging the complexity of the model will be considered within Chapter 4. Flood and Jackson make the distinction between the complexity of the system and the complexity of having multiple stakeholders within the decision making process in their book 'Creative Problem Solving: Total Systems Intervention'.[92] They categorise the complexity of the system into complex and simple, in the way described above. They then categorise the level of stakeholder agreement as unitary (stakeholders agree on goals and have similar views and beliefs), pluralistic (stakeholders act on agreed objectives but they have divergent views and beliefs and may need to compromise on their goals) and coercive (stakeholders have conflicting views, beliefs and goals and genuine compromise is not possible). From these classifications, Flood and Jackson suggest which systems approaches might be used given the particular type of problem.

The theoretical basis of Public Health economic modelling means that the ultimate goal for each assessment is to estimate the cost-effectiveness of competing interventions and as such there is general consensus around this goal. Moreover, the topics considered within decision making processes tend to be constrained by what is regarded as politically and culturally acceptable (see Chapter 5 for further discussion of this), thus the processes that are typically employed exclude any decision problems where some level of agreement is not possible. I would therefore argue that the level of stakeholder agreement within most decision making contexts for assessing the cost-effectiveness of Public Health interventions is not coercive. However, there are a number of intermediate goals which may not be agreed upon by all stakeholders. I would argue that a key use of the model should be to help to answer the question of whether the intervention under consideration is effective in the long term, taking into account all consequences. There may be disagreement between stakeholders about how to measure effectiveness and what the consequences of the intervention are. There may also be disagreement about the long term outcomes of current practice and what current practice is. In addition, subjective decisions around model scoping or value judgements may be required. As such, I would suggest that these problems are pluralist rather than unitary. Thus, within Flood and Jackson's classification, Public Health problems are generally Complex-Pluralist.[92] Flood and Jackson suggest that problem structuring methods (described in Section 3.3 below) are appropriate for these types of problems. If a fundamental shift were to occur in the way that topics within Public Health are divided up, then the decision problems could become Complex-Coercive, for which no methods have currently been identified.[92]

Summary

This section concludes that Public Health systems tend to be dynamically complex. This means that they are characterised by feedback loops (leading to non-linearity), that heterogeneity, interactions between elements, and timing and time delays are important, they are characterised by self-organisation which are dependent upon networks, there may be unintended consequences of the interventions, there is no clear boundary around the system, and elements adapt over time. This section also highlights two levels of complexity in addition to the dynamic complexity of the system; that of the model and that of the decision making process.

3.3 Systems thinking for complex systems

Case studies within Public Health have been published which adopt a systems thinking, or a systems approach, to attempt to handle the complexity of the systems.[41;98] A systems approach takes a holistic way of thinking about complex systems, and focuses upon the interactions between the entities and between entities and their environment, rather than assuming that a system can be understood by breaking it down into its individual entities and studying each part separately. Within a systems approach, it is recognised that by considering one aspect of a system in isolation, there may be unintended consequences which, if ignored, may make the problem worse. It is infeasible to take a completely systemic approach as this would involve modelling the whole world; and it is thus important to understand the most appropriate boundary around the model in order to avoid excluding important consequences of an intervention. This section aims to review existing literature and the potential use of systems thinking for Public Health systems.

Key systems approaches

Key systems approaches for modelling are shown in Table 3.3 based upon a four volume book on Systems Thinking by Midgley and a book on Total Systems Intervention by Flood and Jackson.[92;99] These key systems approaches are referred to within the review below.

Table 3.3: Main systems approaches for modelling

Approach	Description
Critical systems heuristics & boundary critique	A qualitative approach which involves the analyst identifying the boundary judgements (what is included in the system and what is part of its external environment), questioning the practical and ethical implications of those judgements with all relevant stakeholders (the choice of stakeholders being part of the boundary judgement in itself), and challenging claims of the stakeholders using factual knowledge.
Problem structuring methods	Qualitative techniques to draw out the structure and nature of a problem situation from all stakeholders' perspectives in an exploratory and transparent manner, acknowledging uncertainties.
Network analysis	Qualitatively mapping and measuring relationships between entities including people and groups.
Cybernetics	Quantitatively describing the flow of information around a system, and the way in which this information is used by the system as a means of controlling itself.
System dynamics modelling	A quantitative cohort simulation modelling approach which captures the stocks and flows and positive and negative feedback loops within the system over time.
Agent-based modelling	A quantitative individual-level simulation modelling approach which is made up of agents (which may be people or other entities) which follow a set of rules about their interactions with other agents and their environment.

<u>Review of the use of systems thinking in Public Health modelling</u>

A basic additional search was undertaken to identify key methodological challenges in modelling in Public Health associated with systems approaches to understand whether there are any additional methodological challenges which have been substantially explored by previous researchers which are not considered within the economic modelling literature. As such, the broad search terms 'public health', 'method', 'model' and 'systems thinking' / 'systems approach' were employed as keywords within the databases Medline, Scopus and Web of Knowledge. It was not intended to be an exhaustive search and case studies were not included in order to develop a manageable review.

Seven relevant papers were identified, all of which were included within a special issue of the American Journal of Public Health which was published in 2006 around 'Systems Thinking and Modeling in Public Health'. All of the included papers provide discussion around the benefits and/or issues associated with the use of systems thinking within Public Health modelling.[91;100-105]

Papers discussing the potential use of systems thinking within Public Health

Within the editorial paper, Leischow and Milstein argue that systems thinking provides a useful way forward for Public Health action by capturing the dynamic complexity of Public Health.[105] The authors raise key challenges with the application including understanding the interactions between people, linking data and information between disciplines and organisations and matching the Public Health problem with the appropriate systems approach given the numerous methods available. Green raises questions about the benefits of systems science to Public Health and the best way of bringing the two together.[100] This paper reflects upon the introduction of Sociology to Public Health forty years earlier and how previous pitfalls might be avoided. The author suggests that either Public Health practitioners should be trained in systems thinking and/or that systems scientists should be employed in Public Health.[100]

Papers describing the potential of using causal diagrams

Joffe and Mindell describe the benefits of using causal diagrams for analysing the impacts of Public Health interventions.[104] They compare these with conceptualisations of the determinants of health, such as Dahlgren and Whitehead's (see Section 3.4), which give an indication of the complexity of the factors which affect health but do not specify these relationships. They suggest that causal diagrams are a useful way of summarising information about causal relationships for communication and analysis (see Chapter 4 for more detail around causal diagrams), although they state that quantifying the diagrams and the use of feedback loops is beyond the scope of the paper. The authors highlight the similar benefits of causal diagrams and quantitative models including that they allow assumptions to be made explicit and facilitate the identification of data gaps. The authors suggest that causal diagrams can be used to control for confounding factors in a similar way to the use of instrumental variables within Econometrics.[104]

Papers describing the potential of using simulation models

Sterman describes the issues with policy making in a complex world, as described within Section 3.2 (based upon Chapter 1 of Business Dynamics by Sterman[89]) and suggests that simulation modelling is required to understand this complexity within public health.[91] This paper suggests that simulation models such as system dynamics allow the analyst to learn about a system and the impact of interventions upon that system much faster than in real time and at low cost. They allow experiments to be repeated under the same conditions or for extreme scenarios to be tested. Sterman also suggests that the model must capture key features of the real world being modelled and they must have a useful user interface which allows learning to occur. He highlights that in the absence of either of these, a simulation model can potentially do more harm than good. He suggests that in order for these models to be tested for quality, they should be fully documented. Finally, Sterman highlights the dangers of testing lots of options within the simulation model and not stepping back and thinking about what analysis would be most useful.[91] Similarly, Homer and Hirsch highlight the benefits of the use of systems dynamics within Public Health given the dynamic complexity of Public Health.[102]

Practical challenges of using systems thinking in Public Health

Trochim *et al.* present the results of a study of 133 practising Public Health professionals from two systems-based Public Health initiatives (Syndemics Prevention Network and the Initiative on the Study and Implementation of Systems (ISIS) project) to highlight practical challenges with the use of systems thinking within Public Health. One hundred key challenges were identified, from which eight rules were derived which were that Public Health professionals should: (i) support dynamic and diverse networks, (ii) inspire integrative learning, (iii) use systems measures and models, (iv) foster systems planning and evaluation, (v) expand cross-category funding, (vi) utilise system incentives, (vii) show the potential of systems approaches, and (viii) explore systems paradigms and perspectives.[103] Whilst the paper seems comprehensive in identifying the key challenges, limited discussion is provided around how to deal with the key challenges identified. In addition, whilst the eight rules identified have interesting implications for the use of modelling and are informative about the fact that the use of systems thinking within Public Health is in its infancy, they focus upon the Public Health practitioner's role rather than the role of modelling.

Methodological pluralism

Finally, Midgley describes a range of systems thinking methods that he has found useful within Public Health: boundary critique; system dynamics; problem structuring methods including interactive planning and Soft Systems Methodology (SSM); the viable systems model from cybernetics (five functions required of a viable organisation); and critical systems heuristics (see Table 3.3).[101] The author highlights the benefits of methodological pluralism in two senses; (i) building upon existing methods to constantly improve them; and (ii) using a range of methods for a decision problem. In particular, he suggests that boundary critique should be used alongside methodological pluralism, which he defines as systemic intervention, so that the weaknesses of each approach can be recompensed by another. The benefits of methodological pluralism are well described within this paper, although there may be practical issues with its use which would need to be considered further. This approach appears to be a variant of Total Systems Intervention described by Flood and Jackson[92] (see Section 3.2 for a brief description), which was not developed for Public Health modelling, but advocates the use of a range of systems approaches which are appropriate to the decision problem. It may be useful to consider multiple systems approaches in further detail (see Chapter 7).

Summary

This section provides evidence that systems approaches are appropriate for modelling Public Health systems, that it is not yet standard practice, and that it may be useful to combine systems approaches. There may be practical issues associated with adopting these systems approaches within Public Health modelling.

3.4 Determinants of health and health inequities

The determinants of health are individual, community and population level factors which affect health.[40] Within the Public Health literature, the determinants of health and health inequities have been studied considerably in order to understand how policy might improve population health and health inequities. For example, in 2010 the World Health Organisation published a report aiming to establish what governments and Public Health can do to improve population health and health inequity via consideration of the social determinants of health.[106] As highlighted by Bonnefoy *et al.*, the factors which are causally related to better health may not necessarily decrease health inequity; thus, the determinants of health inequity are different to the determinants of health.[34] The broader determinants of health relating to the community and the population create the dynamic complexity discussed within Section 3.2 due to the interactions between individuals and their social structure. In addition, a description of the determinants of health could facilitate consideration of non-healthcare costs and outcomes and equity issues. Thus, the determinants of health are important within assessments of the effectiveness and cost-effectiveness of interventions, yet little consideration is currently given to them within the health economic literature (see Chapter 2). This section aims to understand what the determinants of health and health inequity consist of and how different classifications of the determinants of health vary in order to identify how such models might feed into a conceptual modelling framework.

Exploring classifications of the determinants of health and the determinants of health inequities

There are many different classifications of the determinants of health and the determinants of health inequities. It would not be worthwhile undertaking a systematic search of all such models in order to achieve the above aim since there are many. Instead a recent classification by Kelly *et al.*

was identified which includes a brief summary of key existing models[23] and these seven models of the determinants of health / health inequities are explored further below.

<u>Classifications emphasising intervention targeting at different levels</u>

Dahlgren and Whitehead developed perhaps the most well known model within a document for the WHO which aimed to describe the determinants of health inequities.[28] The figure developed to illustrate the main influences on health consists of five layers including inherent characteristics, lifestyle factors, social and community networks, living and working conditions and the structural environment. These five layers are then each divided into a number of subcategories. The authors imply that each of the layers affect outcomes within other layers; however the mechanism for these causal relationships is not considered. The authors suggest that strategies to improve health are often considered at one of these levels when they would be more effective if considered at several levels simultaneously. They also highlight that positive influences at one level could be detrimental at another, suggesting that outcomes should be considered at all levels.[28]

Similarly, Krieger defines the determinants of health inequities in terms of levels (global, national, regional, area or group, household, individual), pathways (the lifecourse including in utero, infancy, childhood and adulthood) and power (in terms of the political economy and ecology within a context of class, racial / ethnic and gender inequity).[107] Limited detail is provided around each of these and their causal relationships.

<u>Classifications emphasising the role of the environment</u>

Taylor and Repetti ask 'what is an unhealthy environment and how does it get under the skin?'[108] They identify socioeconomic status and race as key factors which will determine an individual's environment which in turn affects health. The authors argue that the focus on individual lifestyle factors for illnesses affected by behaviour means that the role of the environment is often overlooked. Thus, this paper focuses upon the evidence relating environmental factors to health and to lifestyle factors, whilst not considering the evidence linking lifestyle factors and health. They divide aspects of the environment into community, the family social environment, the peer social environment, adult social environment and work. The authors suggest that environmental characteristics can impact upon biological outcomes directly or via chronic stress, mental health, coping strategies or health habits and they explore the evidence upon each of these mechanisms in substantial depth.[108]

Building upon Taylor and Repetti, Warnecke *et al.* divide the determinants of disparate health outcomes into 3 levels; distal, intermediate and proximal, which relate to the population, community and individual respectively.[109] The distal level is divided into social conditions and policies and institutional context, the intermediate level is divided into social context, social relationships and physical context, and the proximal level is divided into individual demographics, risk behaviours, biological responses and genetic pathways. Whilst this model explicitly shows the determinants impacting upon disparate health outcomes, it does not depict any other causal mechanisms between the different levels.

Kelly *et al.* classify the determinants of health as the following; environmental vector (eg. infectious diseases and environmental hazards), organisational vector (eg. school, work, clubs), population vector (eg. nationwide legislation and taxation) and societal vector (i.e. social, economic and cultural circumstances).[40] The authors highlight that there is a complex interaction between human behaviour and the social structure, and that it is important to capture both the societal patterns of behaviour and individual variation. They suggest that the causal relationships within and between the vectors can be explained by the ideas of the life course (accumulation of 'insults' and 'benefits' which can be magnified or cancelled out by key life events) and the life world (our perceived environment, inhabited by ourselves and the people we regularly interact with). The framework outlined by the authors is currently employed by NICE for developing the scope for assessments of Public Health interventions.[5] Kelly *et al.* suggest that interventions might be more effective if given at specific stages within the life course. They also highlight that in order to alter Public Health, interventions generally need to be multi-faceted, including educational, organisational, economic and environmental components.[40]

<u>Classifications emphasising causality</u>

Evans and Stoddart divide the determinants of health into social environment, physical environment and genetic environment, and these each are causally related to several individual outcomes, including lifestyle and genetic factors, as well as health outcomes.[110;111] The diagram developed shows the complexity of these causal relationships, with many determinants causally related to many others. Within this model, population level factors are not considered.

<u>Classifications emphasising the difference between the determinants of health and health inequities</u>

Starfield aims to consider the impacts of the determinants of health upon both equity in health and average health. The model of the determinants of health and health inequities begins with the political context and population policies. It describes causal relationships between these and environmental characteristics, wealth, power relationships, behavioural and cultural characteristics and health system characteristics. These are then linked to both equity in health and average health. Whilst it illustrates potentially different impacts for health equity and average health, it does not suggest how they might be different.

Warnecke *et al.* distinguish between unfair health outcomes resulting from differences in distribution or access to health (inequitable health outcomes) and those resulting from factors which are not due to policy (differences), such as biological factors, and suggest that different interventions may be required in each case.[109]

<u>Summary</u>

All of the papers reviewed are shown in Table 3.4 to aid comparison. The use of the population, community and individual level classification for the row headings are based upon the NICE guidance on behaviour change.[22] Many of the papers consider all levels and the relationships between them. There is an abundance of evidence around the causal relationships between the determinants of health; however, Kelly *et al.* suggest that whilst much is known about the general relationship between health and social factors, the precise causal pathways are not yet fully understood.[40]

Key implications for methods development that have been identified from the studies are that:

- Causal relationships should be considered across the individual, community and population determinants of health;
- The most effective outcomes are likely to result from interventions targeted simultaneously at the individual, community and population levels;
- The context within which interventions are provided and the stage within the individual life course will impact upon effectiveness;
- The modeller should be aware that the determinants may impact upon overall health and health inequities in different ways;
- Health outcomes are affected by culture and politics in a multitude of ways.

Table 3.4: Summary of papers describing the determinants of health inequities

Levels and outcomes	Author						
	Dahlgren and Whitehead[28]	Taylor and Repetti[108]	Evans and Stoddart[111]	Starfield[112]	Warnecke *et al.*[109]	Krieger[107]	Kelly *et al.*[40]
Population factors	General socioeconomic, cultural and environmental conditions			Occupational, environmental, social, economic & health policy	Social conditions and policies Institutional context	Global/ National	Population-wide vector
				Historical health disadvantage			Environmental vector
Community factors	Living and working conditions*	Work	Physical environment	Health system characteristics	Physical context	Regional/ Area or group/ Household	
							Organisational vector
	Social and community networks	Community	Social environment	Wealth: level & distribution	Social context Social relationships		Social vector
		Adult social environment		Power relationships			
		The family environment		Environmental characteristics			
		The peer social environment					
Individual factors	Individual lifestyle factors		Individual behaviour	Behavioural & cultural characteristics	Individual risk behaviours	Individual	Life-course & life-world
	Age, sex and constitutional factors	Socioeconomic status & race	Genetic endowment		Individual demographics		
Health outcomes		Biological outcomes (precursors/ disease)	Biology, disease, well-being, health and function	Equity in health	Biological responses Biologic/ genetic pathways	Population distribution of health	Health & well-being
				Average health			
Other outcomes			Prosperity				

*including agriculture and food production, education, work environment, unemployment, water and sanitation, health care services and housing.

3.5 Modelling human behaviour within complex systems

Within the review of key challenges in public health economic modelling in Chapter 2 it was recognised that individual and societal behaviour is important for evaluating Public Health interventions, yet no studies were identified which considered how human behaviour might be incorporated into health economic models. The complex systems literature suggests that modelling heterogeneity and interactions between individuals is important in predicting outcomes within such systems (see Section 3.2). This section therefore investigates the possibility of incorporating human behaviour within a conceptual modelling framework for Public Health economic evaluation by exploring the disciplines of Psychology and Sociology. Psychology is the study of individual behaviour, whilst Sociology is the study of people's interactions in shaping the behaviour of groups within society.

Within Psychology, hundreds of models of human behaviour have been developed which provide an understanding of the individual factors required for the adoption of a specified behaviour. However, only a small number of these have had empirical applications. A review by Taylor *et al.* identified the Health Belief Model, the Theory of Reasoned Action, the Theory of Planned Behaviour and the Trans-Theoretical Model as the most commonly used cognitive models within health promotion.[113] This review suggested that none of these four models adequately capture social, economic or environmental factors as predictors and determinants of health behaviour.[113] Recently, case studies have been undertaken to consider incorporating human behaviour into mathematical models of Public Health;[114-116] however there were difficulties with parameterisation in these cases. Whilst theoretically all four of the above behavioural models could be used to quantitatively model how behaviour changes within Public Health, this requires substantial methodological research both in terms of practical implementation and in terms of methods for parameterisation. Currently, health economic modelling has largely overlooked the incorporation of Psychology models and this could be an important area of further research in Public Health economic modelling. Similarly, research around the potential benefits of employing behavioural economics, which integrates Psychology with neo-classical economics, may be useful.[117] However, it is not feasible to undertake this research within the scope of my work.

Sociology seeks to provide insights into the many forms of relationship between people (including cultural, economic and political) to understand how society works.[118] It provides an evidence-based perspective of society, questioning conventional assumptions within society, and could provide tools for modelling the impact of interactions within society upon outcomes. Several sociologists have taken a systems thinking perspective, such as Giddens.[119] He describes the idea of structuration which considers whether it is individuals or social forces (eg. cultural groupings or the law) that shape social reality. He suggests that social outcomes are shaped by both micro and macro impacts, and that it is impossible to disentangle the cause and effect between them. This mirrors the theory associated with complex systems, which considers the interactions between individuals and between individuals and their environment in order to understand the outcomes of the system. As was suggested within Section 3.2, one way to attempt to disentangle these effects is via the use of feedback loops. The idea of structuration is also consistent with the economic theory of Smith's Invisible Hand which suggests that the independent choices of all of the individuals within a society to maximise their own gains within a free market (where the price is determined according to supply and demand) will also benefit society overall.[120]

Within the last decade Sociology has been linked with complex adaptive systems to form a discipline defined as Sociology and Complexity Science (SACS).[121] Both Sociology and Complexity Science follow a non-reductionist, subjective approach, making use of qualitative research methods (as well as quantitative methods in the case of Complexity Science). Many of the terms which have arisen in Complexity Science including autopoiesis (self-replicating), emergence (behaviour arising from the interaction of the elements) and collective behaviour (the behaviour of a group of individual entities which leads to patterns in the behaviour of the group), have been researched within Sociology. Two of the biggest areas of work within SACS are computational Sociology and complex social network analysis.[121] Computational Sociology is the use of computationally intensive methods to analyse social systems. To date within computational Sociology, many models have made assumptions about behaviour based upon limited or no data i.e. they present theoretical models which require future primary research to clarify the model structure and define the parameters.[115] Complex social network analysis involves the use of a range of techniques including agent-based modelling and social network analysis (mapping social networks to understand who is at the hub of the network). Agent-based modelling is an individual-level simulation approach which uses 'rules' to define the interactions between agents and their environment (see Table 3.3).[122] Methods for producing this model type are sufficiently developed to be able to incorporate it within the conceptual modelling framework, and due to similarities with other model types, it would be viable for health economic modellers to learn. Social network analysis could be applied within agent-based models.

3.6 Chapter summary and implications for methods development

This chapter has considered what a dynamically complex system is and concluded that Public Health interventions tend to operate within dynamically complex systems. A systems approach is expected to be an appropriate approach for modelling these dynamically complex systems, taking a holistic view of the system and focusing upon the interactions between variables. A systems approach would also facilitate the inclusion of relevant costs and outcomes within the model. It may be useful to combine multiple systems approaches.

Health economic models help to make predictions about the future and it is not possible to do this well without an understanding of underlying mechanisms. There are a large number of classifications of the determinants of health; however many of them comprise similar factors (see Table 3.4). Many of the papers reviewed highlighted that there are causal effects between many of the determinants of health. In order to provide better long term predictions of the impact of the interventions upon health, the model is likely to need to describe the interactions between each level of the determinants of health; the individual (including the biological and human behaviour), the community and the population level. In addition, interventions are likely to be more effective if targeted at all three levels simultaneously.

The context within which interventions are provided and the stage within the individual life course will impact upon effectiveness. There may often be discrepancies between the data provided by intervention effectiveness studies and the evidence required for models in relation to the determinants of health. Intervention effectiveness studies may capture all or some of the effects of the broader determinants of health and their interactions within the outcomes presented. However, they do not tend to report how the determinants of health impact upon outcomes, making extrapolation of the outcomes over the long term or to other contexts challenging. The modeller should be aware that the determinants may impact upon overall health and health inequities in different ways. In addition, unless the mechanism of the interventions upon outcomes is well understood, it will be challenging to model the interaction of the effectiveness of multiple interventions being provided simultaneously. Capturing the heterogeneity between individuals within the model in terms of the broader determinants of health is likely to be important because it is this heterogeneity that impacts upon the effectiveness of the interventions. Importantly, if sufficient people adopt a type of behaviour, it might lead to a step-change within society and this should be considered within the modelling work. It may also be important to capture the changes over time of the social determinants of health. The culture and politics of the system should be considered during conceptual modelling, as highlighted within Soft Systems Methodology.[123]

Given the dynamic complexity and importance of the social structure within Public Health, methods such as agent-based modelling and social network analysis are likely to be useful within Public Health economic modelling. There is enormous scope for advancing modelling methods within Public Health economic evaluation through collaboration with the disciplines of Public Health, Psychology and Sociology to combine the existing knowledge of the social determinants of health and individual and population behaviour with existing modelling and health economic expertise. Development in this area is considered to be beyond the scope of the current research; however it will be highlighted as a key area for further research.

Thus, based upon the research presented within this chapter, a conceptual modelling framework for Public Health economic evaluation would need to consider:

- The use of systems thinking;
- The social determinants of health;
- The potential assessment of interventions at the population, community and individual level simultaneously;
- Heterogeneity between individuals;
- The culture and politics of the system;
- Modelling methods to enable broader social determinants of health to be incorporated such as agent-based simulation and social network analysis.

A review of existing conceptual modelling frameworks and their potential applicability to Public Health economic evaluation based upon the considerations identified within Chapters 2 and 3 is presented within Chapter 4.

Chapter 4: Literature review of conceptual modelling frameworks

4.1 Chapter outline

This chapter presents a literature review of existing conceptual modelling frameworks. The aim of the review is:

- To understand what comprises existing conceptual modelling frameworks, in terms of the stages of model development considered, the level of detail provided, the definition of a conceptual model, the methods / methodologies recommended and the relationships between them, and the theory associated with the framework.
- To understand the strengths and limitations of these frameworks, how they have been evaluated, and their potential application within Public Health economic modelling.

Sections 4.2 and 4.3 describe the methods and results of the review respectively. The review has been divided into five sections; (i) Stages of model development included within the conceptual modelling frameworks; (ii) Methods / methodologies employed within the frameworks, including strengths, limitations and potential application to Public Health economic modelling; (iii) Methods of evaluation of the frameworks and their theoretical underpinnings; (iv) Benefits of a conceptual modelling framework; and (v) Areas identified by the authors for further research. Section 4.4 presents a discussion of the review, whilst Section 4.5 summarises the findings of the review and the implications for methods development.

4.2 Methods of review of conceptual modelling frameworks

As explained within Chapter 2, methodological reviews often require alternative search strategies to the traditional Cochrane search.[61] This is because methodological reviews aim to enhance understanding about the methods, rather than aiming to identify all studies which describe or use a preconceived idea of the methods. This review aims to capture key information around conceptual modelling frameworks. If a Cochrane-type of search was undertaken, in which strict inclusion and exclusion criteria were identified at the start, important information may have been lost if it did not fit into my initial understanding of a conceptual modelling framework. Therefore, it was appropriate to explore and inform the scope of relevance via the searching process using an iterative approach to searching.[63] I used my initial understanding of conceptual modelling frameworks to develop a search strategy to identify key literature, which was then explored in order to inform further retrieval using hand searching of bibliographies of retrieved articles, citation searching of retrieved articles, key author searching and title searching of new, relevant terms that emerged from the initial search. This process was repeated for any relevant articles identified.

These methods helped to identify papers where the term 'conceptual modelling framework' is not employed and is also a more efficient way of searching given that the term 'conceptual model' has numerous meanings within different contexts.

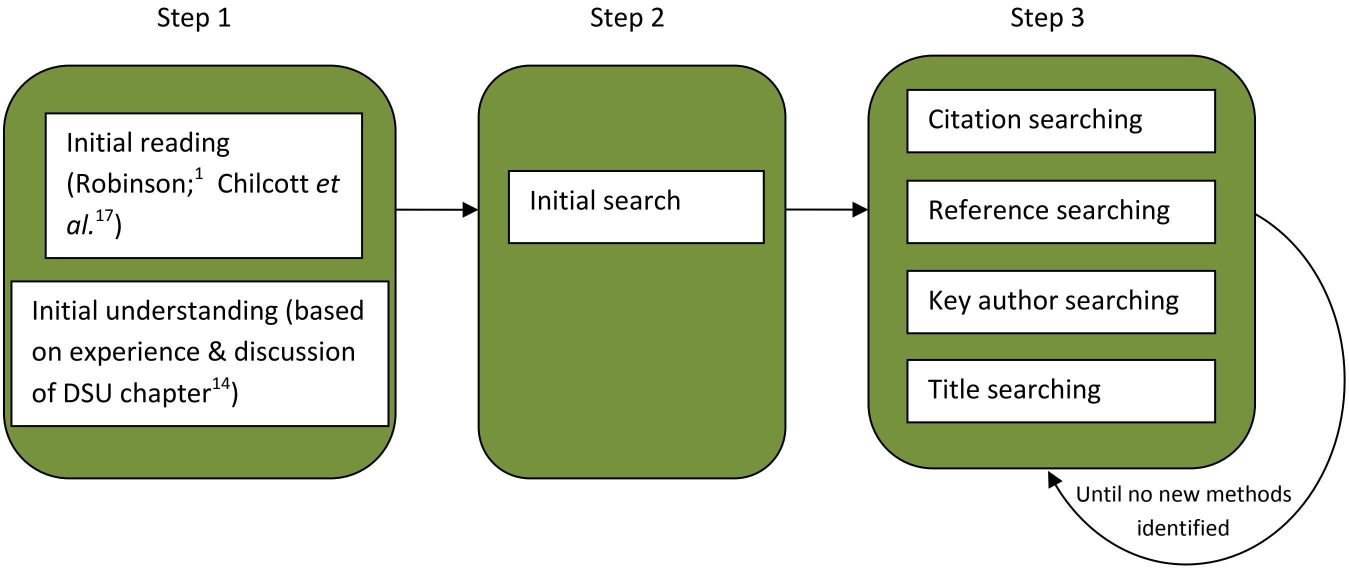
<u>My initial understanding of 'conceptual modelling frameworks'</u>

My initial understanding of conceptual modelling frameworks was based upon: (i) a book by Robinson from 2011 reviewing conceptual modelling for discrete event simulation (DES);[1] (ii) a Health Technology Assessment (HTA) monograph by Chilcott *et al.* published in 2010 about avoiding and identifying errors within HTA;[17] and (iii) the discussion generated with colleagues whilst co-authoring a Model Structuring chapter of a NICE DSU Technical Support Document on identifying and reviewing evidence to inform the conceptualisation and population of cost-effectiveness models.[14] These helped to define the following requirements for a conceptual modelling framework; (1) it should aim to develop a quantitative model since this is required in order to compare the costs and benefits of the interventions; (2) judgements are required about what to include within and exclude from the model; and (3) the type of quantitative model required is not predefined; it is dependent upon the characteristics of the specific problem (see Brennan *et al*.[124]).

<u>Search strategy</u>

Based upon this initial understanding, a search was undertaken to identify potentially relevant articles. The following databases were searched; MEDLINE 1950 to Aug 2011; Scopus 1960 to Aug 2011; Web of Science 1965 to Aug 2011. Three sets of search terms were combined with 'AND'; (1) Terms for conceptual models (limited to title with the aim of ensuring that this is the main focus of the article); (2) Terms for quantitative models (to help to limit studies to those in which the aim of the conceptual model is to develop a quantitative model); and (3) Terms for development (to help to focus the search on methods for development of conceptual models rather than on case studies reporting the output of a conceptual model). The search strategy is presented in Appendix B. Searches were not limited by discipline due to the lack of conceptual modelling methods within Public Health economic modelling, as discussed within Chapter 2. In addition, searches were not limited by study type, publication date or language. The search methodology is presented within Figure 4.1.

Figure 4.1: Search methodology



Study screening and selection

All of the identified literature was screened by me at title and abstract level for relevance, and the full paper was retrieved when insufficient detail was provided within the abstract to determine relevance. Relevance was determined based upon the learning from the searching process, the results of which are described within Section 4.3.1 below.

Data extraction

Following article retrieval, data extraction was undertaken for studies considered relevant using a data extraction form which was specifically developed for this review (shown in Appendix B). The data extraction form was developed after selection of the included articles, following the learning about the topic during the search process.

4.3 Results of review of conceptual modelling frameworks

Firstly, the results of the searching process are described in order to specify relevance for the review, and secondly a critical review of the included studies is presented.

4.3.1 Results of the searching process in determining relevance

The searching process was used to increase my understanding of (a) conceptual modelling frameworks and (b) the amount of literature available in this area; the combination of which led to a definition of relevance for the review.

Definition of a conceptual model

The term 'conceptual model' is used across a wide range of disciplines, and has many meanings, although broadly it is some form of diagram used to represent the perceived key aspects of a system at a point in time. When focusing on conceptual models employed with the aim of developing a quantitative model there remains no agreement for the definition of the term; it has been termed as a mental model of the problem,[123] a written description of the problem[17] or a written qualitative description of the quantitative model that will be (or has been) developed.[8;125] In the case of the latter, the description can range from a basic depiction of the scope of the model[125] to an exact representation of all of the elements within the quantitative model.[8] A conceptual model may be described using more than one diagram, as in Software Engineering.[126] In many cases, the term 'conceptual model' is not employed at all when developing models.[127-129]

Understanding what comprises a conceptual modelling framework

There is little agreement around what comprises a conceptual modelling framework within the literature and the searching process helped to understand what might be included. Given the substantial variation, it was not possible to be more prescriptive than to consider any article to be relevant that described a set of principles and methods / methodologies which facilitate the development of a model structure. Since a reasonable number of conceptual modelling frameworks were identified which provided a process for developing a quantitative model (as is required within Public Health economic evaluation), any frameworks solely considering the conceptualisation of the problem without the conceptualisation of a quantitative model were not considered relevant.

The searching process suggested that formal problem structuring methods (PSMs) are often employed for understanding the problem (see the systems approaches described within Chapter 3). PSMs are 'soft' Operational Research approaches used to facilitate the exploration of 'messy' or complex problems. They are beneficial for problems which are poorly defined, which have multiple stakeholders, differing perspectives, conflicting interests, outcomes which are difficult to quantify and uncertainties.[130] PSMs are expected to improve understanding of complex decision problems from all stakeholders' perspectives in an exploratory and transparent manner, acknowledging uncertainties. They may be employed alone, or as a preliminary analysis to quantitative modelling.[44] PSMs have been developed across a wide range of disciplines within the UK, although their application is limited in most other countries.[131] However, there are very few published studies of the use of formal PSMs within health economic modelling to date and PSMs are not mentioned within guidance to health economic modellers such as within the NICE Public Health intervention evaluation methods guide.[5;132]

Initially, it was unknown whether the understanding of the problem situation was considered to be part of the conceptual modelling process or a preceding step. The searching process suggested that this is usually considered to be a substantial part of a conceptual modelling framework. Based upon an initial reading of a book of key problem structuring methods by Rosenhead,[130] the conceptual modelling frameworks which were identified generally employ the most methodologically developed PSMs[133] and they also have the greatest potential of being applicable to Public Health economic modelling. This is because many of the alternative PSMs focus either upon relieving high levels of conflict between stakeholders or upon organisations within which decisions can be continually revisited. I had initially thought that a separate review of PSMs might be useful, however because of the findings of the searching process, a separate review was not considered to be worthwhile.

Conceptual modelling frameworks for different model types

The search also highlighted that many conceptual modelling frameworks are developed for a specific model type, for example DES or system dynamics, and in some cases no or very limited aspects of the framework were likely to be useful if an alternative model type was required. There are a number of health economic modelling papers which highlight the importance of choosing the model type according to the characteristics of the problem.[124;134;135] Therefore, articles were only considered to be relevant if some aspect of the conceptual modelling framework is able to offer insight beyond one particular model type.

Stakeholder involvement

During the searching process, many of the studies that were identified considered stakeholder involvement in the model development process and these suggested that this involvement was essential in developing valid and credible models. Based upon my initial understanding and the learning from the searching process, stakeholder involvement was thought to be an important characteristic of the conceptual modelling frameworks. Hence, only those which considered stakeholder involvement, in a greater capacity than as a tool for discussion and debate of the final model, were considered to be relevant for the review.

Other exclusions

Having developed a clearer idea of what types of articles were available, a number of types of articles were excluded from this review because more relevant articles were available. This includes those articles solely describing the steps involved within a conceptual modelling framework without describing methods for development. A large number of case studies of conceptual models of the model structure were identified which did not provide detail about the methodological approach or reporting of the conceptual model(s). These were not included within the review because the methodological papers were considered to be more useful for developing a conceptual modelling framework.

It is important to represent the conceptual modelling in a format that allows communication between modellers and stakeholders.[1] However, it was not considered to be worthwhile to review all papers describing conceptual model representations given that the papers that describe the conceptual modelling frameworks also consider conceptual model representation. Therefore, those articles describing only the diagrammatic / tabular representation of a conceptual model without describing methods for choosing what is included or excluded within the representation were not considered to be relevant. In a similar way, those articles describing software tools for the development of a conceptual model, without describing a new conceptual modelling framework were not considered to be relevant. Finally, those articles solely making a contribution of theory such as the requirement for conceptual modelling or the issues with combining 'soft' and 'hard' OR methods were excluded since they do not facilitate specific methods development. Some of these papers provided useful background material and are considered within the discussion of the review.

Since it is a methodological review which does not aim to be exhaustive, included articles must report a conceptual modelling framework which has not been presented elsewhere. Identified sources which were considered to be relevant with the fullest description of each framework were included. If several articles presented the same framework to the same standard, priority was given to the most recent article.

Table 4.1 describes the inclusion and exclusion criteria for those articles included within the review.

Table 4.1: Inclusion and exclusion criteria for conceptual modelling framework review

Inclusion criteria	Exclusion criteria
Must describe a set of principles and methods/ methodologies which facilitate the development of a model structure.	Articles solely describing the steps involved within a conceptual modelling framework without describing methods for development.
The conceptual modelling framework presented must be aimed at developing a quantitative model.	Case studies of conceptual model development which did not provide detail about the methodological approach or reporting of the conceptual model(s).
Some aspect of the conceptual modelling framework must be able to offer insight beyond one particular model type.	Articles describing only the diagrammatic/ tabular representation of a conceptual model without describing methods for choosing what is included or excluded within the representation.
Must consider stakeholder involvement, in a greater capacity than as a tool for discussion and debate of the final model.	Articles describing software tools for the development of a conceptual model, without describing a new conceptual modelling framework.
Must report the fullest description of a conceptual modelling framework if presented in more than one source. If several articles present the same technique to the same standard, priority is given to the most recent article.	Articles solely making a contribution of theory such as the requirement for conceptual modelling or the issues with combining 'soft' and 'hard' OR methods.

Within this review, articles are excluded which Robinson has included in his book on Conceptual Modeling for Discrete Event Simulation.[1] Robinson does not define how he determined relevance within his book; however many of the chapters are discussions around improving understanding of conceptual modelling or conceptual modelling notation such as how Software Engineering representation may be used within DES development, rather than the description of conceptual modelling frameworks which propose methods for developing the structure of quantitative models. It seems that many researchers focus solely upon how a conceptual model is represented, rather than the process of development, which is the focus within my research. Several conceptual modelling frameworks from the defence and computer science fields were identified within the search; however these were excluded from the review. Many of the computer science conceptual modelling papers described how to represent the system within a model rather than describing a process for making judgements about what to include and exclude within the model and they did not aim to develop a quantitative model. The defence conceptual modelling frameworks generally did not consider stakeholder involvement. Excluded studies and reasons for exclusion are shown within Appendix B.

Articles included within the review

Eight conceptual modelling frameworks were considered to be relevant for the review, identified as shown in Table 4.2.

Table 4.2: Identification of included articles for conceptual modelling framework review

Stage of search	Activity	No. of articles considered to be relevant	Included articles. Author (year)
Stage 1	Initial reading	2	Kaltenthaler *et al.* (2011)[14] Robinson (2011)[8]
Stage 2	Initial search	2	Tako *et al.* (2010)[136] Vennix and Gubbels (1992)[128]
Stage 3	Reference, citation, author & title searching		
	Iteration 1	1	Fernández and Kekäle (2008)[125]
	Iteration 2	2	Howick *et al.* (2008)[127] Rodriguez-Ulloa and Paucer-Caceres (2005)[129]
	Iteration 3	0	
-	Identified informally subsequently to the search	1	Roberts *et al.* (2012)[18]

4.3.2 Stages of model development included within the conceptual modelling frameworks

Of the included studies only Robinson provides a definition of a conceptual modelling framework, described as 'A specific set of steps that guide a modeller through development of a conceptual model'.[8] The processes included in the conceptual modelling frameworks within the studies are shown in Table 4.3. The title row of Table 4.3 was developed based upon the findings of the studies, rather than the findings of the studies being matched to some pre-specified idea of a conceptual modelling framework. It suggests that there is substantial variation in what constitutes a conceptual modelling framework.

Table 4.3: Stages within conceptual modelling frameworks

Author	Understand the problem situation and set objectives				Choose model options, determine model scope and level of detail, identify assumptions & determine model type		
Roberts *et al.*[18]	Statement of the decision problem and modelling objectives				Determine model perspective, outcomes, options, model scope, structure, time horizon, level of detail & key uncertainties		Identify appropriate model type
Kaltenthaler *et al.*[14]	Understand the decision problem & the system in which this exists (problem-oriented)				Determine model outputs, scope, level of detail & key structural assumptions (design-oriented)		Identify appropriate model type
Robinson[8]	Understand the problem situation		Determine the modelling and general project objectives		Identify model outputs and options	Determine the model scope and level of detail	Identify any assumptions and simplifications
Tako *et al.*[136]	Initiate the study	Structure the situation of interest	Determine study objectives		Identify model outputs and options	Determine model content	Identify assumptions and simplifications
Howick *et al.*[127]	Gain a deep and rich understanding of the problem		Objectives implicitly identified from understanding the problem		Determine endogenous and exogenous variables to arrive at appropriate level of detail		Identify inconsistencies in structural assumptions
Fernández and Kekäle[125]					Identify factors that might affect the goal	Prioritise important variables to include	
Rodriguez-Ulloa and Paucar-Caceres[129]	Immerse self in unstructured problem situation	Capture the problem situation	Capture the system from each stakeholders' perspective	Capture the system incorporating the stakeholders' perspectives	Check model represents adequately what is happening in the real world	Look for culturally feasible and systemically desirable changes	Iterations to check the model matches the problem situation
Vennix and Gubbels[128]	Define the policy questions		Develop preliminary conceptual model		Knowledge elicitation to establish model structural assumptions & relevant variables		Final conceptual model

Distinction between understanding the problem and developing a design-oriented conceptual model

Within six of the eight included studies, there is a clear distinction between understanding the problem and developing a qualitative description of the quantitative model.[8;14;18;127;129;136] Vennix and Gubbels do not provide a method for model scoping; thus understanding the problem situation is not distinct from the representation of the model,[128] whilst Fernández and Kekäle do not provide methods for understanding the problem.[125] Table 4.4 describes the terminology employed for each of these two stages which shows that there is no consistent terminology between frameworks.

Table 4.4: Terminology for understanding the problem

Author	Understanding the problem	Qualitative description of quantitative model
Roberts *et al.*[18]	Conceptualising the problem	Conceptualising the model
Kaltenthaler *et al.*[14]	Problem-oriented conceptual model	Design-oriented conceptual model
Robinson[8]	Abstract model	Conceptual model
Tako *et al.*[136]	Not defined	Conceptual model
Howick *et al.*[127]	Cognitive / cause map	Influence diagram / system dynamics formal influence diagram
Fernández and Kekäle[125]	None included	Conceptual model
Rodriguez-Ulloa and Paucar-Caceres[129]	Problem oriented	Solving oriented
Vennix and Gubbels[128]	None included	Conceptual model

Stages of developing the design-oriented conceptual model

Within the included studies, the development of a qualitative description of the final quantitative model generally consists of choosing potential options, model scoping, determining the level of detail and defining the structural assumptions. However, there does not appear to be an agreed order for these activities. For example, Robinson considers the potential options prior to model scoping and determining the level of detail,[8] whilst Rodriguez-Ulloa and Paucer-Caceres develop the model scope and then look for 'culturally feasible and systemically desirable' changes.[129] I would suggest that there are advantages and disadvantages to both of these approaches. The conceptual modelling framework by Robinson allows a model to be developed which is specifically able to answer questions about the chosen options.[8] This helps to guide the model scope, which may lead to efficient model development; however it may fail to identify some options which are relevant, meaning that the outcomes of the system might not be optimised. Conversely, the conceptual modelling framework by Rodriguez-Ulloa and Paucer-Caceres uses the model to help to identify potential options.[129] This may lead to a model with a broader scope, which could make the model development less efficient; however it may be useful for situations where it is unclear which options to compare within the model.

Iteration between stages of conceptual modelling

Many of the conceptual modelling frameworks suggest that some of the stages are iterative and hence should not be followed in a purely linear fashion.[8;14;127;129] This is also suggested by Robinson within his book reviewing conceptual modelling in DES.[1] Within his conceptual modelling framework, Robinson suggests that whilst the understanding of the problem is used to develop the qualitative description of the quantitative model (termed the conceptual model), this understanding is often enhanced by later stages of model development. He also suggests that there may be an iterative process between the conceptual model developed and the data collection; the conceptual model should be developed without being driven by the availability of data, but if data are not available to parameterise the initially conceptualised model, then the conceptual model may be changed, leading to new data requirements.[8] Howick *et al.* suggest that the initial model should be developed by moving linearly between the model development stages; however the development of one model stage may lead to learning about a previous model stage, and hence subsequently the modeller can amend any stage providing they amend each intermediary stage in turn.[127] For the conceptual modelling framework developed by Rodriguez-Ulloa and Paucar-Caceres, the authors recommend that model development should be an iterative process across all stages.[129]

Kaltenthaler *et al.* also suggest that there may be an iterative process of development between the design-oriented conceptual model and the quantitative model, however it differs to the above frameworks in that the problem-oriented conceptual model should be developed first and should not be changed as a result of the process.[14] The rationale for this is that whilst data may change what is modelled, the system within which the problem exists does not change.[14] However, the qualitative research described within Chapter 5 suggests that the relationship between conceptualisation and data collection means that it is not possible to undertake the tasks as two completely discrete stages. This is because evidence in some form is required to understand the problem, and a certain level of understanding of the problem is required to inform the collection of evidence. If our understanding of reality was perfect then our understanding of the system would not change as we collected more evidence as Kaltenthaler *et al.* suggest; however in practice our understanding of that system may be revealed to be imperfect as more evidence is identified. Thus I would argue that the problem-oriented conceptual model could be changed at a later stage in the process provided that any changes are documented.

All four of the above frameworks suggest that the design-oriented conceptual model is not completed prior to the quantitative model development, but that it may be iteratively revised according to data availability and/or inconsistencies identified during the development of the quantitative model.[8;14;127;129] All other included conceptual modelling frameworks do not explicitly state that there should be iterations between stages.[18;125;128;136]

Semantic differences between the frameworks

Within these frameworks, the term 'conceptual model' is defined only within the study by Robinson,[8] based upon a previous related paper by the author.[137] The same definition is also employed by Tako *et al.*[136] The definition provided is 'a non-software specific description of the computer simulation model describing the objectives, inputs, outputs, content, assumptions and simplifications of the model.'[8] However, Pidd argues that this definition is broad and may be more 'a conceptualization of a simulation model or a simulation project, rather than a conceptual model'.[138] Within other literature discussing conceptual models they have been referred to with different meanings, as 'a description of one's understanding of the system'[17] or 'a mental model of the problem'.[123] Within the framework by Kaltenthaler *et al.*, the term *conceptual modelling* is defined as 'the abstraction and representation of complex phenomena of interest in some readily expressible form, such that individual stakeholders' understanding of the parts of the actual system, and the mathematical representation of that system, may be shared, questioned, tested and ultimately agreed.' I would suggest that the term 'conceptual model' seems suggestive of only one diagram, whilst the phrase 'conceptual modelling' depicts a broader set of activities which might encompass developing one or more diagrams with accompanying text.

Similarly, there is no consistency around the definition of who should be involved in the model development process. Roberts *et al.*, Kaltenthaler *et al.*, and Rodriguez-Ulloa and Paucar-Caceres and Tako *et al.* all use the term 'stakeholder', but each have different definitions of what this includes. Roberts *et al.* do not define the term but consider 'subject experts' and 'decision makers' in addition to stakeholders.[18] Conversely, Kaltenthaler *et al.* include within their definition of stakeholders, modellers, decision makers, health professionals and 'others who impact upon or are impacted upon by the decision problem'.[14] Similarly, Rodriguez-Ulloa and Paucar-Caceres include 'system dynamics practitioners, clients, actors and problem owners' as stakeholders.[129] Tako *et al.* do not define who their stakeholders would include.[136] Robinson, Howick *et al.*, Fernández and Kekäle, and Vennix and Gubbels do not use the term 'stakeholder'. Robinson refers to 'clients', 'the modeller' and 'domain experts',[8] whilst Howick *et al.* uses the term 'client group', without providing specific information about who this would include.[127] Vennix and Gubbels similarly use the term ‘client’ and define these as multiple audiences including non-scientific and scientific / expert audiences.[128] Finally, Fernández and Kekäle use the term ‘respondents’, who have experience and background of the topic of interest.[125]

These semantic differences often lead to inconsistencies and confusion around what people within the same or similar disciplines are trying to achieve. The key implication is that I need to ensure that my research is clear about what is included within a conceptual modelling framework and which groups of people might be involved in the model development process. If the term ‘conceptual model’ is employed within the framework it needs to be clearly defined.

4.3.3 Methods and methodologies employed within the frameworks, including strengths, limitations & potential application to Public Health economic modelling

This section briefly outlines the methods and methodologies employed within the conceptual modelling frameworks. It focuses upon any strengths and limitations of the frameworks highlighted by the authors, as well as my own judgements of their strengths and limitations for their potential application to Public Health economic modelling, using the research presented within Chapters 2 and 3. To aid comprehension, the frameworks are divided into four non-mutually exclusive groups; (i) conceptual modelling frameworks with non-prescriptive methods;[8;14;18] (ii) those employing diagrams denoting causal relationships;[127-129] (iii) those based on Soft Systems Methodology;[129;136] and (iv) those using Delphi methods.[125;128] These groups were chosen, using the data extraction forms, as the most useful way of combining and comparing the conceptual modelling frameworks based upon the key methods employed within the frameworks.

Before reporting a critical analysis of each of the conceptual modelling frameworks, some of the key methods employed within the frameworks are described.

4.3.3.1 Description of methods / methodologies used within the frameworks

<u>Methods for developing diagrams denoting causal relationships</u>

Cognitive mapping

Cognitive mapping, as used within Management Science, is a method for capturing stakeholders’ views in order to understand the possible options available to them.[139] The map is made up of nodes, or ‘concepts’, which depict the ideas and views of stakeholders (preferably in their own language), connected by arrows which depict the relationships between concepts. Concepts are usually phrases with an active verb. Concepts at the tail of the arrow lead to concepts at the head of the arrow, unless accompanied by a negative sign which suggests that the concepts at the tail of the arrow will have negative implications for the concepts at the head of the arrow. The ultimate goal of the person is stated at the top of the map, with intermediate goals below, and options for achieving the goals at the base of the map. Cognitive maps are intended to portray perceptions of a complex problem and hence each concept does not need to be able to take a discrete value. The process of the development and analysis of cognitive maps is known as Strategic Options Development and Analysis (SODA),[139] which is a type of problem structuring method. Cognitive maps can be developed via individual interviews and then combined via a facilitated workshop into a strategic map, otherwise termed a cause map,[127] (SODA I), or the cause map can be developed jointly using focus groups (SODA II, otherwise known as Journey Making).[139] It is possible to develop cognitive and cause maps within specialised software such as 'Decision Explorer'[140] or 'Group Explorer'[141] or they may be developed using pen and paper, for example, with the use of post-it notes. Cognitive / cause maps can be used to establish whether there are any positive or negative feedback loops within the system, and whether there are any clusters of factors which have greater impact upon the goals than single factors.

Causal diagrams

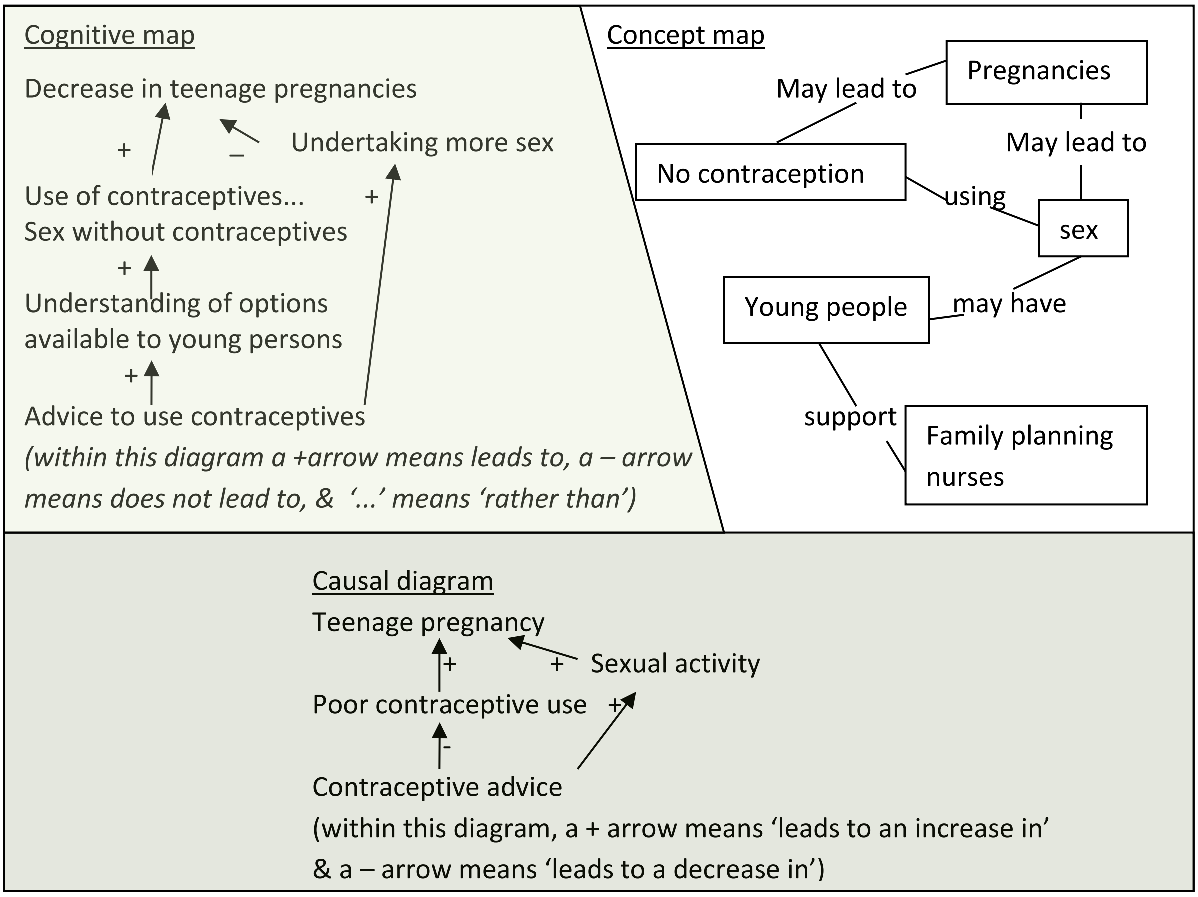
A causal diagram is similar in appearance to a cognitive / cause map; however it represents the causal relationships between events or consequences of an intervention within a system, rather than the relationships between stakeholder views.[129] Each event or consequence has the potential to be a variable within a quantitative model, in that each can take a discrete number of values and can be structurally related by equations to dependent variables. As for cognitive / cause maps, variables are connected by arrows, where those at the head of the arrow are dependent upon those at the tail of the arrow. Next to each arrow a positive or negative sign is used to denote the direction of the relationship; a positive (negative) sign is used if an increase in the independent variable leads directly to an increase (decrease) in the dependent variable.[129] An influence diagram (or causal loop diagram) is conceptually the same as a causal diagram; however feedback loops are graphically specified as either positive or negative.[89] It should be noted that there is an alternative meaning when developing mathematical models for the term 'influence diagram', which can also be used for a diagram which does not consider feedback loops and is isomorphic to a decision tree, including outputs, decision variables and stochastic variables.[142]

Concept maps

A concept map links a group of concepts via arrows with a verb or preposition used to connect each pair of concepts. As such concept maps do not require positive or negative signs to denote the direction of the causal relationship. Whilst concept maps do not necessarily focus upon one goal as for cognitive mapping, they should be arranged in a hierarchical structure with the most general concepts at the top of the map and the most specific concepts at the base.[143]

Figure 4.2 shows examples of a cognitive map, a causal diagram and a concept map.

Figure 4.2: Example of a cognitive map, a causal diagram and a concept map



Soft Systems Methodology (SSM)

SSM is a type of problem structuring method which uses systems thinking (see Chapter 3). It aims to understand a problem in terms of the worldviews of all stakeholders in order to develop feasible and systemically desirable changes.[123] It is a seven step cyclical process, developed by Checkland, divided into Real World Thinking and Systems Thinking about the Real World, as shown in Figure 4.3.

Figure 4.3: Soft Systems Methodology overview

Real World Thinking	*Systems Thinking about the Real World*
(1) Problem situation → (2) Problem situation expressed →	(3) Root definitions of relevant systems
	↓
(6) Feasible, desirable changes ← (5) Comparison of 2 & 4 ←	(4) Purposeful activity modelling
↓	
(7) Action to improve the problem situation	

Step 1 involves the analyst immersing themselves in the current situation in order to understand it; the methods for doing so are not prescriptive. Step 2 entails representing this understanding within a diagram (a 'rich picture'), which shows boundaries, structure, stakeholders in the system, communication flows and barriers in communication, conflicts / harmony, emotions, general attitudes and monitoring activities.[123] In order to facilitate Steps 1 and 2, Checkland suggests considering the roles of the people involved and the culture and politics of the situation. Step 3 moves to the systems thinking world and comprises the development of a 'root definition' (one sentence) for each stakeholder within the system using the mnemonic 'CATWOE'; the Customers (people benefiting within the system), the Actors (people performing the tasks in the system), the Transformation (the core activity of the system), Weltanschauung (or worldview – the objective of the system and its underlying beliefs), the Owner (the person with the power to approve or cancel the system) and the Environment (external factors which may impact upon the system eg. legal rulings). Step 4 involves developing a Purposeful Activity Model (PAM) for each stakeholder, consisting of an ideal view of the activities within the system from their perspective, based upon the root definition. Checkland suggests considering the three 'E's when developing the PAM; effectiveness (is it the right thing to do?), efficacy (does it work?) and efficiency (are the resources required available?). The PAM (systems thinking world) is compared with the rich picture (real world thinking) to identify any mismatches, termed 'problems', within Step 5. Step 6 and 7 entail developing solutions for these 'problems', which may use quantitative analysis.

Summary of methods proposed within the conceptual modelling frameworks

Table 4.5 presents an overview of the suggested methods within the included conceptual modelling frameworks, divided by stage as discussed within Section 4.3.2.

Table 4.5: Overview of methods used within included conceptual modelling frameworks

Author	**Understanding the problem and setting objectives**	**Choose model options, determine model scope & level of detail, identify structural assumptions & model type**		
		Choosing potential options	**Model scoping (including what to include & exclude)**	**Model level of detail, structural assumptions & model type**
Roberts *et al.*[18]	Written statement by understanding relevant clinical & policy literature & reviewing existing similar models.	Determine by the decision problem.	Consideration of relevant population, time horizon, outcomes, perspective for costs, key uncertainties & policy context. Could use expert consultation, influence diagrams (isomorphic to decision trees) and/or concept mapping.	
Kaltenthaler *et al.*[14]	A disease process model and a service pathways model, with a list of issues to consider.	According to NICE scope & clinical input.	Design-oriented conceptual model, with a list of issues to consider & list of evidence requirements.	
Robinson[8]	Not prescriptive. Suggests formal PSMs incl.SSM, cognitive mapping & causal loop diagrams.	Driven by how model objectives might be achieved.	(1) Identify model boundary; (2) Identify all components; (3) Assess whether to include/ exclude. Decisions based on validity, credibility, utility & feasibility.	A template for the level of detail is provided for each component identified in the scoping stage. This is tabulated and is specific to DES.
Howick *et al.*[127]	Cognitive maps.	Not reported.	Identify & analyse feedback loops & triggers from cause map. Represented within an influence diagram.	
Tako *et al.*[136]	CATWOE & Root Definitions from SSM & Care System Model (map of key activities in the system).	Performance Measurement Model (PMM).		Patient flow diagram (equivalent to the process flow diagram in DES).
Rodriguez-Ulloa and Paucar-Caceres[129]	CATWOE, Root Definitions & Rich Pictures from SSM & causal loop diagrams.	Causal diagrams based on root definitions & system dynamics models.		
Fernández and Kekäle[125]	Not reported.	Not reported.	Delphi & Analytic Hierarchy Process (AHP).	
Vennix[128]	Preliminary causal diagram and flow diagram followed by questionnaire, workbook & workshop to finalise the conceptual model.	Not reported.	Preliminary causal diagram and flow diagram followed by questionnaire, workbook & workshop to finalise the conceptual model.	

Note: Green cells are those stages within which stakeholders are reported to be involved.

4.3.3.2 Conceptual modelling frameworks with non-prescriptive methods

Three studies by Roberts *et al.*, Kaltenthaler *et al.* and Robinson were identified which present principles and/or methods associated with the development of a conceptual model, without providing prescriptive methods for each stage.[8;14;18] The frameworks by Roberts *et al.* and Kaltenthaler *et al.* both focus upon the conceptual model development of health economic models,[14;18] and these are the first attempting to do this within health economic modelling. Robinson does not present a domain-specific framework, although it is aimed at operations systems (i.e. systems of resources providing goods or services). All three articles suggest a detailed process to follow for conceptual modelling, with some examples of methods which could be used within the process.[8;14;18]

<u>Overview of framework by Roberts *et al.*[18]</u>

The framework by Roberts *et al.* (2012) suggests that a clear, written statement of the decision problem, modelling objectives and model scope should be developed by consulting a wide range of clinical experts, understanding relevant clinical and policy literature and reviewing existing similar models.[18] It highlights the importance of identifying all relevant options for comparison in order for the results to be useful. It suggests that the conceptual model (of the problem) should not be determined by the availability of data and that an explicit process should be followed for developing the quantitative model from the conceptualisation of the problem such as expert consultations, influence diagrams or concept mapping. The authors suggest consideration of a number of issues prior to the development of the quantitative model including determining the relevant population, time horizon, outcomes, perspective for costs, key uncertainties and the policy context of the decision problem. The framework also suggests that it is important to choose the most appropriate model type for the decision problem.[18] Whilst the framework highlights *what* should be done during conceptual modelling, it does not describe methods for *how* it might be done. For example, it describes the advantages of model simplicity and suggests that the model must be complex enough to fully represent differences between the interventions, but it does not suggest methods for making these judgements about the level of detail.

Whilst the framework described by Roberts et al. divides the conceptual modelling into conceptualising the problem and conceptualising the model, the former appears to contain some of the latter. For example, the former section considers the time horizon of the model and data selection for the model. The conceptualising the problem stage mainly focuses upon ‘PICO’. This is the standard criteria by which the scope of health economic models is defined, and comprises populations, interventions, comparators and outcomes. The conceptualising the model stage mainly focuses upon choosing an appropriate model type.

Overview of framework by Kaltenthaler *et al.*[14]

The conceptual modelling framework by Kaltenthaler *et al.* (2011) was developed building upon the model development process and some of the findings described within Chilcott *et al.*[17] The framework is divided into problem-oriented conceptual models and design-oriented conceptual models.[14] The former aims to understand the parts of the real world of interest based upon stakeholder expertise, whilst the latter aims to identify potentially feasible and credible model development choices including defining the model scope and level of detail according to available evidence, time, expertise and money. The problem-oriented conceptual model is divided into two parts; a disease process model which aims to capture important events within the disease natural history, and a service pathways model which aims to capture all treatment services associated with the intervention being assessed. For all conceptual models, the authors suggest a flow diagram representation accompanied by a text description and they provide a large number of issues for the modeller to think about when developing them. For the disease process model these are issues such as 'Are all relevant competing risks considered?' and 'Should the model differentiate between different subgroups of patients?', whilst for the service pathways model these are issues such as 'Is it clear where and how patients enter the service?' and 'Does the conceptual service pathways model include all relevant resources components?' For the design-oriented conceptual model, examples of possible issues to consider are 'How should trial evidence be extrapolated over time?' and 'Which methodological approach is likely to be most appropriate?' The framework suggests that where the design-oriented conceptual model differs from the problem-oriented conceptual models this should be clearly documented and explained. The paper recommends input from health professionals throughout the model development process.[14]

Overview of framework by Robinson[8]

Robinson divides the understanding of the problem by stakeholders into three levels; (1) Clearly understood and expressed, which can be handled via discussion and careful note-taking; (2) Apparently well understood and expressed, although it is not, which involves speaking with the right people, asking searching questions and suggesting alternative interpretations; and (3) Neither well understood nor expressed, which may require the use of formal PSMs (eg. SSM, cognitive mapping) or a basic simulation model for encouraging debate.[8] The author does not outline methods for deciding which of the outlined three problem situations the modeller is dealing with.[8] Robinson suggests identifying the overall organisation aims and then the model objectives in terms of what the client hopes to achieve, performance measures and working constraints. He suggests that the modeller should be aware of broader considerations such as timescales and project resources, model flexibility needs and who the model users will be. Within the framework, model outputs and decision variables (different options) are determined based upon the model objectives and discussion with the client; and the model boundary is defined based upon these. All components in the real system within the boundary are identified and tabled, particularly those which connect the decision variables to the outputs.[8]

The conceptual model can be assessed in terms of validity, credibility, utility and feasibility. Conceptual model validity (credibility) is defined by Robinson as 'a perception, on behalf of the modeller (client), that the conceptual model can be developed into a computer model that is sufficiently accurate for the purpose at hand'. Utility is defined as 'a perception on behalf of the modeller and the clients, that the conceptual model can be developed into a computer model that is useful as an aid to decision-making within the specified context', whilst feasibility is defined as 'a perception on behalf of the modeller and the clients, that the conceptual model can be developed into a computer model with the time, resource and data available'.[8] Following this, a list of details for each component within the model boundary is tabled, along with a decision about whether to include (and how) or exclude (and why) the detail. Data requirements are listed based upon the level of detail table and any assumptions about the data are documented. Robinson suggests that diagrams, such as process flow diagrams or activity cycle diagrams, may be useful for communication of the conceptual model.[8]

Making modelling judgements within these frameworks

All three frameworks consider, to some extent, how to make judgements about what to include and exclude within the quantitative model.[8;14;18] Roberts *et al.* provide a number of recommendations about what should be considered for inclusion and why, such as which types of costs and outcomes to include.[18] However, this framework does not provide methods for choosing specific variables. Kaltenthaler *et al.* suggest that making judgements about inclusion and exclusion should be jointly decided with modellers, decision-makers, health professionals and other stakeholders who impact upon or are impacted upon by the decision problem, and this is informed by a list of questions relevant to modelling clinical interventions.[14] The authors state that ignoring conflicting views between stakeholders could result in developing models which are 'contextually naïve and uninformed'.[14] Robinson suggests developing a table describing what should be included and excluded from the model, which could be informed by the judgement of the modeller, clients and domain experts, past experience, analysis of preliminary data about the system or testing the effect of including or excluding details in part of the model.[8] He suggests a method for doing this by considering whether each detail adds to the validity, credibility, utility and feasibility (as described above).

Roberts *et al.* describe methods for choosing the model type depending upon the characteristics of the problem.[18] Similarly, Kaltenthaler *et al.* suggest that the modelling approach should be determined during the development of the design-oriented conceptual model, although no methods for doing this are outlined.[14] Within the framework by Robinson, it is assumed that a DES will be the most appropriate modelling tool from the outset.[8] As such, there are no methods for choosing the appropriate model type. This also means that components of some of the stages relate specifically to DES such as the suggested 'level of detail' table.

Stakeholder involvement within these frameworks

These frameworks suggest that stakeholders should be involved throughout model development; however they do not specifically describe methods for involving stakeholders. Roberts *et al.* suggest that stakeholder involvement can facilitate the development of appropriate modelling objectives and may provide a deeper understanding of the values and preferences associated with the problem.[18] Kaltenthaler *et al.* suggest that the problem-oriented conceptual model is highly dependent upon stakeholder involvement and that stakeholders can provide advice around geographical variation of healthcare provision.[14] Robinson argues that a well-documented conceptual model provides a method for all stakeholders to communicate.[8]

Potential application to Public Health economic evaluation

There are several differences between the intended application for the conceptual modelling framework by Robinson[8] and the requirements of a conceptual modelling framework for Public Health economic modelling. These include: (1) within Public Health economic modelling substantial extrapolation of data is usually required, whilst within operations systems data tends to be available for entities from model entry to model exit; (2) within Public Health economic modelling the system is a national average where data is inferred from observations from one or a number of examples of the system, rather than data being based upon observations of a specific system; and (3) capacity constraints are not a focus within Public Health economic modelling because traditional cost-effectiveness analysis assumes that the system is able to cope with any resource changes, whereas they are of key interest within operations systems. In addition, within Public Health economic modelling, the system is generally bigger with a greater number of other systems being integrated within the system of interest than within these applications. Compared with the framework by Robinson,[8] the model type required is not known from the start of the project within Public Health economic modelling whilst it is assumed to be a DES for this framework. In addition, the framework does not explicitly consider how to determine the relationships between model variables, whilst it would be essential to specify relationships between variables within Public Health economic modelling. Finally, Robinson's 'level of detail' table would need to be modified in order to be usable within Public Health economic modelling.[8]

The conceptual modelling frameworks described by Kaltenthaler *et al.* and Roberts *et al.* provide a basis for some of the considerations required within a Public Health economic conceptual modelling framework.[14;18] However, they do not cover issues which are specific to or accentuated within Public Health. As described within Chapters 2 and 3, economic evaluations within Public Health are generally different to economic evaluations of clinical interventions because they usually require the development of models of multi-component interventions with complex causal chains operating within dynamically complex systems, dependent upon the determinants of health, as against models of simple interventions which generally do not depend upon human behaviour operating within relatively clear system boundaries. A key objective of Public Health is often to reduce health inequities rather than to maximise health. The frameworks do not consider these issues and in some cases are explicitly incompatible with them. For example, Roberts *et al.* suggest for the choice of comparators that 'all feasible and practical strategies should be considered',[18] without highlighting the large number of permutations often associated with Public Health interventions. As such a conceptual modelling framework would need to provide methods for dealing with these additional issues associated specifically with Public Health economic modelling.

4.3.3.3 Conceptual modelling frameworks employing diagrams denoting causal relationships

Three key studies were identified which presented conceptual modelling frameworks employing diagrams denoting causality.[127-129]

<u>Overview of framework by Howick *et al.*[127]</u>

Howick *et al.* (2008) describe a model building process (a 'cascade') with the same information being depicted within different diagrams to enable multiple audiences to appreciate the validity of the models being built and their outcomes.[127] Specifically, the authors suggest developing a cognitive map and transforming this into a cause map, followed by an influence diagram and then a system dynamics formal influence diagram (a qualitative version of the system dynamics model), before developing a quantitative system dynamics model. The authors suggest moving back down the 'cascade' to check for inconsistencies and to improve model validity.

Overview of framework by Vennix and Gubbels[128]

Vennix and Gubbels (1992) describe the design and implementation of an iterative group model building approach.[128] This involves the development of a questionnaire containing a preliminary conceptual model (a causal diagram depicting the relationships between factors which affect the decisions of the stakeholders combined with a flow diagram of the physical system) upon which experts can feed back remotely to the analysts. This is followed by the development of a workbook by the analysts which reports the results of the questionnaires and asks for feedback from the experts on submodels of the modified conceptual model. Within the workbooks text statements about the causal relationships are provided followed by the same information within a diagram. Finally, a structured workshop is held to discuss any areas of disagreement within the model in order to agree a finalised conceptual model.

Overview of framework by Rodriguez-Ulloa and Paucer-Caceres[129]

Rodriguez-Ulloa and Paucer-Caceres (2005)[129] describe and illustrate a framework for combining SSM and System Dynamics (SD) (see Section 4.3.3.1 for description of SSM). The framework is divided into three worlds; the Real World, the Problem-Situation-Oriented System Thinking World (i.e. using Systems Thinking to define what will be included in the model) and the Solving-Situation Oriented System Thinking World (i.e. using Systems Thinking to find a solution). Stakeholders develop a Rich Picture of the problem situation to describe the real world as in SSM. Following this, the Problem-Situation-Oriented System Thinking World involves developing a one sentence definition, using the mnemonic 'CATWOE' (Customers, Actors, Transformation, Worldview, Owner, Environment), from each stakeholder's perspective describing the problematic transformations occurring, as depicted within the Rich Picture. This is different to SSM which develops solution-based transformations at this stage in order to try to improve the system. A diagram showing the boundary around the system and the flows between the external inputs and the key internal aspects of the system, defined as a context diagram, is developed for each of these root definitions with different stakeholder worldviews. The analyst then aims to describe the problematic behaviour in a causal diagram for each worldview developed within computer software which allows a range of different relationships between variables to be tested in order to understand the problematic behaviour according to different worldviews. This is compared with the Rich Picture to assess whether the diagram adequately describes what is happening in the real world.

The Solving-Situation-Oriented System Thinking World involves developing a quantitative system dynamics model, the outputs of which can be compared with the Rich Pictures developed initially. Within the system dynamics model, culturally feasible and systemically desirable changes can be identified by expressing them within root definitions using CATWOE and comparing them with the initial root definitions. These changes can then be implemented and learning points noted. An earlier attempt at combining these two systems approaches was described by Lane which provided a similar theoretical argument;[144] however the approach for combining the two methods was largely underdeveloped compared with the framework by Rodriguez-Ulloa and Paucer-Caceres.[129]

Making modelling judgements within these frameworks

All of these frameworks provide methods for understanding the problem and for moving from this initial understanding to the development of a conceptual model describing the variables to be included within a quantitative model and the relationships between them. Howick *et al.* suggest using the initial cause maps developed by stakeholders, and analysing the feedback loops and triggers in order to help to define relevant variables for the subsequent model.[127] Similarly, Vennix and Gubbels suggest relevance of variables should be defined through an iterative process with stakeholders, although they do not suggest any formal analysis to facilitate this.[128] Rodriguez-Ulloa and Paucer-Caceres suggest using the analyst's interpretation of each stakeholder's context diagram to choose relevant variables by developing a model which is sufficient to replicate the problematic behaviour seen in the real world.[129] However, no methods are provided for doing this and it is unclear to what extent the model should 'replicate' reality.

In a similar way to the conceptual modelling framework by Robinson,[8] within all of these frameworks no methods are provided for choosing the most appropriate model type after understanding the problem. Instead, it is assumed that a system dynamics model will be developed. This application of causal diagrams seems intuitive; however it should not constrain the application of these methods. It seems possible to develop other model types from causal diagrams, such as agent-based models, providing that the key causal relationships described by the conceptual models are included within the quantitative model. However, the development of alternative model types may require a different focus on causality, such as a focus upon the 'rules' for agent behaviour within an agent-based simulation. A limitation of the system dynamics modelling approach is that it is a cohort approach which does not allow for patient-level variability or a comprehensive analysis of uncertainty such as probabilistic sensitivity analysis (as would a DES or an agent-based simulation).

Stakeholder involvement within these frameworks

All of these frameworks aim to promote stakeholder ownership of the models by the involvement of stakeholders throughout the model building process and the iterative nature of the processes. Rodriguez-Ulloa and Paucar-Caceres use SSM to understand the problem situation from each stakeholder's perspective,[129] whilst Howick *et al.* uses cognitive and cause maps[127] and Vennix and Gubbels uses questionnaires and workbooks to collect information about each stakeholders understanding of the problem.[128] A potential disadvantage of the method employed by Vennix and Gubbels for gaining the stakeholders' understanding of the problem is that they are presented with a preliminary conceptual model developed by the analysts which may influence the information provided by the stakeholders compared with if they presented their ideas *de novo*.[128] The involvement of stakeholders within the model building process also means that all three frameworks developing a diagram denoting causality carry substantial time requirements for both the modeller and the stakeholders. Vennix and Gubbels attempt to minimise the face to face time requirements for the stakeholders by circulating questionnaires and workbooks prior to the workshop.[128] The amount of stakeholder involvement in the framework by Rodriguez-Ulloa and Paucar-Caceres is unclear.[129] Clearly, there is a balance to be struck between time requirements of the stakeholders and the analyst and the benefits of stakeholder involvement in the model building process.

Howick *et al.* argue that stakeholders need to have confidence in the model outputs by understanding the model structure, in terms that they would use to describe the situation.[127] The authors relate this to validity and state that models have to be both qualitatively and quantitatively valid. The framework which the authors present aims to convert natural language into numerical simulation and then back to natural language in order to increase stakeholder trust of the models.

Potential application to Public Health economic evaluation

Whilst none of these frameworks explicitly consider domain-specific factors such as the social determinants of health, all of them encourage the complexity of the system to be captured through the use of methods which describe non-linearity and feedback loops (see Chapter 3).

Cognitive mapping used within the framework by Howick *et al.* aims to help stakeholders understand the entire breadth of the problem and to uncover and share the sense making systems of the stakeholders rather than adopting the single worldview of the analyst. Cognitive mapping can be used to establish whether there are any positive or negative feedback loops within the system, and whether there are any clusters of factors which have greater impact upon the goals than single factors.[139] The theory behind cognitive mapping, based upon Kelly, is that every person uses a system of bipolar constructs (eg. happy / sad) to categorise people and situations and that this construct system represents reality as the person understands it.[145] Each stakeholder within a project will have their own personal constructs about the problem based upon their background knowledge and experiences. By making these constructs explicit and sharing each stakeholder's background knowledge and experience, it is possible to question these constructs and discuss disagreements around the causal relationships. For each construct, the analyst can ask 'why?' to establish the consequences of the construct and 'how?' to express potential options for change, leading to a hierarchy of goals at the top of the map, then intermediate goals or actions, with options at the bottom of the map.[139] This is useful as it provides an intuitive method for developing and interpreting the map. However, because cognitive mapping was designed to be used within organisations, there is a focus upon how things are managed rather than on prediction. Rather than providing answers to a single problem at one point in time, it aims to provide an approach that people within an organisation can continue to use for making decisions. In contrast, within Public Health economic modelling the aim is not necessarily to impart how to make better decisions, but to develop a useful quantitative model. In addition, each concept within the cognitive map should begin with a verb, for example, employ more staff, which generally cannot be translated easily into a quantitative model. These are normative perceptions of the stakeholders; however, for modelling within Public Health generally positivist factors are of interest such as the number of cardiovascular events which is causally related to the number of deaths.

Causal diagrams, used within the frameworks by Vennix and Gubbels and Rodriguez-Ulloa and Paucar-Caceres, can also be used to establish whether there are any positive or negative feedback loops within the system and whether there are any clusters of factors which have greater impact upon the goals than single factors. In contrast to cognitive maps, each of the concepts within the diagrams are variables which could be used within a quantitative model as required within Public Health economic modelling. However, there are no specific methods for developing causal diagrams or for involving stakeholders within that development. Whilst a causal diagram can provide an explicit description of our hypotheses about causal relationships, the challenge within Public Health economic modelling is to be able to justify the causal assumptions made.

Missing information within these frameworks

There are details missing from all three of the studies in order to understand each framework fully. For example, within the study by Howick *et al.* it is unclear how the endogenous variables which are identified from the cause map are dealt with for inclusion within the influence diagram.[127] It is also unclear how changes made to the structural assumptions within the model when moving up the cascade should be documented. It seems that each map should be modified in turn; however this seems to contradict what is said within the discussion of the article about having a transparent audit trail, unless these changes are documented during each iteration of model development. In addition, Howick *et al.* suggest that the methodology is not entirely simple to use, and in particular point to challenges in moving from the influence diagram to the system dynamics formal influence diagram.[127] However, they do not elaborate on this further so it is unclear what the challenges with using the methodology are, or how they might be overcome. Within the study by Rodriguez-Ulloa and Paucer-Caceres, it is unclear how the culturally feasible and systemically desirable options are identified.[129] Finally, within the frameworks by Howick *et al.* and Vennix and Gubbels there is no consideration of how to choose options to test within the model.[127;128]

4.3.3.4 Conceptual modelling frameworks based on Soft Systems Methodology

Two studies were identified which presented conceptual modelling frameworks based on Soft Systems Methodology (SSM).[129;136]

Overview of framework by Rodriguez-Ulloa and Paucer-Caceres[129]

The study by Rodriguez-Ulloa and Paucer-Caceres (2005) is described above.[129] The authors suggest that a weakness of SSM is that it is not a 'problem solving methodology',[129] as also discussed by Flood and Jackson[92] and Mingers,[146] and it does not offer a technological tool to assess the impact of culturally feasible and systemically desirable options. Therefore, the authors argue that combining SSM with another systems approach would help to address this weakness. The study specifically focuses upon combining SSM with system dynamics. System dynamics employed independently has the weaknesses that it does not consider the different worldviews of the stakeholders and the implications of this, or whether the solutions provided by the analysis are culturally feasible and systemically desirable. The authors argue that combining the two approaches will make use of the strengths of both systems approaches whilst overcoming these weaknesses.[129]

Overview of framework by Tako *et al.*[136]

Tako *et al.* (2010) describe a participative conceptual modelling framework for healthcare applications which involves developing root definitions using the mnemonic CATWOE and a map of key activities in the healthcare system.[136] This map is defined as a Care System Model, adapted from the Purposeful Activity Model within SSM, and includes long- and short-term clinical activities, managerial activities and research activities, using verbs to describe the activities. These are agreed within an initial workshop. Within a second workshop, the three performance criterion from SSM are employed (efficacy, efficiency and effectiveness) to establish performance measures, which facilitates the development of objectives, and in turn the model inputs and outputs. During this second workshop a flow diagram described by the authors as a Performance Measurement Model (PMM) is developed, with the headings 'monitoring activities', 'determine if activities' and 'changes'. A patient flow diagram (PFD), equivalent to the process flow diagram in DES, is employed to choose the model content & level of detail alongside stakeholders.

Making modelling judgements within these frameworks

As described above, Rodriguez-Ulloa and Paucer-Caceres suggest using the analyst's interpretation of each stakeholder's context diagram to choose relevant variables by developing a model which is sufficient to replicate the problematic behaviour seen in the real world.[129] Similarly, Tako *et al.* employ stakeholder involvement to choose relevant model variables by developing the conceptual model with them, although no formal methods are described for justifying the variables chosen. [136]

Stakeholder involvement within these frameworks

An advantage of using SSM is that it introduces the stakeholder's worldviews explicitly which could help the modeller to understand disagreements between stakeholders. However, within both of these studies it is unclear how consensus between stakeholders is reached where disagreements occur. The fact that there are no methods within SSM for resolving conflicts between stakeholders has been a point of criticism of SSM.[92] For a specific stage of the framework (developing the performance measurement model) described by Tako *et al.* there is an exception to this, where the authors suggest that voting between stakeholders may be used if disagreements occur around determining the changes to the system to achieve the performance measures.[136] It is not reported how this affects implementation of the options.

Tako *et al.* do not employ Rich Pictures,[136] unlike the study by Rodriguez-Ulloa and Paucer-Caceres.[129] This may be due to the negative experience of one of the authors in using Rich

Pictures,[147] who suggests that the non-scientific appearance of Rich Pictures may lead to practical problems with their use. As for Vennix and Gubbels,[128] Tako *et al.* provide the stakeholders with preliminary analyses and ask for feedback in order to revise these analyses.[136] An advantage of this approach is that it minimises the time requirements of the stakeholders, although arguably increases the time requirements of the modeller(s). However, the major disadvantage of this approach is that the starting point for the stakeholders may influence the input and limit the thinking of the stakeholders.[128] Moreover, providing root definitions to stakeholders may cause irritation if they do not agree. Since this is likely to be their first point of contact with the modeller, this could lead to difficulties in cooperation during the remainder of the project.

<u>Potential application to Public Health economic evaluation</u>

SSM allows the analyst to understand a problem associated with human activity using systems thinking, considering the different worldviews associated with the problem rather than adopting the single worldview of the analyst. Within SSM, stating the worldview of each stakeholder encourages the paradigms to become apparent (see Chapter 1) and the assumptions questioned. This allows the subjective judgements of the stakeholders, such as which Public Health interventions might be assessed and what might happen in the future, to be discussed. SSM also considers the different types of stakeholders who may be involved. In addition, within a large system where the expertise of stakeholders is unlikely to extend across all relevant issues, as for many Public Health topics, SSM allows the entire breadth of the problem to be understood.

However, the main issue with using SSM for Public Health modelling is that it is an extensive process with lots of different steps to follow. Given the findings of the qualitative research that the conceptual modelling framework should not constrain the process, many analysts would not be happy using SSM for understanding the problem. Although Checkland suggests that not all of the seven steps associated with SSM need to be followed in order for the analyst to be doing SSM once they understand the general way of thinking,[123] these steps would need to be undertaken initially in order to be able to develop this way of thinking. In addition, SSM aims to help people within an organisation continually make better decisions where objectives are unclear due to multiple, possibly conflicting worldviews, whilst within Public Health economic modelling the aim is not to impart how to make better decisions, but to develop a useful quantitative model. SSM is particularly focused within organisations, which means that many stages would need additional consideration in order to be applicable to Public Health economic modelling. For example, case studies of SSM tend to make use of observable data rather than requiring predictions a long way into the future to be made. Finally, there is the concern of Tako *et al.* that drawing rich pictures would not appear 'scientific' to the stakeholders.[136]

4.3.3.5 Conceptual modelling frameworks using Delphi approaches

Two studies were identified which presented conceptual modelling frameworks using Delphi approaches.[125;128] The study by Vennix and Gubbels has been described above.[128]

<u>Overview of study by Fernández and Kekäle[125]</u>

Fernández and Kekäle (2008) use the Delphi method to identify factors which may affect the goal of the system followed by the Analytic Hierarchy Process (AHP) method to determine the most important factors.[125] The Delphi method is an iterative process involving a group of experts who are asked to respond to questionnaires, and then revise their future responses according to the collective results of the questionnaires, with the eventual aim being convergence between the experts. The AHP method is a way of evaluating alternative options by defining criteria by which they can be judged and placing quantitative weights associated with those criteria. The authors suggest that the framework is most useful for problems where there is a mixture of scientific evidence and social values.

<u>Making modelling judgements and stakeholder involvement</u>

The Delphi method is employed as an iterative process whereby stakeholders critique their subjective opinions about important variables and possible causalities in order to reach a consensus. Once all possible relevant factors have been identified by the Delphi method, a questionnaire is developed to ask stakeholders to prioritise the factors within four separate blocks, although it is unclear what all four of these blocks are or how they were chosen. A method defined as 'aggregation of individual priorities' is employed to develop collective priority values of all stakeholders, using the weighted geometric mean. The authors propose a sensitivity analysis whereby adjacent variables change position in the rankings based upon the measure of variation in weightings between stakeholders. These variables can then be used within the quantitative model.

<u>Limitations of study by Fernández and Kekäle[125]</u>

Whilst this study provides a systematic and transparent method for choosing relevant model variables, it has numerous flaws as a conceptual modelling framework. Firstly, it does not consider methods for understanding the problem situation, defining objectives or describing relationships between variables. Secondly, in asking stakeholders to weight the importance of variables within the system, it assumes that stakeholders have a clear understanding of the causalities within the system. This is unlikely to be the case if the stakeholders deal only with a small part of the system or if the system is dynamically complex and hence feedback loops are important as is the case in Public Health systems. Other forms of evidence are not considered within this approach and these might be inconsistent with the stakeholder expertise provided. Finally, very little method detail is provided within the article. For example, it is unclear how factors are identified and consensus is reached using the Delphi method. It is also unclear exactly how the AHP is employed.

Potential application to Public Health economic evaluation

The authors state that the explanatory power of the model is dependent upon the stakeholders' understanding of the system and breadth of knowledge. Stakeholders within Public Health economic evaluation tend to have specialist areas so that they may have an in-depth knowledge about one part of the system, but a poorer understanding of the system as a whole due to its size and complexity. For example, when assessing interventions to encourage young people to use contraceptives and contraceptive services, the family planning nurse had in-depth knowledge about contraceptives and sexually transmitted infections, whilst midwives had in-depth knowledge about pregnancy. This means it would be very difficult for stakeholders to prioritise variables in terms of their impact upon the relevant outcomes in this context. Within Public Health economic modelling, one of the major advantages of modelling is in understanding the system as a whole, and hence it would not be beneficial to employ this method within Public Health economic modelling.

4.3.4 Benefits of a conceptual modelling framework

A wide range of benefits of the use of a conceptual modelling framework are described within the studies, set out within Table 4.6 below. These benefits of a conceptual modelling framework have been used to refine my research question in order to be more specific about what 'quality' is within a conceptual modelling framework. Thus my revised research question is: '*What might a conceptual modelling framework for Public Health economic evaluation comprise and what could its potential be to improve model quality?*', where quality is defined as providing a tool for communication with stakeholders, aiding the development of modelling objectives, guiding model development, experimentation and reuse, and improving model credibility, verification and validation.'

Table 4.6: The benefits of a conceptual modelling framework described within the studies

Benefits	Roberts *et al.*[20]	Kalten-thaler *et al.*[14]	Robinson [120]	Tako *et al.*[129]	Howick *et al.*[121]	Fernan-dez & Kekäle[119]	Rodriguez-Ulloa & Paucar-Caceres[123]	Vennix & Gubbels [122]
1.Modellers need some means to determine what to model. The design of the model **impacts all other aspects** of the study			√	√				
2.A tool for **communication between stakeholders** including the project team, clients, decision makers & domain experts	√	√	√	√	√	√	√	√
-May uncover variations in stakeholders' conceptualisation	√	√	√	√	√	√	√	√
-May uncover geographical variation		√						
-Sharing assumptions highlights invalid judgements		√						√
-Provides the basis of the model documentation			√	√				√
-Encourages creativity in finding a solution			√	√		√		
-Encourages learning about the problem during model development	√		√					√
-Encourages mutual trust between stakeholders &modellers					√	√		
3.Aids the development of **clear, shared, modelling objectives**. Minimises the likelihood of incomplete, unclear, inconsistent & wrong requirements	√		√	√			√	
4.Guides model development & experimentation	√	√	√	√	√	√	√	√
-Improves model-building efficiency	√					√		
5.Adds systematicity & transparency, allowing judgements concerning the **credibility** of the model to be made which increases confidence in model outputs	√	√	√	√	√	√	√	
-Avoids representing a contextually naïve & uninformed basis for decision-making		√					√	
6.Forms the basis for model **verification** & guides model **validation**		√	√	√	√	√		
7. Helps determine the appropriateness of the model or its parts for **model reuse**			√	√				

Dark green shading: Key benefits; Light green shading: Subsets of key benefits

4.3.5 Methods of evaluation of the frameworks and their theoretical underpinnings

Theory-based formative evaluation of the frameworks is undertaken within many of the articles and key elements of this are described throughout Section 4.3.3 above which outlines the frameworks. All of the identified conceptual modelling frameworks are illustrated through their application within a case study and any difficulties during the application have been stated. The frameworks have been developed during the undertaking of numerous projects by the authors, and hence in a sense they have been tested, improved and informally evaluated through a series of trial and error.

<u>Testing the frameworks independently of development</u>

Based upon a citation search of the included conceptual modelling frameworks, only two published case studies were identified which tested the frameworks independently of the original development.[148;149] Both of these case studies were of the Soft Systems Dynamics Methodology by Rodriguez-Ulloa & Paucar-Caceres[129] and were applied by the developers of the original framework. These showed that this conceptual modelling framework could be employed for different applications. The lack of use of these conceptual modelling frameworks by modellers other than the original authors indicates the state of development and highlights difficulties of dissemination and implementation. This issue is raised within the qualitative research within Chapter 5 where some of the modellers suggest that they would not want to follow another modeller's approach to structural development. This suggests that the approach should not constrain the decision making process and should be simple to follow. This is assessed during the evaluation of the conceptual modelling framework developed.

<u>Potential methods of evaluation of the conceptual modelling frameworks</u>

Although no formal evaluation is undertaken, Vennix and Gubbels suggest that participant time requirements are likely to be reduced using the framework and that they thought that the quality of the conceptual model increased compared with the preliminary conceptual model.[128] Vennix and Gubbels also state criteria for evaluating conceptual modelling frameworks including assessing the quality of the final conceptual model, participant time requirements and satisfaction, acceptance of the model by stakeholders and the insight and solutions provided by the model.[128]

The evaluation of conceptual modelling frameworks within a completely controlled experiment is both theoretically and practically infeasible. When comparing the outcomes of one model developed using a conceptual modelling framework and another without a framework, they must either be developed by the same person who has a different level of knowledge at the outset of each or by different people and hence variability will be introduced. Moreover, given the importance of the decision makers and the decision making process within the model development, it is practically difficult to undertake any such analysis since it is not possible to reproduce the same decision making arena.

Evaluation of PSMs

Although there is limited literature on the evaluation of conceptual modelling frameworks, in the context of PSMs the issue of evaluation has been substantially debated. There generally exist two different paradigms within the literature; the positivist view that PSMs should be evaluated within an experiment and is mainly concerned with external validity, and the interpretivist view that every situation is different and methods should be evaluated theoretically, focusing upon internal validity.[150] Mingers and Rosenhead suggest that for PSMs it is generally accepted that a purely positivist approach would be inappropriate,[151] however, there is no agreed method of evaluation. Pawson and Tilley argue that within evaluation it is important to understand what works for whom and in what contexts,[152] whilst Eden and Ackermann highlight that evaluation criteria may differ for people with different roles.[153] The most common methods of evaluation of PSMs are theoretical evaluation, case studies, interviews and observation.[150] However, White argues that these are insufficient alone, and that a pragmatic approach to evaluation which combines methods depending upon the context should be undertaken, involving a theory-based evaluation about how an intervention is supposed to work.[150] Applying these arguments to conceptual modelling frameworks suggest that the most appropriate approach may be theory-based evaluation, alongside other forms of evaluation such as a case study and/or feedback from modellers or stakeholders.

Theoretical underpinnings of the methods employed within the frameworks

It is useful to understand the theoretical underpinnings of the methods employed within the conceptual modelling frameworks to facilitate future evaluation. Cognitive mapping derives from Personal Construct Theory within Psychology.[145] The central idea of this theory is that human beings try to understand their world and predict what will happen in the future based upon a set of constructs, or hypotheses, formed by their past experiences. These constructs are constantly modified as events prove them wrong in order to help manage and control future events. Thus, each person will have different constructs depending upon their past experiences, although some constructs may be shared within social groups. People may not be aware of the constructs that they have developed or of the constructs of others. Cognitive mapping provides an approach for sharing and challenging these personal constructs. Cognitive mapping and SODA are thus underpinned by subjectivism in that they build upon people's interpretation of the world. Sharing and comparing these worlds can be informative in terms of understanding a problem situation and deriving potential options for changes to the situation.

SSM is grounded within systems thinking (described within Chapter 3). The methodology was developed via action research methods in response to the difficulty in using quantitative systems thinking approaches to answer questions about what action should be taken within business organisations. Checkland suggests that in such situations involving humans with different worldviews, there will never be a single testable description of the system and as such the problem to be answered is not always clear.[123] SSM is grounded in an interpretivist, epistemological approach; it analyses the meanings people place on their own and others' actions. The methodology provides a learning system rather than a means to an end, and as such it is important to understand the organisational and cultural constraints present. A fundamental idea of SSM is that the thinking should be divided into two 'worlds'; one requiring logic-based enquiry (systems thinking world) and the other requiring cultural enquiry (the 'real world'). These two 'worlds' should both be considered; iteratively, but distinctly.

Causal loop diagrams were developed alongside system dynamics models. These are also grounded in systems theory, and the central idea is that the dynamic behaviour of a system can be understood by describing the structure of the system in terms of causal relationships.[89] In contrast to SSM, these methods are based in quantitative systems thinking and hence these diagrams do not typically consider different worldviews, and as such they assume that the relationships included are factually correct (i.e. they assume that there is one reality, thus taking a realist ontological stance). In this way they do not explicitly consider social judgements.

The conceptual modelling frameworks by Roberts *et al.*[18] and Kaltenthaler *et al.*[14] are developed alongside welfare economic theory, as discussed within Chapter 1. As such, standard guidance has been developed which aims to facilitate this, such as that all relevant comparators should be included within the analysis and that a sufficient time horizon to capture all relevant differences in costs and outcomes between interventions should be incorporated. Whilst these standard guidelines are outlined within both of these frameworks, numerous methods guides and publications have documented these ideas of *what* should be done previously.[2-4] However, these conceptual modelling frameworks go some way beyond this and attempt to consider *how* these should be achieved and *why*. The framework by Kaltenthaler *et al.*[14] builds upon qualitative research reported within Chilcott *et al.* and pilot use of PSMs within a HTA study.[17;132] Within the framework by Roberts *et al.* the choice of model types is based upon the theoretical underpinnings associated with each of the economic modelling methods. However, other aspects of the framework describing the process of model development are based upon experience of the authors rather than any specific theories. This is also the case for the framework by Robinson.

<u>Theory around combining qualitative and quantitative approaches</u>

Four studies within the review suggest combining PSMs with quantitative analysis.[8;127;129;136] Within published case studies where PSMs such as SSM and SODA (including cognitive mapping) have been employed previously, they have more often than not been used as the sole analysis for complex problems, rather than for the basis of the development of a quantitative model.[44] Some experts argue that PSMs cannot be combined with quantitative methods because of their different theoretical underpinnings;[154] however many experts oppose this view[44;155] and increasing numbers of successful examples of mixed methodology studies support the idea that it is possible to combine PSMs and quantitative methods successfully.[133] According to Kotiadis and Mingers, it is practical rather than theoretical constraints which might prevent the combination of these methods.[154] They suggest that in order to combine PSMs with quantitative methods the modeller needs to believe that it is a worthwhile thing to do, to have the type of personality which is able to switch between analysis of quantitative data and facilitating qualitative analysis, and to have understood and practiced the relevant PSM(s).[154]

4.3.6 Areas identified by the authors for further research

The review suggests that conceptual modelling is generally an underdeveloped area of research. This is evidenced by the lack of agreement of the definition of a conceptual model and of what is involved in the conceptual modelling process, the fact that the majority of the included articles were published within the last ten years and the limited learning between pockets of researchers in this area. There appears to be a small discrete event simulation community aiming to advance conceptual modelling frameworks specifically for discrete event simulation projects,[8;136] and several system dynamics researchers progressing 'group model building'.[127-129] There are also several researchers within health economic modelling who have recently recognised the need for documenting the conceptual modelling process and using it to help to make model development decisions.[14;18] Therefore, there is a wealth of further research required in this area, as outlined by the authors.

Robinson[8] suggests that one of the purposes of his framework is to provide researchers with a basis upon which to undertake further research. The further research identified by Robinson is not specific to his framework, but is part of the conclusions within the final chapter of his book.[1] The author provides a table reporting research themes which would benefit from further research. These include the use of soft Operational Research, how best to work with and use the information provided by subject matter experts and other sources of information, developing and evaluating conceptual models, how Software Engineering techniques might be used, methods for appropriate representation and model simplification, exploring the creative aspects of modelling, understanding the organisational acceptance of models, understanding the impact of other modelling stages upon the conceptual model, and developing university and industry courses on conceptual modelling.[1] In his book, Robinson also suggests that domain-specific conceptual modelling frameworks would be useful, and in particular suggests that frameworks are required for healthcare modelling since none currently exist.[1] Since this book was published, two conceptual modelling frameworks for health economic modelling which are included within this review have been developed;[14;18] however both of these are specific to modelling clinical interventions rather than Public Health economic models. Tako *et al.* have also developed a conceptual modelling framework for healthcare process modelling.[136]

Tako *et al.* suggest testing the proposed framework within other systems,[136] whilst Vennix and Gubbels suggest that future research could be to assess the acceptance of the model by stakeholders given that they were presented with a preliminary model.[128] Rodriguez-Ulloa and Paucer-Caceres state that the methodology is not a finished work; however no further research is suggested, and no later studies extending the methodology have been identified.[129] Following Robinson's recommendations, this research aims to develop and evaluate a domain-specific conceptual modelling framework and to consider the use of soft Operational Research techniques and methods for appropriate representation and model simplification.

4.4 Discussion

<u>Stages within a conceptual modelling framework</u>

This review suggests that there are two broad stages for a modeller to undertake prior to the development of a quantitative model: (1) understanding the problem and setting the objectives of the model; and (2) choosing model options, determining the model scope and level of detail, and identifying structural assumptions and model type. Not all frameworks consider the former as part of conceptual modelling. The studies within the review suggest that it is very difficult to effectively represent all of these stages within one single diagram,[8;18;127;129;136] which may have led to the semantic confusion in this area as to which diagram is the 'conceptual model'. The studies generally suggest that each of the stages should inform the other within an iterative process of conceptual model development. Some of the studies suggest that the development of the quantitative model may also inform the conceptual model.[14;120;121;123]

Flexibility of methods

Five conceptual modelling frameworks included within the review clearly specify the methods to employ for each stage of the model development process,[119;121-123;129] whilst the remaining three frameworks are flexible about the methods which might be employed. [14;20;120;130] The study by Kaltenthaler *et al.* explains that this is because methods which are too prescriptive would 'fail to reflect the unique characteristics of each individual technology appraisal and could discourage the development of new and innovative modelling methods.'[14] These concerns are important within Public Health economic modelling as it is important to consider the needs of the decision makers and the decision making process, as also discussed within Chapter 5. Therefore, it would be appropriate not to provide methods which constrain the decision making process within a conceptual modelling framework for Public Health economic modelling.

Potential methods for each stage of a conceptual modelling framework

Most frameworks either use SSM or causal diagrams for understanding the problem. Both methods allow multiple stakeholder perspectives to be captured; however causal diagrams provide a method for considering all of the relationships between variables within a complex system. Few formal methods have been identified for objective setting and many frameworks do not explicitly consider this stage. Tako *et al*. suggest the use of a Performance Measurement Model (a flow diagram outlining 'monitoring activities', 'determine if activities' and 'changes').[136] The problem structuring stage generally results in a defined set of options to assess within the model, although detailed methods for defining these are not provided within the identified frameworks. Five out of the eight frameworks identified assume that a specific type of model will be developed, either DES or system dynamics, irrespective of the problem.[8;127-129;136] Only two sources explicitly consider alternative model types.[14;18] Importantly, many health care modellers have suggested that the characteristics of the problem should guide the model type;[117;127;128] hence it is important that the problem is understood prior to choosing the model type.

Conceptual model representations

Six of the conceptual modelling frameworks identified describe several forms of conceptual model representation for the different stages of model development.[14;20;120;121;123;129] A paper about conceptual model representation by Onggo *et al.* based upon Robinson's framework suggests that since conceptual models comprise several components, more than one conceptual model is required for the different stages of model development to provide a more comprehensive representation.[142] Within the study by Vennix and Gubbels only one conceptual model diagram is presented which seems to represent understanding the problem, model scoping and describing the model level of detail.[128] However, it is unclear whether each of these stages is appropriately handled.

Within the included studies, the use of causal diagrams is strongly associated with the development of a system dynamics model. This is supported by the system dynamics literature where the use of some form of causal diagram is recommended within key texts.[50;89] Whilst the two diagrams complement each other, there is no reason why the development of a causal diagram must lead to a system dynamics model; they could be used for the development of other model types. Similarly, Activity Cycle Diagrams are often developed prior to programming DES models; however prior conceptual modelling stages do not appear to be consistent across the studies, and may include SSM, objectives diagrams and/or tabling variables.[120;129;130] Within the review, those frameworks employing discrete event simulation tend to focus less on the relationships between model variables than those employing system dynamics; however this is likely to be due to the type of system that they are attempting to model, which also guides the model type, rather than due to the model type *per se*. Those employing discrete event simulation tend to be answering questions around the impact of interventions upon capacity within organisations, whilst those employing system dynamics tend to be answering questions around the impact of interventions upon the costs (and possibly other outcomes) of a process, without considering capacity constraints.

Stakeholder involvement and making judgements within the frameworks

Studies were only considered relevant to the review if they considered stakeholder involvement. However, the extent to which stakeholders are involved in the model development process is highly variable within the frameworks and a range of methods are employed including focus groups / workshops, interviews and questionnaires. The majority of the studies reviewed suggest that stakeholder involvement is important in making judgements about what to include and exclude within the conceptual modelling frameworks, although three of the frameworks employ only the decisions of the analyst for this stage.[8;18;129] Howick *et al.* use formal analysis of feedback loops and triggers for choosing which variables are relevant for the model,[127] whilst three studies employ guidance about what could be considered for inclusion within the model in order for the modeller (and the stakeholders in some cases) to think through and justify the inclusion (or exclusion) of each.[8;14;18] Fernández and Kekäle also employ a formal process using AHP to choose relevant variables; however there were many limitations to this approach including that it does not consider the relationships between the variables and it is solely dependent upon the stakeholders' understanding of the system.[125] Tako *et al.* and Vennix and Gubbels employ stakeholder involvement to choose relevant model variables by developing the conceptual model with them, although without formal methods for justifying the variables chosen.[128;136] The amount of stakeholder involvement in the framework by Rodriguez-Ulloa and Paucar-Caceres is unclear.[129] There are differences between each of the studies around which groups of people might be involved in the model development process and in most studies this is poorly defined.

<u>The potential application of the frameworks to Public Health economic evaluation</u>

Decisions about what factors to include and how to include those factors within an operations system such as a manufacturing plant may be inherently different to those required for a health economic model because the aims of the models, the decision making arena and the data requirements and data availability for the factors within the system are different. In addition, Robinson suggests that domain specific frameworks can provide more guidance about the approach than generic frameworks. In particular, he suggests that frameworks are required for healthcare modelling,[1] and until 2010 none existed. Although three healthcare-related conceptual modelling frameworks have been reported in 2010 – 2012, none of these consider Public Health economic modelling. Thus, characteristics which are more often key considerations within Public Health economic modelling such as the determinants of health and non-healthcare costs and outcomes, are not highlighted within these frameworks. Based upon Chapters 2 and 3, these were considered to be important for the framework. Thus whilst all of the included conceptual modelling frameworks will provide useful contributions to my framework, none of the eleven existing conceptual modelling frameworks are sufficient for applying to Public Health in their current form.

<u>Benefits of a conceptual modelling framework</u>

Benefits of a conceptual modelling framework identified by the authors include: a tool for communications between stakeholders; aids the development of clear, shared, modelling objectives; guides model development and experimentation; adds systematicity and transparency and forms the basis for model verification and guides model validation, as well as guiding model use.

Evaluation of the conceptual modelling frameworks

Limited evaluation of the frameworks has been undertaken. Most of the articles included within the review reported the methods and results of a case study to demonstrate the use of the conceptual modelling framework and some form of theory-based evaluation. Several authors also suggested evaluating the frameworks by speaking to stakeholders; however this was not undertaken within any of the included studies. Drawing upon the problem structuring methods literature suggests that the most appropriate approach to evaluation may be theory-based evaluation, alongside other forms of evaluation such as a case study and/or feedback from modellers or stakeholders.[150;151]

4.5 Chapter summary and implications for methods development

This chapter presented a review of existing conceptual modelling frameworks. The implications of the review for methods development are that:

1) A conceptual modelling framework specifically for Public Health economic modelling has the potential to provide more guidance about the approach than a generic framework.
2) A conceptual modelling framework should include, as a minimum, stages for (i) Understanding the problem and objective setting, and (ii) Choosing model options, determining model scope and level of detail, and identifying structural assumptions and model type.
3) For each stage, a different diagram should be developed.
4) Whilst a diagram of each stage is essential for communication purposes with stakeholders and experts, it is the process of development of each which is particularly important for sharing knowledge.
5) The purpose and intended use of the conceptual model(s) within the framework should be clear; is it for planning the final model or reporting the final model? If the term 'conceptual model' is employed within the framework it needs to be defined and which groups of people might be involved in the model development process should be clear.
6) Key benefits are to aid the development of modelling objectives, provide tools for communication, guide model development, experimentation and reuse, and improve model validation and verification.
7) Importantly, modellers must want to use the conceptual modelling framework. Thus, the framework should aid the model development process but not constrain it. It should allow for the variation in requirements of different Public Health economic modelling and for

scope for further methods development given the early phase of development of a framework within Public Health economic modelling.

8) Cognitive mapping, causal diagrams and SSM may be useful for objective setting and developing the understanding of the problem.
9) The conceptual modelling framework needs to be practical within a decision making context, and the needs of the decision makers should be of key consideration, including the time requirements upon the stakeholders, during methods development.
10) Theory-based evaluation of the framework should be undertaken to explain why it is expected to be effective, as well as qualitatively obtaining stakeholders'/ modellers' views.

Chapter 5: Qualitative research relating to modellers' experiences with developing the structure of Public Health economic models

5.1 Chapter outline

This chapter aims to describe modellers' experiences with developing the structure of Public Health economic models and their views about the benefits and barriers of using a conceptual modelling framework in order to facilitate the development of a useful conceptual modelling framework. More specifically, the objectives are as follows:

1) To develop a description of the model development process in practice for Public Health economic modelling in order to (a) understand the context within which issues arise during the model development process and (b) be clear about if and how the conceptual modelling framework deviates from the way in which modellers usually develop Public Health models;
2) To understand how and why modellers make decisions about model scope and structure in order to develop guidance that helps modellers to attempt to undertake this process;
3) To establish some of the key issues during model conceptualisation in order to highlight these key considerations to modellers and suggest potential solutions and pitfalls to be avoided where possible; this includes understanding what has worked well or poorly by modellers and identifying some of the requirements and constraints of decision makers;
4) To identify the potential benefits and barriers associated with the use of a conceptual modelling framework in order to develop a tool which will be useful to modellers.

Qualitative research methods have been employed in order to achieve these objectives. Sections 5.2 and 5.3 describe the methods and results of the analysis respectively. Section 5.4 presents a discussion of the qualitative research findings, whilst Section 5.5 summarises the key findings and the implications of these upon the development of the conceptual modelling framework.

5.2 Qualitative research methods

As discussed within Chapter 1, reflexivity is the idea that meaning from qualitative research is developed based upon the complex relationship between the understanding of the participant and the researcher prior to the research combined with the additional meaning gained from the research.[58] Thus the researcher will always influence the outcome of the research to some extent.[58] Throughout this chapter I have employed a reflexive perspective, in that I attempt to fully consider my impact as a researcher upon the analysis. This is because in collecting and interpreting the data I will inevitably influence the outcomes of the research, and as such it is preferable to be explicit about this. This is particularly important because as part of the analysis I am using my own notes as data, in addition to data collected from in-depth interviews and a focus group (described in more detail below). Because of this reflexive perspective, I have adopted the first person throughout the chapter. Throughout data collection and analysis I found a book by Lewis and Ritchie particularly useful.[156] ScHARR ethical approval was obtained for this work (see Appendix C).

5.2.1 Data collection

Theoretically, the richest data around modellers' experiences with developing the structure of Public Health economic models may be obtained by following model development in real time over a range of public health modelling projects, which could involve the use of an action research approach[157]; however this would not be practical within the time and resource constraints of this research. Therefore, I took a pragmatic approach to qualitative data collection comprising three phases.

<u>Phase 1: Analysis of my own notes</u>

Phase 1 involved using my own notes as data from a Public Health project where I had undertaken the health economic modelling assessing the cost-effectiveness of intervention to encourage young people to use contraceptives and contraceptive services, referred to hereafter as 'Contraception project' (also referred to within Chapter 3). The aim of this was to reflect upon my own experience of developing the structure of a Public Health economic model. The notes were written by me during the development of the model for the purpose of developing my own thoughts based upon the outcome of stakeholder meetings or literature searching, with the exception of a couple of notes which were written to communicate an idea to other members of the team (made up of an information specialist, two reviewers and a public health expert / project lead). The notes are of my thinking during the project in terms of understanding the decision problem and developing the scope and structure of the health economic model. They contain thoughts about what is important for inclusion in the model and how those factors chosen to be relevant for inclusion should be represented. I kept the notes from the project because I was applying for the fellowship funding at the time of the project and I thought they may be useful, although at the time I did not plan to use them as data as part of this analysis. This phase allowed me to reflect upon my own experience of developing the model structure, using my own notes as data so that my reflections were based on the real process rather than being biased by my perceptions of what had happened in hindsight.

Phase 2: Tracking the development of a Public Health economic model including undertaking and analysing in-depth interviews

Concurrently to the analysis within Phase 1, Phase 2 involved tracking the development of a Public Health economic model by undertaking in-depth interviews with the two modellers on the team during the development process and making notes on the process during meetings between the modeller, the group of stakeholders involved in NICE Public Health decision making (referred to as the Programme Development Group (PDG) throughout) and the NICE Project Team. The modellers were recruited because of the appropriate timing of their project within my research. There was an additional benefit that one of the modellers was considered to be experienced, with over 20 years developing healthcare models, whilst the other was considered to be relatively inexperienced, thereby allowing for different perspectives of the same model development to be reflected in the analysis. The modellers were recruited by contacting them via email and providing an information sheet about the project (see Appendix C). A consent form was also sent to the participants (see Appendix C) and they were informed that the data would be anonymised, that they would be audio recorded and that they could withdraw from the research at any time. The NICE Project Lead was approached via an informant and she passed on an information sheet and consent form to the other members of the NICE Project Team and the Chair of the PDG, who agreed to pass the details on to the PDG members. All of the NICE Project Team and the PDG members were asked to sign a consent form prior to my taking notes at their meetings.

The project that the modellers were undertaking involved an assessment of the cost-effectiveness of interventions to encourage people to walk and cycle, hereafter referred to as 'Walking and Cycling project'. I attended and took notes at the three meetings which had the most focus upon model conceptualisation; one with the whole PDG and two teleconferences with the economic subgroup (which included six members of the PDG who had some expertise in health economic modelling and the modellers on the project team), all of which took place within a three month period. I also undertook two in-depth interviews with each of the two modellers on the project within the same three month period which were audio recorded and then transcribed. Some of the transcription was done by me and some was done by a transcription specialist; both of which were checked for accuracy by listening to the entire audio recording whilst reading the transcript. The participants seemed unaffected by the presence of the audio recorder. During the interview if an interviewee said something which I wanted to revisit later within the interview I discreetly noted a word down to remind me. An example of the questions asked within the interviews is 'How did you go about making those decisions?' and 'Early on you mentioned about interventions, and that you would probably get them from the effectiveness reviews. Do you have an idea of how you'll be going about that at this stage?' Probes were used to investigate a response in more depth such as 'why did you do that?' The questions and probes were expressed as open questions. Whilst this provided depth of analysis, it could not provide sufficiently varied experiences and views.

<u>Phase 3: Focus group with Public Health modellers</u>

Phase 3 involved holding a focus group with five modellers, each of whom were from different institutions within the UK, to provide a broader understanding of modellers' views and experiences. Focus groups provide a forum for discussing and debating different views,[17] which are likely to be present between different modellers given the lack of documentation in this area. In addition, since the participants might not have thought about some of the questions asked previously, ideas might be developed by each participant reflecting upon the statements and discussion of others. Participants were chosen purposively due to their extensive work within Public Health economic modelling within the UK. Some of the participants were known to me; however insider knowledge was considered to be an advantage because of the range of perspectives that could be accessed.[158] I chose people who I thought might have varied perspectives from one another because they had worked on different types of Public Health economic modelling projects and they had different backgrounds and experience. For example, some of the modellers had undertaken Public Health economic evaluations for NICE, whilst others undertook work for other funders that had different decision making processes. In addition, the modellers had a mixture of backgrounds including Health Economics, Operational Research and Engineering. Within the focus group meeting I was not looking for agreement from the participants, but to understand the range of perspectives, and in what areas agreement and disagreement occurred.

As with Phase 2, the focus group participants were recruited by contacting them directly via email and providing an information sheet about the project. A consent form was also sent to the participants and they were informed that their participation would be anonymous and that they could withdraw from the research at any time. I had stated within the ScHARR ethics process that the respondents would be sent one additional email if they did not respond, but that then they would not be contacted again to avoid them being pressured into participating. Six participants were contacted; however one of the modellers could not attend due to other work commitments. I expected participants to be happy to fully express themselves within the group setting given the insensitivity of the topic and the level of status of the participants. I suggested that it might be useful for each participant within the focus group to think about a specific case study that they had worked on with the aim to encourage reflection rather than theoretical reasoning. The meeting was audio recorded and then transcribed by me. My role within the focus group was to ask open questions which were not aimed to influence the participants views in any way and I did not add to the discussion between participants with my opinions.

Topic guides

For both the in-depth interviews and the focus group, topic guides were developed to inform the general structure of the sessions (see Appendix C). This was a page of A4 which highlighted key areas to cover within the meeting. For the interview, I designed the topic guide based upon my findings from Chapters 2, 3 and 4; the latter of which was undertaken in parallel. The focus group topic guide was based upon the outcomes of Phases 1 and 2. Data from the interviews were used within the focus group to provide a starting point for some of the discussions, and the participants were asked to comment on whether they agreed or disagreed with some of the interviewee responses. Whilst my previous work informed what was covered within the interviews and focus group, I was aware that it was important to avoid using leading questions, because I was interested in the perspective of the interviewees and did not want this to be shaped by my perspective.

5.2.2 Data analysis

Thematic analysis and open coding of data

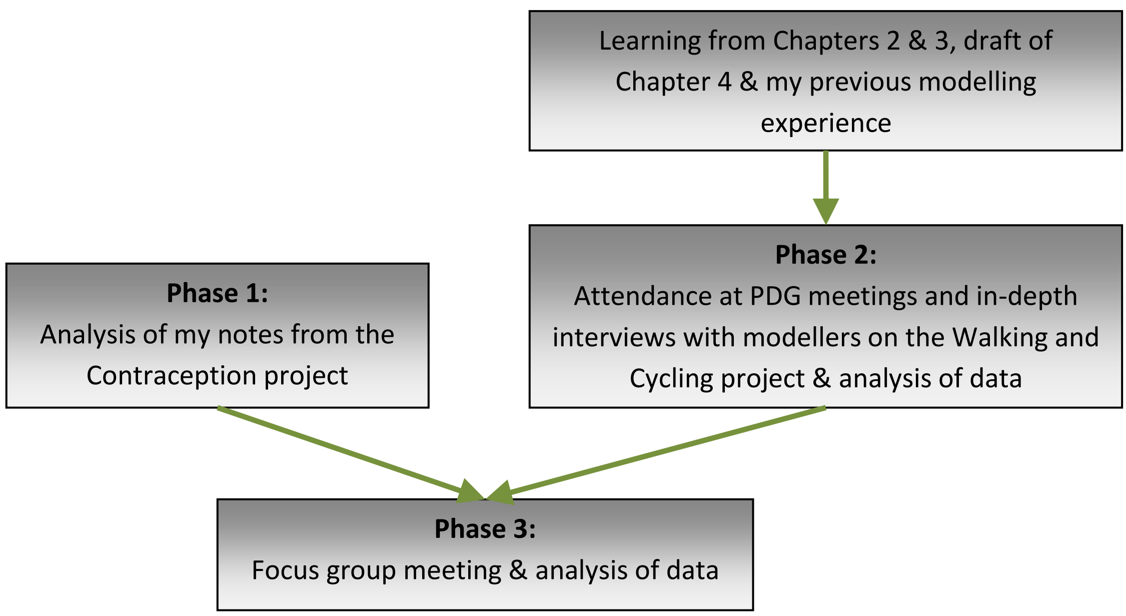
I undertook thematic analysis of the data collected[159] which included my own notes from the Contraception project, notes of the PDG meetings, the transcripts of the interviews and the transcript of the focus group meeting. I began the analysis after the first set of interviews and this was used to inform the following interviews with the modellers from the Walking and Cycling project and subsequently the focus group meeting. I familiarised myself with the content of the transcripts by reading them through so that I knew what sorts of data were available. Each sentence from the interview transcripts and the notes from my contraception project were subsequently copied across to an Excel spreadsheet into categories. The category headings were constructed according to what I initially thought each sentence related to, and these were gradually developed as I went through the notes and transcripts sentence by sentence. I strictly treated my own notes as data in the same way as the other data collected, such that the methods remained systematic. There was no restriction on the number of categories employed and during this process it was necessary to divide some of the initially defined categories into two categories due to the emergence of related but different issues as more of the transcript was coded. All data were open coded in this way,[160] apart from any parts of the notes and transcripts considered irrelevant to the aims outlined above. This meant that all perspectives were included within the analysis. Open codes were developed for the first and second interviews and were subsequently revised during open coding of the third interview, generally by dividing the codes into more categories.

After open coding of the first three interviews was complete, similar categories were grouped together into themes. These codes and themes were then employed for the subsequent data analysis. For example, the focus group topic guide was set out in terms of the themes and subthemes which had been identified from the interviews. The focus group data were open coded in a similar way and individual participants were identified; however the original transcripts were also used within the analysis to note where participants had agreed or disagreed with each other, and how the quotations related to each other.

<u>Selecting quotations and interpretation of data</u>

For each open code, key points were identified and for each of these a quotation was selected according to whoever had made the point being described in the most complete and succinct way. Issues identified during the analysis of the interview data were based upon both what the modellers said they are and upon my interpretations during observations of the Walking and Cycling project. An outline of the data collection and analysis process is shown in Figure 5.1.

Figure 5.1: Qualitative data collection and analysis process overview



5.3 Results of the qualitative research

Three key themes were identified from the data analysis; (1) The model conceptualisation process in Public Health economic modelling; (2) Use of evidence in model conceptualisation; and (3) Barriers and benefits of a conceptual modelling framework. These themes are considered in turn within this section.

Theme 1: The model conceptualisation process in Public Health economic modelling

It is important to understand the model conceptualisation process in Public Health economic modelling in order to understand the issues which arise. This theme has been subdivided into three subthemes: (i) the stages of model development, (ii) how decisions are made by modellers about model conceptualisation, and (iii) the communication with the experts and decision makers. Documenting the modelling conceptualisation process can help inexperienced modellers understand what it involves, but it can also help more experienced modellers to identify which factors to consider in making modelling decisions. It also allows me to understand how my conceptual modelling framework will deviate from the way in which modellers usually develop models.

Stages of model development

As described within Chapter 1, Chilcott *et al*. undertook a qualitative research study about avoiding and identifying errors for the Health Technology Assessment programme in 2010 and one of the key findings of the study was that the stages of model development within health economic evaluation are not well defined.[17] This has also been highlighted within a NICE Technical Support Document by Kaltenthaler *et al.*[14] It is useful to have an understanding of the current model development process within Public Health economic modelling to enable the development of a conceptual modelling framework.

It is clear from the interviews and focus group that the modellers do not share a vision of the stages of model development. The less experienced modeller interviewed indicates the lack of a formalised model development process and the uncertainty that this creates in the process that they are involved in.

> *Modeller 1 (interview data): "You must realise this is the first time I've done this, so this is the first time I've been the one making the decisions, so I don't really know what's around the corner yet."*

The more experienced modeller interviewed suggested that the initial stages of model development include identifying the decision, understanding what the problems are, and what the issues associated with these are, and then looking at the available evidence and iterating between the evidence and the data analysis.

> *Modeller 2 (interview data): "So I start with the problem and the thinking and so it kind of goes okay what is the decision, what are the problems, what are the issues that link into that and then go well that is the first map of that, what is the evidence about that, have we got the trials, what's your databases, where do we get some stuff from and then start cycling, like here between data available, data analysis."*

This indicates a reflective process, and does not mention the involvement of other people. The use of the word 'map' is interesting as it implies a representation at a particular level of abstraction, which could be otherwise termed a conceptual model. He hints that this map may change as data are obtained. The modeller mentions the use of trials and databases, but implies that sources for other evidence are less clear. When the modellers within the focus group meeting were asked whether they agree or disagree with the above statement, the modellers generally agreed that it is an iterative process. Modeller 7 also said that he agreed with the importance of deciding what the question is.

> *Modeller 7 (focus group data): "The bit that chimed with me I guess was the bit about trying to decide what the question is, because most of the models are decision support models so they're aiming to help people make decisions. So whenever I've done this I've tried to concentrate on, well, what is that they need from the modelling, and that kind of has primacy over any subsequent decisions, except when they're in support of trying to identify those things."*

This highlights that the purpose of the models within Public Health economic evaluation is to help decision makers make decisions, as opposed to trying to represent reality. The modeller puts the decision makers and the question that they are trying to answer at the forefront of his modelling activities, and this informs future decisions about the model structure.

In practice it may be that understanding the problem evolves throughout the project rather than something which is completed in the early stages. For example, within the second economic subgroup meeting on the Walking and Cycling project, one of the modellers said that he wanted to link walking and cycling to overall physical activity since some studies report walking outcomes and some report cycling outcomes, and it is overall physical activity that affects morbidity and mortality. By this stage in the process the modellers had undertaken numerous analyses of datasets and had developed a first draft of an implemented model; however it is the first time that they discussed having an outcome of 'physical activity' with the PDG and NICE.

Within the second economic subgroup meeting on the Walking and Cycling project, Modeller 2 stated that he would be able to split the time doing physical activity into more categories within the model but that he thought he would need to restructure the model to do it. This illustrates the benefits of model planning prior to implementation. However, when asked towards the end of the project 'is there anything that you did and changed because it didn't go so well or you would do differently?' Modeller 2 said the following:

> *Modeller 2 (interview data): "I do think that we could layer some more things on top; we could layer that lag to full effect that I was talking about, we could layer something keeping the cohorty structure but somehow layer something about prevalence of diseases related to sedentary versus physically active on top."*

This highlights that model development may be constrained by the time and resources within the decision making process. The use of the term 'layer' within the data above gives the idea of a pragmatic approach where a basic model structure can be gradually built upon to become more and more complex if time and resources allow. This layering is undertaken following initial model implementation, which suggests potential iteration between model conceptualisation and implementation.

When asked within the focus group meeting whether the modellers develop conceptual models, they generally said that they develop some form of diagram or qualitative description of the model, although they do not necessarily call it a conceptual model, and between the modellers there was no agreed way of presenting it.

> *Modeller 3 (focus group meeting): "When you asked the question in the first instance, I thought no we never bother doing conceptual models, but actually we do quite a lot in terms of, we know we've got to write the model up and present it. So it tends to be not such a*

separate process, but an integral part of the model development process that we're writing down the links that we're making, we're writing those down as fundamental assumptions of the model. Apart from anything we're communicating with our systematic review colleagues as to what sort of data we're going to need from them."

This participant intimates that modellers have to go through some sort of conceptual modelling process and develop some form of communication of the model, even if it is not a formal process. He suggests that one of the reasons for communicating the model during the early stages of model development may be to communicate with the systematic reviewers in order for them to extract appropriate evidence for the model. The modeller talks about 'writing down the links' which relates to the causal relationships, which were consistently described as being an integral part of a conceptual model by the modellers. One of the modellers makes the distinction between causation and association within a conceptual model he developed.

Modeller 5 (focus group data): "...I came up with a conceptual model, where it wasn't just that there were different boxes with arrows, but different coloured arrows depending on how strong the evidence was first of association and second of causation and even reverse causality in some cases."

This modeller suggests that a conceptual model depicting causal relationships needs to be developed gradually and that it can differentiate between types and strengths of evidence of those relationships. The modeller reported that the project team found the use of different colours to represent the level of causality useful and created discussion.

Many of the modellers within the interviews and focus group talked about drawing evidence from a wide range of sources and bringing all of the information gathered together into the model.

Modeller 1 (interview data): "We've drawn a lot of stuff together and its like a huge jigsaw and I suppose from now is when we start putting the pieces together; we've got to make sure we've got the right pieces and how we start putting it together."

This simile of putting together a jigsaw used to describe the process implies that it is a complex task which requires different pieces of evidence to fit together. It involves both excluding available pieces of evidence which are not relevant or do not fit together within this particular problem and obtaining missing pieces before it can be completed.

The members of the focus group generally agreed that it is important near the start of the project to understand what other models have been developed and whether these could be used as a basis for the current modelling. Modeller 2 stated that a useful way to develop the model structure is to think about a few specific interventions, whilst the focus group members extended this and agreed that the model structure would be driven by the interventions chosen. Some of the focus group modellers also suggested that one of the things they do at an early stage is to understand the baseline situation and what evidence is available to model that baseline situation.

Modeller 2 had developed a draft paper drawing on his previous experience to define a framework for helping modellers develop alcohol policy models which outlines seven issues that he considers during model development which he described during an interview.

> *Modeller 2 (interview data): "The first issue is classifying and defining population subgroups of interest, the second issue is identifying and defining harms and outcomes for inclusion in the model, the third is thinking about modifiable components of risk... ...and then I have got specifying the baseline position on policy variables... ...so five is estimating the effects of changing the policy variables on the risk factors... ...And then risk functions relating risk factors to harm... ...in one sense that is your model, that is what you usually think of as your model, how do you estimate your longer term outcomes. And then finally monetary valuation, how do you think about the value of these things."*

The use of the word 'issue' for describing the themes within this framework indicates that each of these can be problematic. I would suggest that this framework may have been developed as a result of the lack of guidance for modellers about the Public Health economic model conceptualisation process, although this was not stated by the modeller. Issues 1 - 4 relate to specifying the scope of the model, whilst issues 5 – 6 relate to defining the model structure and issue 7 is about parameterising the costs and outcomes. I have referred to these, where relevant, throughout subsequent analysis within this Chapter.

Non-evidence related considerations during model conceptualisation

It is important to understand the key issues and considerations during the conceptualisation process in Public Health economic evaluation in order for them to be addressed or highlighted within the conceptual modelling framework. The review within Chapter 2 identified some fundamental issues including the dynamic complexity of Public Health systems, the potential requirement to include non-healthcare outcomes and the impact of the determinants of health upon outcomes; however there are additional practical issues which modellers have experienced during model conceptualisation.

I noted within one of the Walking and Cycling PDG meetings that the PDG were constrained by the project scope, for example, they were not allowed to make recommendations on national policy; it had to be local policy. When Modeller 2 was asked within the in-depth interview 'You mentioned knowing what the (modelling) question was earlier, what did you mean by that, you said that that was an issue?' he suggested that this was not a big issue.

> *Modeller 2 (interview data): "Well, I think that is often an issue at the beginning, but I think in this case it wasn't that difficult because the scope was quite clearly set, we needed to look at the cost effectiveness of interventions that encouraged walking and cycling in local communities and they explicitly wanted something done on congestion and that was it. So the big picture question was set, what wasn't set was exactly what interventions would get included. So that was quite a lot and you are best off talking to the reviewers about that."*

This illustrates that the model scope may be reasonably well defined by the decision makers; however one of the key scoping issues for the Walking and Cycling project related to which interventions to include within the model. This was echoed by the modellers within the focus group meeting. Modeller 2 stated that the reviewers are best placed to talk about the interventions, which implies that it was the reviewers who made decisions about which interventions to model rather than the modellers or the experts involved. The choice of interventions is discussed further within Theme 2.

Within the focus group meeting, the modellers highlighted that the choice of model population and subgroups is a key consideration which drives structuring decisions.

Modeller 7 (focus group data): "We knew that there were certain things that we needed to know about like different subgroups in society that they (the PDG) were interested in finding out about, and obviously that also drove the structuring decisions in the model."

The modeller implies that the choice of subgroups is driven by what the experts and decision makers want to explore. This suggests that these decisions are not led by the modeller, although it is the modeller's interpretation of what the stakeholders want to explore which drives model development. There is no reference by the modellers to these decisions being dependent upon evidence.

One of the PDG members on the Walking and Cycling project raised the issue of the interventions steepening the social gradient and that this needs to be considered within the modelling since the health gains will be smaller if the intervention increases walking and/or cycling for people with a lower socioeconomic status more than for people with a higher socioeconomic status, as discussed within Chapter 1.

One of the key considerations during model conceptualisation described by many of the modellers involved in this work was what a 'good' outcome would be, as discussed within the review in Chapter 2. Within the Walking and Cycling project one of the PDG members suggested that the interventions may change somebody's knowledge, which may change physical activity levels in five years' time, and this may not be identified within short term studies. Within the Contraception project, there was a question about what would render an intervention which prevented a pregnancy successful, as this raises questions about what would happen in the future and when the optimal time to become pregnant is, as illustrated below.

My notes on Contraception project: "If an unwanted pregnancy is delayed it may later become a wanted pregnancy, it might be aborted, or it might result in an unwanted birth. What is it that we wish to avoid? If a pregnancy is delayed from age 14 to age 16 by the intervention is this a good outcome? Is there an 'acceptable' age at which to have children or is it about it being unintended?"

This suggests that social value judgements underlie, either explicitly or implicitly, what is considered when determining a 'good' outcome, for which there may be disagreements between stakeholders. One issue is whether behaviour is being prevented or delayed, which may be difficult to determine from the evidence available. How to resolve these sorts of disagreements was not discussed by the modellers; this is considered further within Chapter 6.

Within the Contraception project, the decision makers and I also considered potentially negative outcomes associated with the interventions such as increases in sexual activity; however we decided that this would be captured within those studies reporting pregnancy outcomes. Within the focus group meeting the modellers indicated that some of the decision makers within projects assessing the outcomes of harmful substances, such as ecstasy or alcohol, had debated whether the pleasurable effects of these drugs should be considered as benefits or harms since it is these effects which make them addictive. In addition, within the focus group meeting, one of the modellers highlighted the difficulty of incorporating potentially unintended consequences of the intervention, as also discussed within Chapter 2.

> *Modeller 7 (focus group data): "But I think there's others (factors) that you just don't know, the (un)known unknowns or whatever that you haven't even thought about, that may still be important. Particularly with sort of macro-level behaviour change, where there's a lot of unintended consequences, you know that's something that's likely to arise in practice."*

The modeller intimates that unintended consequences may be sufficiently important to affect the decision and may be more prominent for interventions which alter behaviour on a macro-level, but that they may be difficult to identify.

The modellers and PDG members have considered the implications of having a heterogeneous population upon the outcomes, which is identified as one of the key features of a complex problem within Chapter 3.

> *My notes from Contraception project: "What are the benefits of preventing pregnancy for a girl who would or would not go on to further education? What about for a girl who can/ cannot cope? Is ethnicity important? Is it possible across all women to say when it is best to have a baby?"*

From the Contraception project, I have questioned whether the heterogeneity between different groups of young women may lead to different benefits of preventing pregnancy. The questions raised relate to possible factors which might impact upon the woman's life trajectory, illustrating that there may be variation in causality at the individual level. Similarly, for the Walking and Cycling project a PDG member focuses upon subgroups where the risk factors for different subgroups are expected to have differential impacts upon the outcomes.

> *My notes on Walking and Cycling economic subgroup meeting: "A PDG member said that people that are doing the most walking for transport do not have a car, whereas the more affluent people who are more likely to live in the suburbs where it is not practical to walk, walk for pleasure in the countryside. This means interventions will have different impacts upon these different subgroups."*

The PDG member above makes the assumption that the ability to own a car leads to the amount of walking for transport and does not consider explicitly other plausible explanations such as that the ability to walk for transport may lead to whether or not the person owns a car. I would suggest that a key issue is that this assumption is not questioned. One of the modellers within the focus group meeting raised the issue of modellers knowing what assumptions they are making.

> *Modeller 7 (focus group data): "I think a key is sort of knowing what assumptions you're making when you decide on a structure, and I'm not sure that that's necessarily a very simple task particularly in the macro-level population things, where you have dynamic effects, and second order effects, third order effects."*

He implies that it is important for modellers to fully understand the implications of the structural choices they make. The modeller suggests that this is not straight-forward, especially when there are not only direct causal effects of the intervention, but also additional impacts caused by interactions between people, or indirect effects of the intervention such as a response to the intervention by a third party and the impact of this to consider.

The modellers consider the most appropriate outcome to employ, even for those projects for NICE which has a Reference Case. For example, within the contraception case study the use of the QALY would have led to difficulties due to lack of evidence, controversial value judgements about abortions, and the fact that the intervention was aiming to prevent life rather than extend or improve the quality of life. My notes highlighted the difficulty with choosing the most appropriate outcome.

My notes on Contraception project: "By not considering QALYs, we're almost saying an abortion doesn't have an effect on mother or child. If just (apply a) cost (to) an abortion (without valuing outcomes of an abortion) it may be better in the model if everyone had an abortion than to encourage contraceptive use."

My notes on Contraception project: "Cost per under age x pregnancy averted... ...allows the decision maker to place more weight on <16 than <18 etc. It lets the decision makers make the value judgements."

The former data illustrates the issue of deciding upon a meaningful outcome and making sure that all key factors are valued in the model appropriately in terms of both costs and outcomes. The latter relates to what is considered to be the most useful outcome for decision makers given the valuation issues. Within the Walking and Cycling project, similar issues were raised in terms of producing meaningful outcomes.

Modeller 2 (interview data): "So we had to work out a way of getting a cost per QALY and a way of getting some kind of outputs that were meaningful in terms of reduced congestion as you encourage more people to walk and cycle and they almost became two separate parts of a project that we had to keep linking together."

Here there are two different outcomes which need to be brought together in such a way that would help the decision makers to make decisions.

The perspective of the analysis was considered in substantial detail in the contraception work as it was unclear whether it was methodologically most appropriate to include or exclude government funded Benefit payments such as Income Support within a Public Sector Perspective. This is because it was uncertain to what extent impacts would be being included within both the cost and effect side. Within the Contraception project, I included the costs associated with maternity care but did not include benefits associated with having a baby.

My notes from Contraception project: "If intervention reduces the number of babies the woman has, then it will save the cost of maternity care. This implies that it is better to have less babies in a lifetime (unless also include the associated benefits of the baby). Discounting emphasises this issue."

This also raises the issue of whose costs and benefits should be included within the evaluation. Within the contraception project, intergenerational impacts were considered but not included within the model, with my notes on the project asking "*teen mother likely to lead to teen mother?*".

Making decisions about the model conceptualisation

Model development is inevitably a subjective process which requires modellers throughout the process to make decisions about what factors should be included and excluded and how those included factors should be represented. It is useful to understand how and why those decisions are made in order to develop guidance which allows modellers to attempt to undertake this process.

The inexperienced modeller interviewed suggested that he is unsure about how to make decisions about model conceptualisation, on a number of occasions throughout the interview voicing "I don't know". He indicates the frustration which may occur for inexperienced modellers in trying to make the 'right' decisions but being told that they are not appropriate and perhaps not really understanding the reasons why.

> *Modeller 1 (interview data): "Well, he (Modeller 2) decides the best way it is - well he does decide; he keeps telling me to but he does it himself anyway. If I make the wrong one, he puts me right. He tells me to make the decision and if he agrees with me that's fine, and if he doesn't agree he changes it."*

His use of the word 'wrong' here could imply that the modeller believes that his decisions would be considered to be inappropriate by all modellers such that it is universally wrong, or it could be that he believes his decisions could be considered to be appropriate but that the other modeller has a different opinion on these subjective judgements. Chilcott *et al.* highlight the difficulty in defining and agreeing on what constitutes a model error within the Health Technology Assessment around avoiding and identifying errors.[17] The term 'reasonable' is used in many contexts where there is not an objective right and wrong answer, for example deciding whether somebody has broken the law ("beyond reasonable doubt"). This is about modellers making a judgement around how reasonable a modelling decision is considered to be.

A range of methods for making decisions about the model conceptualisation were suggested by the modellers. Modeller 1 proposed that one approach to making decisions is through discussions with the other modeller(s) on the team, whilst Modeller 2 described making decisions by understanding the importance of each potential factor.

> *Modeller 1 (interview data): "Well its just its me and Modeller 2, discussing it, and deciding."*

> *Modeller 2 (interview data): "I can tell that this could be important or it could be not quite big but given my level of uncertainty as to how important this is and how it might affect the priorities of the activities that we do on the project, I need to find out about this."*

Here, Modeller 2 talks about the process of not knowing which factors are the most important and needing to find out about potentially important factors in order to make decisions about how the project is organised. He explains that more time will be spent during the project on the more important factors which suggests that the modeller is acutely aware of the time and resource constraints of the decision making process. This implies that the modeller is not trying to develop the 'best' model that he could possibly build, but that he is developing the most appropriate model given the constraints of the decision making process. This pragmatic approach is resonated with the modellers from the focus group meeting.

> *Modeller 3 (focus group data): "In terms of one of the big practical issues that determines the complexity and structure is the time you've got to do it, particularly in relation to reporting to a committee that you know is going to meet. And at the very least you've got to get a report in on time that says this is the model you want, or this model cannot be built to the complexity you want for the following reasons, and therefore you need to make the sort of changes that Modeller 4's been talking about, and change the focus of your work. But at least you've got to get a report within a certain time."*

This intimates that delivering the model by the deadline is considered to be a priority, and may be outside of the influence of the modellers. The modeller implies that it would be more culturally acceptable to change the focus of the work than to rearrange committee meetings or report deadlines. He agrees with another of the focus group modellers that it may be necessary to change the focus of the work so that it becomes more exploratory, suggesting that the process followed needs to be aligned with the constraints of the decision making context. One of the modellers within the focus group meeting indicated that it is unlikely that a Public Health economic modelling project would ever be without time pressures.

Modeller 7 (focus group data): "I think in terms of timescales, I can't imagine there ever being a decision analytic model that's got a long timescale on it. I just think the nature of it is that you're trying to support a decision and that six months, a year, are the sort of time... I just can't imagine it turning into a blue sky modelling exercise where you can explore all of these different model structures and do something which is slightly unusual and not anchored as a modelling method."

The modeller suggests that it will never be possible to develop the 'best' model, or develop a model with multiple possible structures, but that compromises will be required due to time constraints. He implies that the nature of decision making in Public Health is such that decisions need to be made relatively quickly. The modeller also highlights that models may be 'anchored' as a result of the time constraints, in that the structure will be largely dependent upon the structure of previous models that have been identified in that area. Similarly, Modeller 2 explained that the decision about model type is not necessarily about the type of problem being considered, but that this also depends upon the time and resources available and the other circumstances surrounding the project. He mentioned the need to have total control to meet the deadline rather than depending upon the input of other modellers, and that this may be dependent upon the circumstances of the other modellers. Modeller 2 also described the influence of the customer upon this decision, as illustrated below.

Modeller 2 (interview data): "…and I knew that there was nothing in existence on walking and cycling really that went very far in terms of cost per QALY and the model that both, that the PDG had used most, the HEAT tool, Health Economic Analysis Tool for walking or something used this Copenhagen study, so I knew that there was some kind of acceptance of it amongst the customers really."

Modeller 2 suggests that it is important to them that the model is seen as credible by the customers. It illustrates the influence of previous health economic modelling work upon the expectations of the current modelling work, as already described by one of the modellers within the focus group.

The modeller states that he 'knew' that there were not many economic models on walking and cycling. This relates to the idea of bounded rationality whereby rationality in making a decision is limited by the information a person has, their cognitive limitations and the time available.[97] The modeller has, possibly subconsciously, made the decision that it was a better use of time to make sense of the existing relevant information rather than to spend time searching for more evidence. Paisley explains that this is an enrichment strategy.[63] In reality, the modeller cannot ever 'know' that relevant information is not being missed; modellers can only collect what they consider to be sufficient evidence to be able to make such a judgement. Thus methods to help to minimise prejudiced judgements may be beneficial.

When I asked the focus group about the tensions between using a flow chart to determine model type and the constraints of the project, Modeller 3 explains what he thinks are the two key issues that can really be considered with these sorts of flow charts.

> *Modeller 3 (focus group data): "I really think they come down to four groups, as soon as you've really decided these two issues; are you looking for infections or not, and are you able to classify into cohorts or not, then I think you've gone past the usefulness of that sort of thing. Then it's the issue of what features you're including in the model, and again they more or less choose the model type.... ...How much of the richness of the real world structure needs to be included in the richness of the structure of the model? Then the model type just drops out from that I think."*

He indicates that other than deciding whether to include interactions and whether you need a cohort or individual level model, the model type required will be clear from deciding what the most important features of the problem are. He suggests that there is a decision to be made about how much of the complexity of the real world structure needs to be included in the model structure, although he does not expand on how this decision is made. One of the modellers from the focus group also highlighted that "...*where the algorithms or flow charts might be useful, even if you have constraints of time, is that they make you aware of things that you might be missing out if you don't use a more complex model so that you can at least flag them up as important things."*

Within the focus group meeting there was a discussion about what factors affected the decisions about model structure and the modellers did not agree on the key trade-offs. Modeller 4 indicated that they were transparency, accuracy and credibility, whilst Modeller 3 suggested that they were adequacy, efficiency and transparency. I would argue that, based upon what has been discussed within the interviews and focus group meeting, the key trade off is developing an appropriate structure for the problem versus ability to meet deadlines.

One of the modellers within the focus group raised the issue of appropriately highlighting the structural uncertainty to the decision makers, either by quantifying it or by qualitatively describing it within the report.

> *Modeller 5 (focus group data): "I think on that issue of the sort of transparency versus realism trade off, I think one of the key elements I think I've found is correctly conveying uncertainty in the results... ... I think when we do simplify models it's really important to say well even if we can't quantify these areas of uncertainty they do exist it's just we've not incorporated them into our modelling."*

This modeller intimates the need to specify what is not incorporated within the model i.e. that the scope of the model can be defined by what is excluded from the model rather than by what is included. The above quote reiterates the idea that the purpose of these models is for decision making, and not to produce a model which simulates reality. Thus models need to be transparent and provide decision makers with all of the caveats and uncertainties associated with the model and the evidence. The same modeller also suggests that decision makers often prefer simpler models. This relates to the credibility of the model, discussed previously. There was a discussion within the focus group meeting about building in alternative structural assumptions within the model.

> *Modeller 4 (focus group data): "We often talk about model structures as if they are irreversible choices, and I guess for many of the short timeline projects we work on they feel pretty irreversible because once you've committed to and once you've invested time in collecting data, you reach a point where it's... But there are other things within models which are structural where you can test alternatives, and you leave them open, and you can have switches in the model that turns bits of it on and off."*

This modeller highlights that model structures can be modified at any time during the model development process, although within the time constraints of the decision making process this may be difficult. He suggests that different structural assumptions can be tested within the model. However, one of the other modellers argued that in practice this rarely happens.

One of the modellers from the focus group indicates that the choice of structural assumptions may depend upon how likely the intervention is to be considered to be cost-effective.

Modeller 3 (focus group data): "... the results were so clear cut that we could take hugely conservative assumptions and still get a very favourable result, and so in that case we were able to use a very simple model. I think, possibly in primary prevention more generally that may well be the case if you're talking about population wide programmes."

The modeller intimates that if the incremental cost of the intervention is expected to be small then it would be possible to make assumptions which are more likely to underestimate effectiveness and overestimate costs and show that the intervention is cost-effective. He suggests that this means that a very simple model can be used in these situations. This implies that the modeller began with a 'back of the envelope' approximation in order to facilitate making these structural assumptions. However, even within a very simple model it is necessary to make decisions about what factors are important, and how these factors are chosen are not discussed here. Modeller 1 mentioned the NICE process as a contributing factor as to why some decisions are made. However, the same modeller also suggested that this process does not constrain many of the decisions about model assumptions when asked how these decisions are made.

Modeller 1 (interview data): "Sometimes I think it's almost protocol, it's the way things are done, or maybe it's the way NICE has decided they want it done."

Modeller 1 (interview data): "Completely ad hoc I reckon, the way things are going at the moment; we don't seem to be straight-jacketed into a particular routine, we can pretty much decide what we want to do, what we want to include and how we're going to do it."

The same modeller indicated that making decisions may have implications for future decisions for the same model, although again he highlighted his uncertainty with the process.

Modeller 1 (interview data): "I'm guessing that once we start making a few hard and fast decisions, then that's going to affect other decisions later on, but I'll wait to find out."

This is likely to be the case only if the structural assumptions have already been implemented into a quantitative model. Within the focus group, there was a lot of discussion around the influence of the modelling culture within Health Economics upon structural decisions.

Modeller 5 (focus group data): "I think in infectious disease evaluations there's sort of like two worlds; there's the world of infectious disease modellers… …doing extremely sophisticated models to predict how flu pandemic will spread around the world with people moving between cities and flights and things like that. And then there's the Health Economics world where the sort of modelling expertise is in things like how do we capture uncertainties and probabilistic sensitivity analysis and so on... ...And there's not that many people who try to bridge (the gap)... And sometimes that's not too helpful for decision making because what you need is a combination of both."

This suggests that the modellers' backgrounds and the culture of the discipline may influence the decisions they make about model structure. Modellers with an infectious disease modelling background are likely to develop dynamically complex models, whilst modellers in Health Economics may develop simpler models which focus upon capturing the uncertainties within the model results. These alternative methods are due to the different paradigms within each of these disciplines, as discussed within Chapter 1. Modeller 5 is suggesting that it is important to merge the learning from each of the disciplines in order to more usefully help decision makers. This observation highlights the absence of any methods guidance for developing model structures which would help to align the two 'worlds' and the importance of methods for sharing existing knowledge and assumptions. The modellers from the focus group meeting all agreed that decisions about model structure will be affected by the skills of the modeller.

Modeller 4 (focus group data): "...we're all limited by the modelling tools, you know I've never done agent-based modelling, I don't know how to do system dynamics modelling. There's all sorts of different varieties of modelling because I've come mainly from a HTA background, you know I can do decision trees, I can do Markov models, I can do some sort of individual or stratified models sometimes, but each of us has our own spectrum of software and experience for modelling different things."

Specifically, this modeller who has a background in HTA, states that he does not know how to develop agent-based models or system dynamics models. This is likely to be true of other modellers with a HTA background since these types of models are generally not required for cost-effectiveness analyses of clinical interventions (see Chapter 2). One of the modellers within the focus group indicated that modelling for Public Health economic evaluation may follow a 'Public Health tradition'.

Modeller 7 (focus group data): "We kind of went down a particular route that was mostly informed by a public health tradition in modelling in that you had various population and subpopulation level models like Prevent from the 1980s that are quite seminal, and guided our thinking. And so the alcohol model as it stands is a public health model essentially very much. But then the Institute for Fiscal Studies who are now our collaborators on the behaviour change elements of the alcohol model, and independently produced their own conclusions from us as a team; It's really quite interesting to read their discussion documents, which are essentially around modelling, and how they're culturally different. So they have discussions around the externalities due to drinking, they think about it in a very fiscal way."

Modeller 7 suggests that there is a Public Health tradition in modelling that focuses upon the impacts of the interventions upon the population as a whole (which may be divided into subpopulations) rather than on individuals, although one of the other modellers asked for more explanation about this because he was not aware of such a tradition. Modeller 7 contrasts the Public Health tradition with the view of collaborators from the Institute for Fiscal Studies who focus to a greater extent on the impact of the interventions on third parties such as crime or accident rates that affect other individuals. He highlights that the same piece of work can be interpreted in different ways depending upon who is reading it and their cultural perspective. Related to this, the modeller suggested that within the bigger Public Health economic modelling projects large groups of people might make decisions about different parts of the model structure, each with different expertise. He implied that the decision about how to divide the modelling work up within the team helps make some of the decisions about the level of complexity of the model structure.

Theme 1 Summary

The data suggest that model development within Public Health economic evaluation is iterative but that modellers do not follow a set process for model development, which is likely to create uncertainty in the process, particularly for inexperienced modellers. Modellers may not have thought about how to make decisions about what to include and exclude within a model, and it may cause frustration for inexperienced modellers in trying to make the 'right' decisions. It is clear that modellers have to go through some sort of conceptual modelling process and develop some form of communication of the model, although there is no consistent terminology associated with this process. Many modellers develop diagrams of the causal relationships between factors. The data suggest that some of the issues which modellers are facing during model conceptualisation within Public Health economic evaluation are how to define a 'good' outcome (including dealing with social value judgements), how to handle heterogeneity, what the most appropriate outcome measure and perspective is and differentiating between causation and association. Additional issues include identifying unintended consequences, ensuring that the impacts of the intervention are incorporated within both the costs and benefits and determining whether to include intergenerational impacts.

Modellers suggest that they tend to develop an understanding of the question before making structural decisions, although in practice it may be that the understanding of the problem continues throughout model development. The impact of the interventions upon the social gradient may need to be considered as well as the overall effectiveness of the interventions, as discussed within Chapters 2 and 3. The data suggest that the choice of interventions and the model population and subgroups are key considerations which drive structuring decisions, and these may be driven by what the experts and decision makers want to explore, although there is variability between modellers around the basis of these choices. The modelling work is constrained by the project scope and the decision making process. Model credibility is important to modellers, as also discussed within Chapter 4. Some methods for making decisions about the model structure outlined by the modellers are: (i) reviewing the strengths and weaknesses of previous models, (ii) having discussions between other modellers, experts or decision makers, or (iii) finding out more information to assess how important a factor is. The choice of structural assumptions may depend upon how likely the intervention is to be considered to be cost-effective. The data suggest that some decisions may be limited by the skill set of the modeller, standard processes and the culture of the discipline, or previous decisions which have been made. Within bigger modelling teams, decisions about how to divide the modelling work up may help to make decisions about the level of complexity of the model. Different structures can be incorporated into the model, although this is rarely done in practice. Modellers suggest that they should fully understand the implications of the structural choices they make.

Modellers are generally clear that the purpose of model development is to help decision makers make decisions, as opposed to trying to reproduce reality. Model development is constrained by the time and resources available within the decision making process and modellers are acutely aware of this. This means that modellers are not aiming to build the 'best' model, but the most appropriate given these constraints, and this includes decisions about model type (for example, cohort Markov models versus individual-level simulation). There is thus a need to specify what is not incorporated within the model. Models may be 'anchored' as a result of the time constraints, in that the structure is likely to be largely dependent upon the type and complexity of previous models that have been identified in that area. This is one example of the enrichment strategies modellers use by making sense of existing relevant information rather than spending time searching for more evidence, as described by Paisley.[63] Modellers must collect sufficient evidence to be able to judge whether they are making appropriate simplifications. Due to time constraints, modellers may 'start simple and build', as proposed by Pidd,[44] which would require iterations between model conceptualisation and model implementation. Finally, the data suggest that time restrictions may lead to changing the focus of the work so that it becomes more exploratory.

Theme 2: Use of evidence in model conceptualisation

It is important to understand the influence of evidence upon the model conceptualisation process, and the way in which the two interact, in order to incorporate these considerations into the conceptual modelling framework. Similarly, the sort of evidence that informs decisions about model conceptualisation, and how and why, might be included within the conceptual modelling framework. Each of the following subthemes are considered in turn: (i) The role of evidence; (ii) Effectiveness review; (iii) Other literature; and (iv) Communication with the experts and decision makers.

The role of evidence

Within Public Health economic evaluation, different forms of evidence are generally available than evidence for health economic models of clinical interventions.[64] Good practice guidelines for modelling in health economic evaluation have suggested that the development of model structures should not be data-led.[18;161] However, developing a conceptual model without any knowledge of the data available could lead to a number of subsequent iterations of altering the model structure according to the availability of data.

The iterative nature of model conceptualisation and the collection of evidence are highlighted within my notes. I have written numerous questions about whether any evidence is available to show specific relationships such as the relationship between teenage pregnancies and social care. There is a cycle of setting hypotheses, testing them with evidence and then generating new hypotheses. The first cycle is based upon background reading and discussions with the PDG. Subsequent cycles are based upon other literature and further discussions with the PDG. One of the interview participants suggested that different modellers use data in different capacities during model conceptualisation, and that this varies according to the mindset and preference of the modeller.

Modeller 2 (interview data): "I don't take too long to get round to it (looking at data), so you could contrast my mind set with some other modellers who can live with just conceptualising the whole and even parameterising and writing the software for the whole model before they have thought about what data might fit in those bits."

The use of the term 'can live with' implies that Modeller 2 would find it very difficult to work by conceptualising the whole model prior to looking at the data. This indicates that modellers may find it difficult to adapt their processes, which should be borne in mind when developing the conceptual modelling framework. Theme 3 (benefits and barriers of the use of a conceptual modelling framework) considers this in more depth.

The same modeller highlighted the inevitably iterative nature of the model development process between model conceptualisation and data use.

Modeller 2 (interview data): "If the data is not there in some sense that frees up your conceptualisation because you don't have to fit the conceptualisation to the data and if you are going to make assumptions or elicit you reconstruct the configuration of the model to fit how you are going to make the assumptions or how you are going to elicit more easily from an expert or from yourself what the shape or a curve might be or whatever else."

This suggests that the relationship between conceptualisation and data collection means that it is not possible to undertake the tasks as two completely discrete stages. This could be likened to the idea that researchers can state that they are taking an inductive approach (where data leads to theory) or a deductive approach (where data either proves or disproves a theory), when to some extent the researcher inevitably has to work both inductively and deductively.[58] For example, evidence in some form is required to understand the problem, and a certain level of understanding of the problem is required to inform the collection of evidence. The focus group members generally agreed that it is an iterative process between collecting evidence and structural development, although some may start using data at an earlier stage in the process than others.

Modeller 2 stated that a lack of data is not necessarily an issue, but that he does not feel happy developing a model without knowing what data are available.

Modeller 2 (interview data): "It doesn't bother me no data, what does bother me is ignoring whether there is data or not. Because what I find is that issues emerge from the data, so it re-conceptualises; you find out, I don't know what we will find but…"

The modeller suggests that the reason that he does not like ignoring whether there are data or not is because issues emerge from the data. This may relate to the idea raised within Theme 1 that the modeller is developing the most appropriate model given the constraints of the decision making process. I would suggest that the modeller prefers short iterations between model conceptualisation and data collection perhaps because he is aware of tight deadlines within the decision making process. If the availability of data is not considered until a later stage in the process and issues emerge from the data at this stage, it could lead to more cycles between model conceptualisation and data collection which could lead to a longer model development process. The modellers within the focus group meeting resonate this.

Modeller 5 (focus group data): "There are kind of like two types of subprojects if you like... ...one is you have a tight timeline with a pretty narrow kind of question; what is the cost-effectiveness of this intervention to this decision maker? And that's where it's really that process; what data is available and how did it influence the structure of the model. And the other kind of work I get is maybe something with a much longer timeline, and a much more loosely defined question, like well what are potentially cost-effective interventions in this disease area? And that's where it might be over several years. There's more of an opportunity not just to say what data are available but also how can we influence data collection over these years."

He implies that given more time for a project, it is more feasible to think about the model structure without considering data availability, because there may be time to collect the data required by the model structure. However, given tight project timeframes where it is unlikely to be possible to collect more data, it is necessary to think about data availability at an early stage in the process as it is likely that the model structure will need to be modified accordingly. The latter was reiterated by Modeller 3 within the focus group who said "then you're getting into what data's available and so on, and invariably there isn't the right data, so then you're getting into compromises." The theory of not developing data-led models seems to be in conflict with the practical necessities in order to complete the work. The quote by Modeller 5 above also indicates that the timeframe may affect how the interventions being assessed are chosen; given short timeframes the interventions being assessed may be clearly pre-specified, whilst longer timeframes may allow more scope for assessing which of a broad range of interventions are likely to be cost-effective. Importantly, this highlights that different projects may require different processes to be followed and hence any conceptual modelling framework would need to be flexible for different decision making jurisdictions.

In response to this focus group discussion, another modeller stated that these models are developed for the purpose of prediction, and as a result it is not possible to simply use the data that are available to develop the model structure.

> *Modeller 7 (focus group data): "...ultimately you're in the business of prediction. And for prediction, if you just look at data modelling then you've got a static view of the world, okay you can look at a trend line maybe and extrapolate it a bit, but you're just in the data whereas really what you're trying to do is causal ultimately... ...so for me it has to go, you can look at that data structure to start with but there's more to it."*

This modeller is suggesting that models need to estimate what will happen in the future within Public Health economic evaluation, and as such it is not possible to have all the data. This means that a key element of the modelling must be in estimating causal relationships, and hence the structural assumptions cannot be developed based upon datasets alone.

The modellers indicated that lack of data may affect both the intervention(s) and the population(s) being modelled. This relates to the first and second issues identified within the model development framework described by Modeller 2 (classifying and defining population subgroups of interest and identifying and defining harms and outcomes for inclusion in the model). For example, within the Contraception project, the population identified within the project scope was socially disadvantaged young people; however lack of effectiveness data for socially disadvantaged young people meant that it was not possible to focus only on this subgroup of the population despite the fact that outcomes would be different for this subgroup.

> *My notes on Contraception project: "Proportions of births, miscarriages & abortions are affected by deprivation. No effectiveness evidence by deprivation. If [the intervention] targeted specifically socially deprived [populations], can only approximate [effectiveness]."*

One of the modellers within the focus group suggested that lack of evidence may lead to changing the purpose of the model so that it becomes more exploratory.

Modeller 4 (focus group data): "…the cost-effectiveness estimates, or the cost benefit estimates we're going to be producing are going to be so heavily qualified and based on such strong assumptions, we've definitely been in the situation where we've just gone back to NICE and said shall we turn it into this kind of an exercise instead, where we just explore these different things. And so actually part way through the model development process… …it actually changes what sort of structural decisions you start making because you say right this is explicitly going to be a model for exploring internal trade offs within the model, rather than one that's all geared up for producing one specific answer."

The modeller implies that there is a point at which models may be based upon too many assumptions and there is insufficient evidence for the results to be considered valid. He indicates that structural decisions are directly related to the purpose of the model, and that this purpose may change from what was agreed at the start of the project to be more exploratory if limited evidence is identified.

Modeller 2 suggests that one of the problems is in terms of deciding what evidence to use and how to use it.

Modeller 2 (interview data): "So I think that the big questions were exactly what evidence to use, and exactly how to translate that evidence into a coherent framework that would allow one model to analyse very disparate interventions."

This highlights that interventions which are assessed within the model may be very different and hence difficult to compare.

Effectiveness review

A review of the effectiveness literature is common practice within national Public Health decision making jurisdictions.[5] Modeller 2 described the iterative nature of using the effectiveness evidence in a similar way as for other evidence as described within the 'Role of Data' section above.

Modeller 2 (interview data): "And now that I say it to you it is quite simple you do minutes walking to minutes cycling, physical activity, kilometres driving but when you didn't know what data existed you didn't know exactly until the evidence reviews was produced, which is quite late in terms of constructing the model, what the evidence looked like before the interventions, how they were measuring effectiveness, it kind of all went round in many circles for quite a long time."

This illustrates the additional work created due to the constraints of the process in terms of the timing of the delivery of the evidence reviews. It suggests that the modelling work must fit into the wider process required for making a decision, which the modeller may have little or no control of. However, Modeller 4 from the focus group implied that the effectiveness evidence would be the main starting point for the modelling. Both of these modellers suggested that what is modelled is dependent upon the effectiveness evidence available and it was stated that they must have a "reasonably well designed effectiveness study conducted on them". Importantly, whilst the modellers indicated that the outcomes of the intervention review are a key influence upon the model scope and structure, none of the modellers described the starting point for the intervention review and how this is determined. The modellers also did not discuss any of the complexities associated with reviewing Public Health interventions (that they are often multi-component and non-standardised, as discussed within Chapter 2). This implies that, from the modellers' perspective, the review of the effectiveness evidence is considered to be the job of the reviewer(s) and information specialist(s) rather than the modeller, with the modellers generally making use of the output of the review. Conversely, some of the modellers from the focus group suggested that the experts or decision makers would choose which interventions to assess.

Modeller 7 (focus group data): "We elicited that there were certain interventions that they (the PDG) wanted to model."

This highlights the lack of consensus around the way in which interventions are chosen for assessing within the model. Within the focus group, the modellers indicated that the intervention must not be current practice and should be feasible.

The modellers tried to understand the full short term impact of the intervention which may not be captured by the effectiveness studies. This relates to the third issue identified within the model development framework described by Modeller 2 (modifiable components of risk). My notes from the contraception study suggest that the effectiveness studies do not capture all relevant consequences of the comparators and interventions. This relates to identifying unintended consequences, described in Theme 1 and Chapter 3. A large proportion of my notes are asking questions to try and understand the possible consequences of the interventions and to assess whether evidence will be available to allow modelling of these consequences.

> *My notes to ask the PDG from Contraception project: "Do you know of any evidence of a relationship between contraceptive use and (i) knowledge of contraception; (ii) intent to use contraception; and (iii) service provision."*

My notes and the other modellers suggest that the studies of effectiveness usually have short term follow up and that one of the issues within Public Health modelling is in terms of lack of long term evidence of the impact of the intervention. This relates to the sixth issue identified within the model development framework described by Modeller 2 (risk functions relating risk factors to harm). Modeller 2 implied that this is an important issue and said that he wanted to "*make clear to the research community that long terms impacts are important to collect, and he will be suggesting further research within the report*". Within the contraceptive work I have noted:

> *My notes from Contraception project: "We have one data point (% pregnant) and need to extrapolate this over time."*

Modeller 2 highlights that decay in the effectiveness of the interventions needs to be considered, which is unlikely to be captured within the short term studies.

> *Modeller 2 (interview data): "…it became clear that for some interventions like pedometers you give somebody a pedometer, they use it for a while, and then they stop using and they are back to square one by the end of the year. So you can measure the effectiveness at the three months and six months but you also need to account for the fact that there is a decay in effectiveness so we had to build in a decay."*

Problems were identified with modelling the outcomes over time for both the comparator and the intervention. My notes from the Contraception project suggest that modellers need to distinguish between cause and correlation, as was highlighted within Theme 1. Econometric techniques were used to control for factors which have not or cannot be controlled for within a trial within the Contraception project.

Other literature

One of the major benefits of modelling is to draw together evidence from a wide range of sources.[2] It is useful to know how and why those sources are chosen for the model conceptualisation in order to incorporate some guidance about relevant types of sources into the conceptual modelling framework.

The modellers from the interviews and the focus group were generally in agreement that they try to identify models in the same area near the beginning of the project to see if there is an existing model that could be adapted or if there are aspects of them that could help to develop their own approach. This may involve a formal systematic review or informal searches.

> *Modeller 3 (focus group data): "That's one of the first things we try to do. Is there a model and is it fit for purpose for the current decision? Is there a model for a related decision that can be adapted?"*

One of the modellers also indicated that he tries to identify what is relatively conservative methodology and what is more advanced methodology in that area. The modellers suggested that experts are consulted, both via the information on their websites and personally, to understand alternative methodological approaches and what data are available in that area.

> *Modeller 2 (interview data): "We had a look at some of the websites from the Department for Transport… …and we had at least two teleconferences with people from the Department for Transport who are somehow connected with the NICE process to ask them how things work there, what they do, what good datasets would be."*

This highlights that different sectors may develop models differently and have different cultural norms, as discussed in Theme 1. The modeller proposes understanding what modellers in that area do and what datasets may be useful. One of the issues raised within the focus group meeting is the difficulty in gathering all of the evidence together because of the diversity of the evidence within Public Health economic modelling.

Modeller 7 (focus group data): "I think in your more clinical stuff it's a much more well described and scoped problem and it all fits together quite nicely. Whereas here, you're looking over here for information, you're looking over here for information; there's this real sort of discovery exercise in terms of trying to gather the evidence, and the quality of the evidence is variable across that landscape. And you're doing different things with different bits of evidence… …There's this view (by peer reviewers) that these mixed hierarchies and mixed levels of abstraction are fundamentally wrong in some way to do that, in ways that are never fully described."

This highlights that within Public Health economic modelling the evidence is from a much broader sphere and the information tends not to be coordinated or designed for use within health economic evaluation, such that there may be difficulties with combining these different types of diverse sources. Because the quality and type of evidence available are often variable, this leads to different levels of abstraction within a model. The modeller emphasises the issue that there may be an expectation by peer reviewers that, when synthesising evidence, the level of abstraction will be consistent across each part of the model.

The use of the term 'discovery exercise' within the above quote suggests that this is not a systematic process and indicates a lack of a definable and explicit process when searching within the literature to inform the model structure. This may also be why the modellers did not spend much time talking about how literature for models is identified. In addition, the modellers did not refer to different types of literature such as Psychology and Sociology sources for facilitating the development of the model structure, as discussed within Chapter 3.

Communication with the experts and decision makers

Research around simulation modelling for operations systems suggests that communication with experts during model development can have a number of advantages including encouraging learning about the problem, developing appropriate model requirements, facilitating model verification and validation, helping develop credibility and confidence in the model and its results, guiding model development and experimentation, and encouraging creativity in finding a solution.[1]

Reasons described by the modellers for communication with experts and decision makers included finding what modelling work is useful to them, updating them on progress and receiving feedback, helping with developing appropriate model assumptions and obtaining data and expertise.

Modeller 1 (interview data): "So there are things we're concentrating on to get some material, apart from that its just to update them (the PDG), and see whether we're doing the right thing, what they want, and whether they've got any other ideas, because obviously several of them are experts in this field, that's what they're there for, so they'll know better than us... ...Hopefully we've picked their brains a bit, and not just got their approval, we need to get some constructive criticism out of them as well."

It is interesting that the modeller has mentioned both 'doing the right thing' and 'what they want', which implies that these are not necessarily the same thing. For all of the reasons for communication with the experts described by Modeller 1, they are actively helping to make decisions in order to facilitate the model scoping or conceptualisation. The need for the experts to actively provide their expertise, rather than more passively agreeing with what has been done is clearly highlighted by one of the modellers. The use of language within this text, 'we need to get some constructive criticism out of them', suggests that the experts are considered by the modellers to be a tool for facilitating model development in much the same way as any other source of evidence. The same modeller talked about communication with the PDG as a required process.

Modeller 1 (interview data): "So its not specifically the PDG will have to tell us what this is, its more of a we're going to talk to them anyway so we might as well see what they want and what their opinions are, rather than just going ahead and then they say you shouldn't have done it that way, we want something else."

This intimates that it is more efficient to obtain the PDG's input at an earlier stage in the process rather than having to amend the model at a later stage as a result of feedback. One of the members of the focus group also stressed the importance of involving experts in the early discussions to give an idea of the issues that they think will be relevant. The same modeller also emphasised the importance of credibility.

Modeller 3 (focus group data): "There is always a chance that the decision maker, even if they've commissioned the model, may decide not to use it. So we have to present the model in a way that actually they will believe the results, and that means if there's something that they want to see there, it's got to be there."

This highlights that it is important for the decision makers to know how the model works and what assumptions it is comprised of. The modeller also implies that even if something does not impact upon the model results, it may be important to include it so that the decision makers are happy with the model. The modellers within the focus group generally agreed that it is important to have a shared understanding between the modelling team and the decision makers.

The modellers also considered the impact of the process from the perspective of the experts and decision makers and the implications of this.

> *Modeller 1 (interview data): "In fact, all they (the PDG) want from us is a cost per QALY at the end of it I guess; really just one number in amongst all the other considerations, so maybe they haven't put a great deal of thought into what they want."*

This suggests the possibility that the PDG members may be waiting for the model results before they provide input because of their other priorities within the process. There may be a lack of understanding of what would be helpful to the modelling team throughout the process. This is in conflict with the idea of efficiency of communication with the PDG at an early stage in the modelling process, and hence it seems important to align these expectations of the modellers and the experts and decision makers, as was highlighted by one of the focus group members. In contrast to Modeller 1's view above, some of the modellers within the focus group meeting agreed that the development of the model could be used as a tool for thinking about the issues for the stakeholders.

> *Modeller 4 (focus group data): "...sometimes the model is just a tool for deliberation. It's like a numerical thought experiment that gets the people in whatever committee it is that are having to develop and finalise this policy thinking about the issues in a different way, so then I don't know if heuristic is the right word, but it just serves as an on-the-hoof learning device about what are the implications of us making the policy in this way as opposed to this way."*

The modeller implies that the model can provide an alternative way of understanding the issues which can then allow learning about the potential impact of interventions which otherwise may not be possible. The data above refers to the implemented model, however some of the modellers also talked about this being an outcome of the model development process itself.

The modellers who were interviewed mentioned that it may be that the PDG members can provide more useful input into the modelling work if they have some initial work to critique rather than being asked more broad questions.

> *Modeller 2 (interview data):* "So had we gone on Tuesday and just waffled about the framework again it would have been a waste of their time and our time, so I insisted that we get nitty gritty because they said we are happy with the framework, we can give better feedback when we get nitty gritty."

Within the interviews Modeller 2 explained that 'nitty gritty' meant "*data, specifics, how we are going to do stuff*". This highlights the iterative nature of model conceptualisation and obtaining expert advice, in much the same way as the iterative use of other evidence has been described. The modellers agreed within the focus group that the use of the PDG within NICE projects is good because it is an iterative process where the committee are not just being shown the finalised model, and because "*the development of the model and the choices about what the model's going to be for, were done jointly together in a very large group, who were very sensibly the same group who were also beginning to flesh out and think well what pieces of recommendation, on the basis of the effectiveness evidence (are we developing)."*

Based upon my notes from the Walking and Cycling PDG meetings, generally the modellers presented something to the PDG and they provided feedback or asked questions about the assumptions. This generated some discussion, from which either a decision about how to proceed was made, or the modellers subsequently made a decision about how to proceed following the PDG meeting which was discussed at the next meeting.

Within PDG1 of the Walking and Cycling project, the presentation by the modelling team focused upon what they were doing and what data they were using, rather than why they were doing it. However, some of the PDG asked questions about why certain analysis was being done. My notes state:

> *My notes from Walking and Cycling PDG meeting: "The PDG had less than ten minutes to comment on the presentation and only 4 or 5 PDG members out of 11 provided feedback. It is only the subset of PDG members that are familiar with economics which input into this*

feedback. The majority of this was about data sources the PDG knew of rather than decisions about what to include and exclude within the model."

This suggests that PDG members who have no economic background may feel less confident about providing input into the modelling work. It also highlights the constraints of the process upon the stakeholders' involvement in the modelling work. Within this PDG 1 meeting held near the start of the project there was a focus upon data sources. During the project, the modellers asked the PDG about a wide range of information including current service provision within England and Wales, identification of data sources, reasons for data not tallying, and appropriateness of structural assumptions, as well as methodological input from the Walking and Cycling economic subgroup.

Within both the Walking and Cycling and the Contraception project recommendations were suggested by the PDG based upon the short term effectiveness studies and then the modelling was used to assess whether the interventions recommended were cost-effective almost as a distinct stage in the process. Modelling did not take a central role in understanding the problem or helping to develop the initial recommendations through estimating the long term intervention effectiveness.

Within one of the Walking and Cycling PDG meetings, I noted that there is "*very little discussion of the long term effectiveness; much more focus on generalisability of short term outcomes*". However three PDG members did ask about long term evidence and the review group reported that this was presented within the evidence review where available. The modelling team were not present at this part of the meeting to promote a more detailed discussion about this, which may have been useful. However, Modeller 2 indicates that the experts and decision makers place much more weight on the effectiveness outcomes from the modelling work than upon the cost estimates within the model.

Modeller 2 (interview data): "…And nobody has got any idea about whether those costs are right, except you play them in front of people and nobody says anything. So they could easily be 50% wrong in any direction… …and you can talk for hours about the effectiveness evidence and do days and days worth of work and literally I would say all the costings were done in one day."

Modeller 2 is suggesting that the amount of time spent on the effectiveness and the costs is inappropriately imbalanced. It highlights the great influence that the process, culture and the experts must have upon the modelling work, since it is the modeller who is so openly unhappy about this process, and yet it is him that has developed the model in this way. It is unclear whether he is suggesting that the experts and decision makers were not interested in the cost-effectiveness estimates generally or whether they were not interested in the costing assumptions resulting in those estimates.

Within the focus group meeting there was a discussion about who should provide expert advice during model development. It was stated that some experts see cost-effectiveness modelling and the decision-making process as a "threat to their autonomy" or "fundamentally object to decision modelling". One of the modellers indicated that there may be ongoing debates within a topic area, such as valuation of alcohol pleasure, which experts may feel strongly about, and the modelling team needs to be aware of this. One of the modellers within the focus group meeting suggested that the choice of experts could affect the interventions and comparators modelled.

> *Modeller 4 (focus group data): "I think in public health it's more likely that you'll end up with a few, a much more limited range of ways of specifying a given policy. And it's those specific ways that are chosen to be modelled which will be driven by that kind of committee preference and what they think the country will find palatable at this point in time."*

This modeller indicates that the policies evaluated within a model are constrained by what the committee believe to be politically and culturally acceptable. The use of the term 'palatable' suggests that any highly controversial topics and approaches will be avoided. This means that there is likely to be a higher level of agreement between stakeholders than if more controversial topics were considered or if the decision problems were divided up differently (see Chapter 3 for discussion of stakeholder agreement). The modeller also implies that the choice of committee could affect what interventions are assessed within the model. For example, within the Contraception Project, one of the interventions modelled was dispensing condoms in schools. Other committees during different political times may have decided that that was not an appropriate intervention to model given the law on sexual activity below age 16. Modeller 5 suggested that to obtain an overview of what people think in a particular area, one idea is to go to a conference on that subject if one exists, and another is to "*think from the outset, can we get some dissenting voices that actually have a stake in the other direction".*

Within the second economic subgroup meeting on the Walking and Cycling project, whilst the members of NICE involved with this project were generally happy with the work that had been done, they said that they thought "the draft economic modelling report was too difficult to understand". It is unclear whether this meant that it was too difficult for them to understand personally or too difficult for a lay person to understand; however it illustrates that clear written communication for a non-technical audience is important.

Theme 2 Summary

The data suggest that modellers inevitably iterate between model conceptualisation and collection of evidence by oscillating between setting hypotheses, testing them with evidence and then generating new hypotheses. This applies to all types of evidence including the effectiveness studies and communication with decision makers and experts. Different modellers use data in different capacities during model conceptualisation. Given more time for a project, it may be more feasible to think about the model structure without considering data availability; however, given tight project timeframes where it is unlikely to be possible to collect more data, it is necessary to think about data availability at an early stage in the process as it is likely that potential model structures need to be modified accordingly. Modellers suggest that limited data availability may lead to the purpose of the model changing so that it becomes more exploratory, which may change structural decisions. However, models within Public Health economic evaluation need to estimate what will happen in the future and are thus inevitably causal, and as such it is not possible to have all of the required data.

Modellers suggest that within Public Health economic modelling the evidence is from a much broader sphere than for modelling of clinical interventions and the information tends not to be coordinated or designed for use within health economic evaluation. Thus there may be difficulties with combining these different types of diverse evidence and different levels of abstraction may be required within the same model, which may cause criticism of the model. When the scope of the model extends beyond health, it is important for modellers to understand the modelling methods and outcomes in these other sectors. Models may also be improved via exploration of different types of literature such as Psychology and Sociology sources for facilitating descriptions of how behaviour might affect outcomes.

The effectiveness studies often do not capture all relevant consequences of the comparators and interventions and there is generally no long term follow up within the effectiveness studies. Therefore, modelling could take a more central role in understanding the problem and helping stakeholders understand the possible long term effectiveness of the interventions. Econometric techniques could be used to help distinguish between cause and correlation. The data suggest that lack of evidence may sometimes prevent subgroup analyses and limit the interventions assessed. Interventions may be diverse, making them difficult to compare. There is variability around how the short term effectiveness evidence is employed; however the modellers tend to view the construction and development of the review of effectiveness evidence as the job of the reviewers, with the modellers generally only making use of the output of the review. It may be more useful for the modeller to be involved throughout the development of the review and this process is considered further within Chapter 6.

Modellers use other people's models and consult other experts in order to help develop their own approach. The data suggest that experts and decision makers are actively involved in helping modellers make decisions about model scope and structure by discussing what is useful to them and providing feedback on the work in terms of current service provision, identification of data sources, reasons for data not tallying, appropriateness of structural assumptions, and methodological input. The choice of experts could affect what interventions and populations are modelled. The experts seem to provide more useful input into the modelling work if they have some initial work to critique rather than being asked more broad questions. It also seems important to align the experts' and decision makers' expectations of the process and their requirements with the modellers' expectations. Moreover, the decision making process has a substantial impact upon the modelling work due to cultural norms. Different projects may require different processes to be followed.

The data suggest that a shared understanding of how the model works and what assumptions are being made between the modelling team and the decision makers and experts is beneficial because it encourages learning about the problem as well as confidence in the model results. An iterative process with the experts seems to be useful. The model development process and the model itself may be used as a tool for thinking. Modellers should be aware of any ongoing issues of social judgement within the topic area. In addition, the report to the experts and decision makers needs to be communicated in such a way that they understand what has been done without requiring an extensive mathematical background.

Theme 3: Barriers and benefits of a conceptual modelling framework

It is important to understand the potential barriers and benefits of a conceptual modelling framework within Public Health economic modelling so that these can be considered during the conceptual modelling framework design. This theme is divided into three subthemes: (i) Potential barriers associated with the adoption of a conceptual modelling framework; (ii) Possible constraints upon a conceptual modelling framework; and (iii) Potential benefits of a conceptual modelling framework.

Potential barriers associated with the adoption of a conceptual modelling framework

In order to attempt to address, during methods development, any potential barriers associated with the use of a conceptual modelling framework for Public Health economic evaluation, it is useful to understand modellers' perceived barriers to the adoption of such a framework.

One of the modellers from both the interviews and the focus group indicated that some modellers may resist guidance around developing the model structures of Public Health economic models.

> *Modeller 7 (focus group data): "If I was at my most pessimistic… …all of this soft stuff that we've been discussing it is experiential almost, it's like an art. And there's also an almost personal, even if you're working in a team, there's a sort of human factor, personal element to it that it comes about through a process of osmosis and working with other experts, and there's some sort of, there's something to it this element of quality, if you like, to it, that makes a reductionist approach to this issue (big pause) unpalatable… …I can feel myself sort of resistance to doing that, you know this is how I go about doing conceptual modelling or problem structuring and talking to different people and I don't need some flow chart to sort of help me with that... ...That you don't apply the same modelling methods to your own process of modelling, I think there's something like that going on."*

The modeller identifies the conceptual modelling process as an art rather than a science, as it has been described within some of the literature (see discussion within Chapter 1). He suggests that it requires the input of other experts and it is not possible to follow set rules to undertake the process. He uses the term 'reductionist' to describe such an approach which implies that he thinks it is not possible to capture the complexity of the process within a conceptual modelling framework. As a result, he feels he would resist trying to follow this sort of guidance. He highlights that each modeller does not even have a consistent approach to the conceptual modelling process between their own individual projects, and consequently he intimates that it does not seem possible to develop successful guidance for all modellers to follow.

Not all of the modellers felt this way; however the focus group modellers all agreed that it was important that the conceptual modelling framework was not imposed on modellers as something they need to adhere to. Modeller 3 emphasised that "*it must not contain the word 'must'!*" In addition, Modeller 4 said that he would try using the guidance, but may stop using it if he found it restrictive and he implied that it should not be hard to use in practice, since this may be a barrier to the use of the conceptual modelling framework.

One of the modellers who was interviewed highlighted an issue of generalisability of a conceptual modelling framework outside of the UK decision making process.

> *Modeller 2 (interview data): "But I think as well there will be an issue of generalisability with the work that you are doing and about to do; how that would feel in the US in the Harvard School of public health, or in Brazil or in the World Health Organisation in Geneva, or in India might be very different."*

He suggests that a conceptual modelling framework for the UK Public Health decision making process might not be applicable to the decision making processes in other countries. In addition, Modeller 2 states that it is important not to over claim on what the conceptual modelling framework can do.

> *Modeller 2 (interview data): "…one of the barriers is that if you over claim on the power of the conceptual model and disappoint modellers and stakeholders and analysts that when you tried it it cannot deliver with this value, then it can get chucked aside."*

Modeller 2 is suggesting that it is important to be clear about what the conceptual modelling framework can and cannot do so that when it is employed it provides the guidance that the user is expecting, or there is a risk that people will be disappointed with it and it will not be reused.

Possible constraints upon a conceptual modelling framework

It is important to understand the possible constraints upon a conceptual modelling framework for Public Health economic modelling so that these can be considered within the framework.

The modellers proposed several possible constraints within which the conceptual modelling framework may need to be designed to operate within. These included practical considerations within the decision making process such as time requirements and modellers' skills, as well as cultural acceptability of the requirements of the conceptual modelling framework.

> *Modeller 2 (interview data): "I think it's going to be time, fit, cultural acceptability to both the client and the stakeholders and the modellers, the data custodians."*

Modeller 2 suggests that one of the constraints for a conceptual modelling framework is that it needs to be acceptable for use within the decision making process which means that it must be a credible approach for the modellers, the client and the stakeholders to employ. For example, the modeller recommends that the conceptual modelling framework should be sensitive to the time available and the processes followed within the decision making process. Within Theme 2 one of the modellers intimates that insufficient time is spent on costing the interventions, however I would suggest that part of the reason may be because this is considered to be an appropriate part of the process by the experts and decision makers i.e. it is culturally acceptable.

The modellers within the focus group also discussed the constraints associated with the skills of the modellers, as was described within Theme 1.

> *Modeller 4 (focus group data): "...we're all limited by the modelling tools... ...And I guess that always inevitably limits the scope of structures and methods that you use."*

It is thus important that a conceptual modelling framework should take this into account.

Within the focus group meeting, Modeller 4 highlighted that there may be a 'conceptual model' already developed by other parts of the team or the decision makers to understand the problem.

> *Modeller 4 (focus group data): "…there will be a conceptual model there already, developed by either the other parts of the team, or by NICE… …And for us to go off in a different direction with our modelling and either completely ignore that model or not try and create a model that's somehow emulated their breakdown of how the problem unfolds would have created problems."*

The modeller highlights that it is important not to ignore any conceptual models developed by other parts of the team or to do something different from what they have developed. Thus it will be important to consider and use these other diagrams developed within the process within the conceptual modelling framework.

Potential benefits of a conceptual modelling framework

It is useful to understand the potential benefits of a conceptual modelling framework for Public Health economic evaluation so that, where appropriate, these can be captured within the framework.

The modellers generally agreed that a conceptual modelling framework could help with communication. This includes communication between people within the modelling team, with the systematic reviewers, and with the stakeholders and decision makers. When asked about the benefits and barriers of a conceptual modelling framework, one of the modellers within the focus group described how communication with stakeholders may help.

> *Modeller 6 (focus group data): "Do you think it'll be useful for the stakeholders? Because you know so many people talk about the black box and you're privileged and experienced enough to understand what goes into that black box. But many people use the information and it can all just seem like magic. So conceptualisation, even if some of it could be argued against, at least it might provide a sort of framework for stakeholders to, perhaps a simplified way for them to understand what we're trying to do?"*

This modeller from the focus group meeting uses the terms 'black box' and 'magic' to describe some stakeholders' perceptions of Public Health economic models, because they may understand the model outputs but they may not understand how those outputs are produced. She suggests that some form of conceptual modelling might help with this. Similarly, within the interviews, Modeller 2 indicated that conceptual modelling is important for communication.

> *Modeller 2 (interview data): "But I do think that the conceptual model... ...is a boundary object... ...the central purpose of the pathways model wasn't to develop the model it had a social purpose which was to act as something that all people from different places could engage with kind of like Strictly Come Dancing for a family; you can all sit there and watch and laugh at what's his name in his gold suit."*

The use of the term 'boundary object' was originally defined by Star (1989) as 'those objects that are plastic enough to be adaptable across multiple viewpoints, yet maintain continuity of identity.'[162] Using the metaphor of Strictly Come Dancing, the modeller explains that a conceptual model would allow people from different social groups to communicate and take action, without everyone having to understand exactly how it is being used by each of the involved groups. This means that all stakeholders could communicate their expertise and assumptions and understand those of the other stakeholders, so that all assumptions can be questioned.

The modellers also generally agreed that a conceptual modelling framework could be used to help the modeller themselves in understanding the problem.

> *Modeller 7 (focus group data): "... helping us to understand, to try and understand the causal pathway, so there's an understanding for us in developing that conceptual model."*

One of the modellers suggested that a conceptual model "...*helps the audience and the modeller be clear about what's in the model and what's not in the model*", which the other modellers from the focus group agreed with.

The modellers intimated that it would be helpful within a conceptual modelling framework to provide methods for deciding which simplifications are viable and acceptable and which are not.

> *Modeller 2 (interview data): "When you are modelling you will take some short cuts, you will say that is good enough for that bit... ...The problem is that in an application in a quantified model there might be 20 such short cuts and you would like your conceptual modelling framework or something about theory or something to help you decide which of those short cuts is viable and acceptable and which are over simplifications and need breaking out."*

This modeller uses the term 'short cuts' to mean simplifying assumptions within the model. The idea of a short cut is that you come out where you would have done if you had taken the alternative route but it is quicker, and this is the aim of short cuts within the modelling work; we wish the result to be in the same vicinity as if a more complex option had been taken. Modeller 2 indicates that the problem is that there are a lot of these decisions to make about how to simplify the model and that it would be useful for the conceptual modelling framework to help make these decisions.

Within the focus group meeting, modeller 5 suggested that they could "...*see the value of an educational tool with some examples and principles to say well these are some things you might consider as you develop your models, especially for junior modellers, for whom there's a lot of these unconscious processes that could be made explicit for them.*" Here the modeller highlights that there are a lot of processes which are currently not explicit for which it would be helpful if they were, especially for junior modellers. The modeller also proposes using some examples within the conceptual modelling framework to illustrate what is being said.

Theme 3 Summary

The data suggest that some modellers may not be happy adopting a conceptual modelling framework, particularly if it is too prescriptive. One modeller raised the issue that we do not follow the same conceptualisation process ourselves for each project, so it may be difficult to develop a framework that is helpful to all modellers for all projects. The modeller suggests that conceptualisation is more of an art than a science, as discussed within Chapter 1. The modellers agreed that a conceptual modelling framework should not be imposed on modellers and should not contain words such as 'must'. However, the modellers generally could see value in an educational tool with some examples and principles to make the process explicit, especially for junior modellers. In addition, the modellers agreed that a conceptual modelling framework should not be restrictive, but it should take into account that modellers will have different skill sets. The framework should not be hard to use in practice and should be culturally acceptable. It is also important not to over claim on what a conceptual modelling framework will do and it may not be possible to generalise to all Public Health economic modelling contexts.

The data suggest that it would be useful if the conceptual modelling framework helped the modeller to judge what would be appropriate simplifications of the problem. The framework should also consider any diagrams developed by other parts of the team on the same project. Examples could also be used to illustrate the approach. The modellers suggest that one of the benefits of a conceptual modelling framework would be that it allows communication with the project team and stakeholders and that it helps these and the modeller to be clear about what is included and what is excluded from the model. A conceptual modelling framework could also be used to help the modeller themselves in understanding the problem.

5.4 Discussion

The outcomes of this qualitative research are generally consistent with the literature in the small number of instances where literature is available. For example, in the study by Chilcott *et al*. on avoiding and identifying errors for the Health Technology Assessment programme, one of the key findings of the study was that the stages of model development within health economic evaluation are not well defined,[17] as was suggested by the modellers within this qualitative research. Within the same study, Chilcott *et al.* suggest that some health economic modellers divide model conceptualisation and model implementation into two stages, whilst others do not distinguish between the two.[17] In general, the modellers within this qualitative research did not distinguish between these two stages. This qualitative research highlighted a number of advantages of conceptual modelling frameworks including helping the modeller and stakeholders understand the problem, facilitating communication between the modellers, other members of the team, decision makers and experts, and helping develop credibility and confidence in the model and its results. These are consistent with research about simulation modelling for operations systems by Robinson *et al.*[1]

The modellers suggested that the model structure would be driven by the interventions being assessed. However, across the themes identified, the modellers were inconsistent with respect to how interventions would be chosen for assessment within the model. They suggested that: (i) the reviewers chose them based upon an evidence review; (ii) experts or decision makers chose them, based upon an evidence review and/or based upon what is considered to be culturally and politically acceptable; and (iii) decision makers specify them given shorter timeframes, but given longer timeframes they may be specified based upon the modelling activity. This suggests that there is substantial variability associated with defining interventions, which the modellers described drives the model structure. Within the literature it is suggested that decisions made by the government and organisations are dependent upon public readiness for the intervention being considered.[163] As such it follows that the decision makers will, as a minimum, be involved in making these decisions if the interventions are controversial. The way in which to choose which options to assess within the model was considered in more depth within the review of conceptual modelling frameworks within Chapter 4.

The modellers describe activities associated with understanding the problem and making judgements about the model structure; however the distinction made between these two activities is less prominent compared with the distinction made within most of the conceptual modelling frameworks reviewed within Chapter 4. In practice, the iterative nature of model development and the lack of a formal process for conceptual modelling may mean that modellers are not conscious of the two different activities.

Modellers are however acutely aware of the time and resource constraints of the project. This is consistent with the literature where the importance of these constraints has been highlighted within the defined purpose of a decision model. Griffin *et al.* state that this purpose is ‘to provide unbiased estimates of expected costs and effects, and of decision uncertainty, in a timely fashion and within resource constraints as determined by the decision-maker that commissions the model.’[164]

The modellers raised many of the issues described within Chapter 2 about the key challenges of Public Health economic modelling, including issues with incorporating relevant costs and outcomes, the relevant perspective and the inclusion of unintended consequences. However, whilst a couple of the modellers touched on the issue of dynamic complexity, it was not apparent that the majority of the modellers had a thorough grasp of the implications of Public Health systems being complex systems and it was not something which they generally reported as a key concern.

There are several outcomes identified within this research which to my knowledge have not previously been raised within published literature. These comprise:

- General requirements of a conceptual modelling framework for Public Health economic evaluation (see Section 5.5; points 1 - 17);
- The identification of specific considerations for modellers of Public Health economic models including:
    - Encouraging understanding of the modelling requirements in other sectors when the scope of the model extends beyond health and wellbeing;
    - Considering whether behaviour is being prevented or delayed;
    - Encouraging reflection upon whether there are other consequences not considered by the effectiveness studies;
    - Considering whether a more exploratory analysis may be more useful given the time and data constraints.

One clear omission from the data collected here is how evidence is used within model development. For example, evidence may be used for a wide range of reasons during the development of the model structure including testing a possible model structure which is based on theory, comparing against other evidence to decide on a model structure, or refining a model structure. Similarly, the modellers did not spend much time talking about how literature for developing model structures is identified. The lack of data in this area is not a result of this not being included within the topic guide, but may be due to the lack of an explicit definable process. Apart from discussions about the effectiveness review and previous Public Health economic models and databases (which were not described further), the data sources used to develop the model structure were not described by the interviewees or the focus group participants. Recently a PhD thesis by Paisley has suggested that modellers tend to begin with high yield sources and develop further searches for evidence based upon these in order to develop their understanding of the problem and the model structure.[63] This is discussed further within Chapter 6. Notably, the modellers did not refer to different types of literature such as Psychology and Sociology sources for facilitating the development of the model structure, as discussed within Chapter 2. The modellers suggested that there is a need to specify what is excluded from the model. Paisley suggests that the scope is defined by what is excluded rather than what is included since what is excluded helps to justify what is included.[63]

As described within Chapter 1, this work follows an interpretivist epistemology and a subtle realist ontological perspective. I have described the systematic methods which have led to the outcomes of this research and reflected upon the possible meanings of the data in order to present a valid and reliable analysis. Although my notes from the Contraception project were written prior to this research, I knew how it was developed and why, and the analysis of these data was systematic. It thus seemed preferable to include this valuable information within the analysis, than to discard it because it was not collected as part of this research. The use of these notes provided additional reflection on developing the model structure within the time and resource constraints of the project, and had the advantage that the notes were not affected by the research project in any way.

The participants involved within the qualitative research were from six different institutions within the UK, and whilst data were not collected to the point at which theoretical saturation was reached due to time and resource constraints, there was substantial resonance between participants on these issues. Thus, the outcomes of this qualitative research should facilitate the development of a conceptual modelling framework which is appropriate for modellers within UK Public Health economic modelling. It may not be possible to generalise this research to other public health decision making jurisdictions outside of the UK because there were no non-UK participants and hence it would be useful to test the conceptual modelling framework developed outside of the UK as further research.

5.5 Chapter summary and implications for methods development

This chapter presented qualitative data collection and analysis to describe modellers' experiences with developing the structure of Public Health economic models and their views about the benefits and barriers of using a conceptual modelling framework. The implications of the qualitative data collection and analysis for the development of the requirements of a conceptual modelling framework are that it should aim to:

1) Be clear about what it can and cannot do;
2) Not constrain the decision making process;
3) Take into account that modellers have different skill sets and encourage modellers to recognise potential skill set biases and moderate impact;
4) Be simple to use in practice and be culturally acceptable;
5) Consider any diagrams developed by other parts of the team on the project;
6) Provide a general outline of the model development process in Public Health economic modelling;
7) Provide a tool for communication with the project team and stakeholders;
8) Consider the trade off between developing an appropriate structure for the problem versus ability to meet deadlines;
9) Help modellers determine appropriate and inappropriate simplifications of the problem;
10) Encourage the use of modelling for helping stakeholders to develop policy recommendations via increasing their understanding of the problem and estimating long term effectiveness, as well as by producing cost-effectiveness estimates.
11) Incorporate the iterative nature of model development between model conceptualisation and data collection. Given tight project timeframes where it is unlikely to be possible to collect more data, it is necessary to think about data availability at an early stage in the process;
12) Highlight the difference between cause and correlation and suggest techniques for disentangling this such as econometric techniques;
13) Facilitate a clear description of the methods for the report to stakeholders, including highlighting ways of communicating what is not in the final quantitative model;
14) Consider, in some form, each of the following: (i) classifying and defining population subgroups of interest, (ii) identifying and defining harms and outcomes for inclusion in the model, (iii) thinking about modifiable components of risk, (iv) specifying the baseline position on policy variables, (v) estimating the effects of changing the policy variables on the risk factors, (vi) risk functions relating to risk factors to harm, (vii) monetary valuation.

15) Include an example to illustrate the methods;
16) Provide a transparent approach for choosing model interventions;
17) Consider a process for searching for evidence to develop the model structure;
18) Encourage the modeller to think about:
    a) Helping decision makers make decisions, as opposed to trying to reproduce reality;
    b) Fully understanding the implications of the structural choices that they make;
    c) At an early stage, developing an understanding of the question and the interventions and the model population and subgroups of interest;
    d) The trade-off between providing stakeholders with something to critique and limiting their thinking;
    e) Evidence requirements;
    f) The most appropriate outcome measure and perspective to report to decision makers;
    g) Heterogeneity and whether there are any appropriate subgroups, including socioeconomic status;
    h) Whether there are other consequences (positive or negative) not considered by the effectiveness studies;
    i) Intergenerational impacts;
    j) Whether behaviour is being prevented or delayed;
    k) The exact meaning of topic specific terminology which also has a lay meaning;
    l) Questioning the assumptions of the experts and decision makers;
    m) The likely cost-effectiveness of the intervention;
    n) Consideration of equity and the social gradient;
    o) The influence of standard methods guidance (eg. NICE methods guide);
    p) The constraints of the project scope;
    q) Use of existing models in the same area;
    r) Understand the modelling requirements in other sectors when the scope of the model extends beyond health;
    s) The choice of experts and the implications of these choices;
    t) The impact of interactions and heterogeneity upon model type;
    u) Aligning the stakeholders' expectations of the process and their requirements with the modellers' expectations;
    v) Whether a more exploratory analysis may be more useful given the time and data constraints.

Chapter 6: Critical reflections upon a diabetes prevention case study

6.1 Chapter outline

A draft conceptual modelling framework was developed based upon the research presented within Chapters 2 – 5. This chapter aims to describe my experience and critical reflections on the use of this draft conceptual modelling framework within a case study assessing the cost-effectiveness of screening and prevention interventions for type 2 diabetes in order to further develop the conceptual modelling framework. Section 6.2 describes the methods of analysis employed within the chapter and Section 6.3 describes a brief overview of the conceptual modelling framework in order to place the reflections upon the diabetes project in context (Chapter 7 presents the full revised conceptual modelling framework resulting from the research undertaken within Chapters 2 – 5 and this critical reflection). Section 6.4 describes the case study around the cost-effectiveness of screening and prevention interventions for type 2 diabetes and Section 6.5 describes my reflections upon the use of the draft conceptual modelling framework within the case study. Finally Section 6.6 summarises the key implications of these reflections upon methods development.

6.2 Methods of analysis

As described within Chapter 1, all of the research undertaken within this thesis follows a cyclical learning process of diagnosis, planning, analysis and reflection. Following multiple cycles of this process, I piloted the draft conceptual modelling framework within a diabetes prevention case study and reflected upon its use in order to develop the framework further. My reflections upon the use of the earlier stages of the draft conceptual modelling framework in some cases led to modifications of aspects of later stages of the framework, through a process of diagnosis and planning, prior to these later stages being tested within the diabetes case study. These were subsequently tested within the case study, followed by further reflection, diagnosis and planning.

The approach taken within this chapter is critical reflection and, as such, the chapter takes a more exploratory perspective. As such, this chapter is written in the first person. However, the reader should note the change in the style of writing within this chapter compared with the preceding chapters. Reflective writing involves a description of the situation and attempts to find meaning within this, supported by ideas and theories.[165] Critical reflection also involves consideration of the broader context associated with the situation. Throughout the chapter, I reflect upon my learning in a systematic way by (1) outlining the relevant guidance within the draft conceptual modelling framework (the data); (2) describing what happened within the diabetes project; and (3) critically reflecting upon this data. The resulting revisions to the conceptual modelling framework are outlined within Section 6.6. To aid the critical reflection I drew upon a list of questions from the book titled 'Practising critical reflection: a resource handbook' by Fook and Gardner.[165]

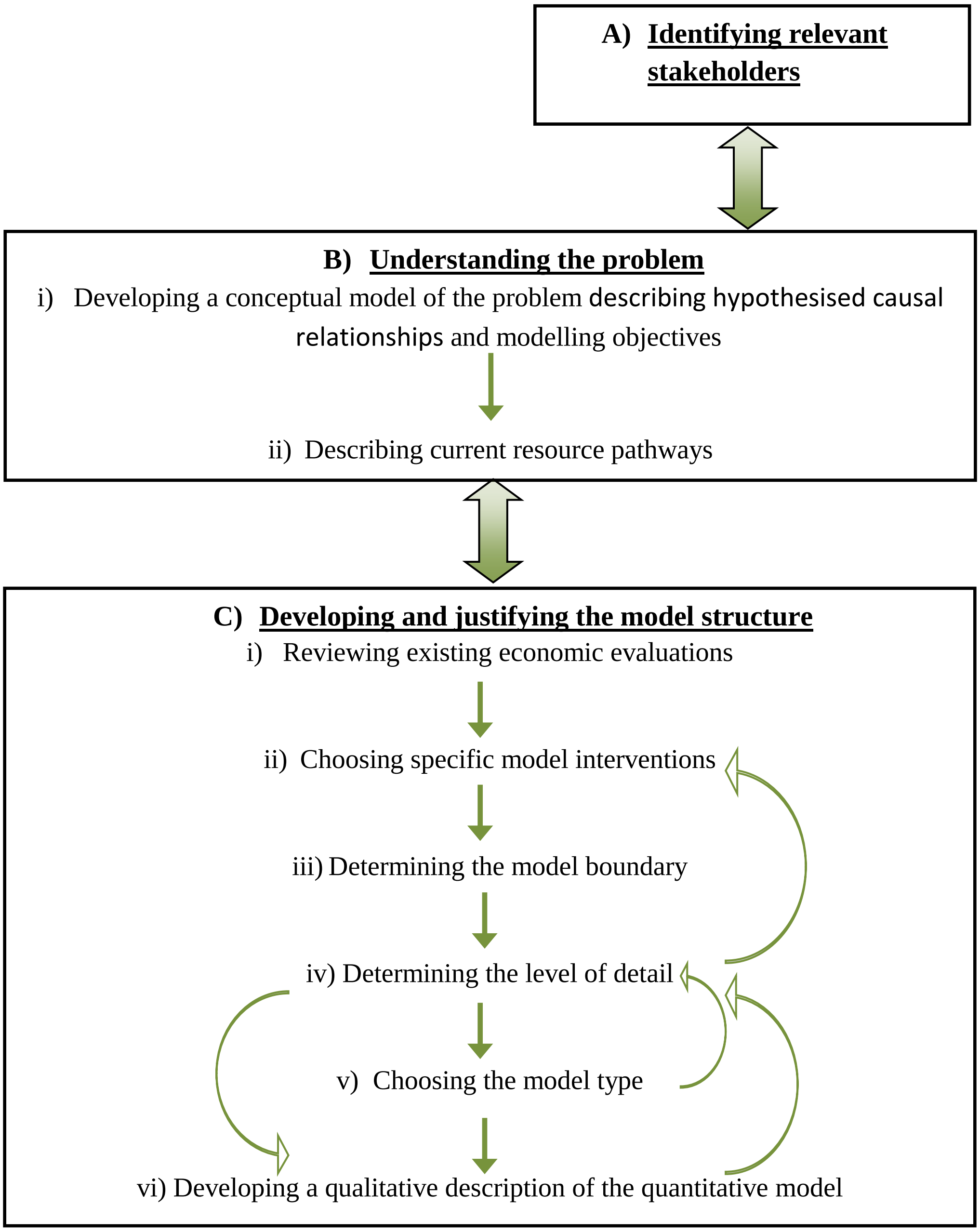
6.3 Brief overview of the draft conceptual modelling framework

A draft conceptual modelling framework was developed based upon the research presented within Chapters 2 – 5. The conceptual modelling framework following revisions based upon the reflections from this case study is described within Chapter 7, along with the justification for each part of the framework. In order to put the reflections upon the diabetes project into context, a brief outline of the draft conceptual modelling framework is required here (although all of the detail is omitted).

The draft conceptual modelling framework comprises four key principles of good practice, a proposed methodology and some suggestions for processes which may be followed if considered appropriate. In order to develop valid, credible and feasible Public Health economic models, the four key principles of good practice are that; (1) a systems approach to Public Health modelling should be taken; (2) developing a thorough documented understanding of the problem is imperative prior to and alongside developing and justifying the model structure; (3) strong communication with stakeholders and members of the team throughout model development is essential; and (4) a systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling.

An outline of the approach described by the draft conceptual modelling framework is shown in Figure 6.1.

Figure 6.1: Overview of draft conceptual modelling framework for Public Health economic evaluation



6.4 The diabetes project

Aims and objectives of the diabetes project

Two diabetes prevention / screening models have previously been developed within ScHARR; one to assess the effectiveness and cost-effectiveness of lifestyle interventions to prevent type 2 diabetes; and one to assess the effectiveness and cost-effectiveness of different screening options for Impaired Glucose Tolerance (raised blood glucose levels) and type 2 diabetes. It is not possible within these models to compare the cost-effectiveness of screening with lifestyle interventions since the models consist of different structural assumptions, particularly relating to the disease natural history of diabetes and its associated complications. Thus, a third diabetes project was proposed to develop a model which is able to compare these interventions in a consistent and appropriate way with the aim of supporting commissioners of Public Health services and other stakeholders in their decision making. This third diabetes project, referred to hereafter as 'the diabetes project', was used to pilot the draft conceptual modelling framework. The diabetes project is a two year project which was funded by the NIHR as part of collaborative research between eight leading academic centres in England within the NIHR School for Public Health Research.

Why use this project as a case study?

This project was chosen for its suitability and its timing relative to this research. A key part of the project involved conceptualising the model structure and it began at the point when I had developed a draft conceptual modelling framework. Some of the features of the diabetes project are different to the other key Public Health research projects that have contributed to the development of the draft conceptual modelling framework including the Contraception Project and the Walking and Cycling project.[166;167] For example, there is greater data availability and there are a substantial number of existing health economic models assessing diabetes prevention and screening interventions. In addition, the project proposal was developed by modellers based upon previous research rather than the requests of specific decision makers. Thus, there was more flexibility in terms of the project process compared with some decision making arenas and it was our responsibility to identify all stakeholders. These differences were beneficial because it facilitated consideration of whether the conceptual modelling framework is sufficiently flexible for a variety of types of problems and decision making arenas.

The diabetes project continues until March 2014; however the main part of the conceptual modelling had been completed by March 2013. The draft results of the model will be discussed at the third stakeholder workshop in January 2014. The intention of this case study is not to consider the impact of the conceptual modelling framework upon the model results, but to reflect upon the use of the framework for developing the model structure.

Key documentation developed during the project

The data associated with the critical reflection, including the conceptual modelling protocol and discussion documents for stakeholders, are shown in Appendix D and these are referred to where appropriate throughout the chapter.

Key roles within the diabetes project

My role within the diabetes project was to undertake the conceptual modelling using the draft framework. The rest of the project team consisted of two project leads who jointly managed the project, an expert in diabetes modelling who had developed the previous two ScHARR type 2 diabetes models and provided advice throughout model development, an information specialist who undertook the literature searches and reviewed the literature, and a health economic modeller who began working on the project after the first six months in order to undertake the review of economic evaluations of diabetes screening and prevention and to develop the mathematical model.

A group of stakeholders were recruited to provide advice throughout model development. Two stakeholder workshops were held: (1) to discuss the understanding of the problem and (2) to discuss the development and justification of the model structure. Table 6.1 shows the stakeholders involved within the project and whether they attended the stakeholder workshops.

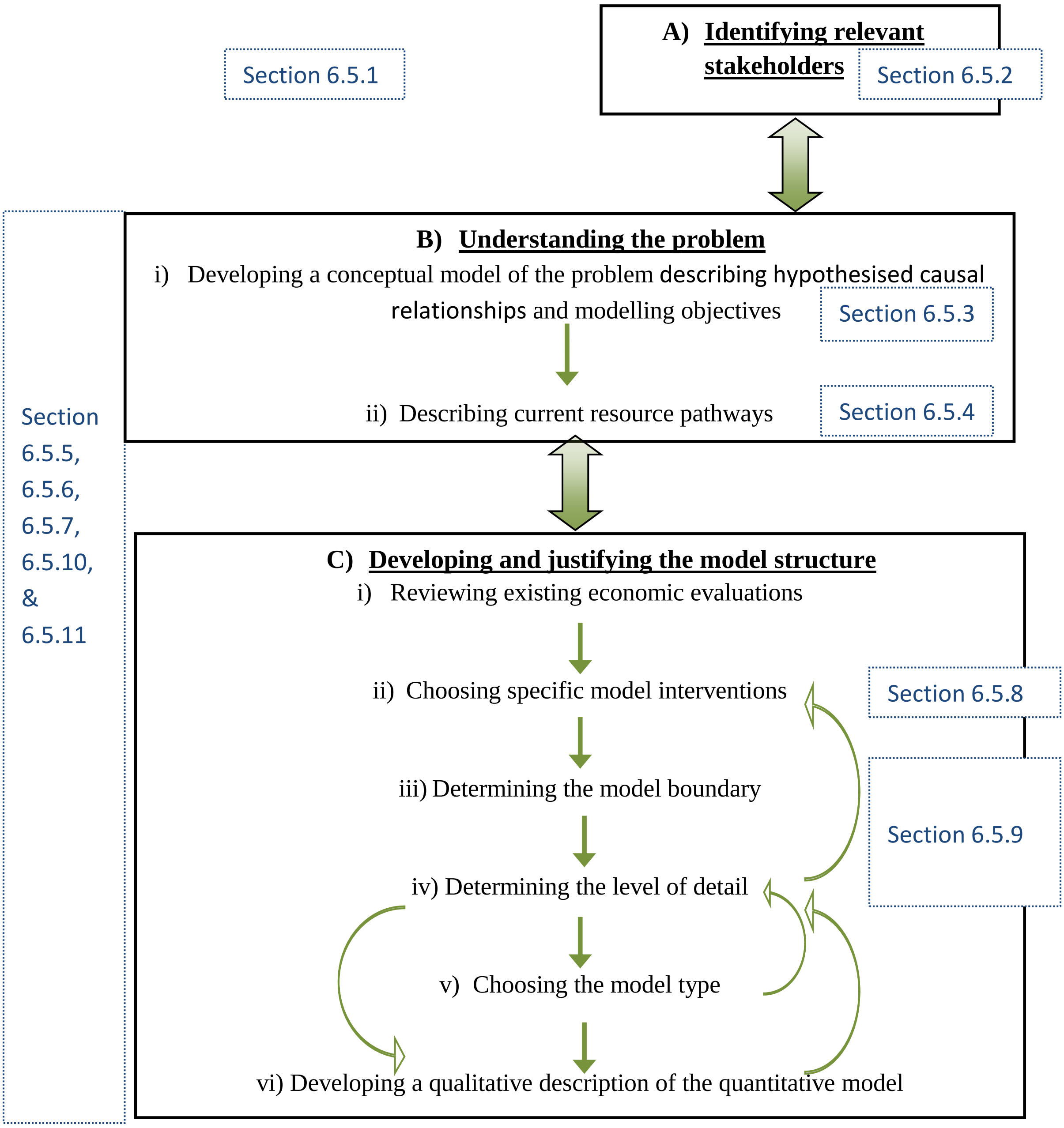
Table 6.1: Description of stakeholders involved in the diabetes project

Description of stakeholder	**Attended workshop**	
	1	**2**
Initially a GP. Currently based in academic research of Public Health interventions. Has a diabetes background and interested in screening & prevention.	Yes	Yes
Previously Director of Public Health in North Eastern Derbyshire. Now based in academic research into the effectiveness and cost-effectiveness of Public Health interventions.	Yes	Yes
Lead commissioner in a Doncaster PCT.	Yes	No
GP in Sheffield with a special interest in diabetes. PCT diabetes lead.	Yes	Yes
Type 2 diabetic. Had bariatric surgery 4 years ago, but put weight back on. Is currently diet rather than insulin controlled. Member of many local and national patient groups.	Yes	Yes
Type 2 diabetic. Involved in patient groups for 7 years. Described himself as GP's worst patient because he has spent many years not adopting the lifestyle changes advised.	Yes	Yes
Health psychologist specialising in diabetes, obesity and CVD.	Yes	No
Consultant specialising in diabetes.	No	Yes
GP specialising in diabetes and obesity.	No	Yes
Clinical specialist in diabetes and obesity.	No	Yes
Clinical specialist in cardiovascular disease and stroke.	No	Yes
Clinical specialist in cardiovascular epidemiology.	No	Yes
Clinical lecturer in diabetes.	No	Yes
Professor of clinical diabetes.	No	Yes
Statistician specialising in longitudinal data analysis.	No	No
Professor of Health Economics currently undertaking research on diabetes prevention.	No	Yes
Researcher evaluating key diabetes prevention studies.	No	Yes

6.5 Critical reflections upon the use of the draft conceptual modelling framework

The critical reflection of the use of the draft conceptual modelling framework is described below. To illustrate which stage of the conceptual modelling framework the reflection is relevant to, the section numbers have been added to the outline of the draft conceptual modelling framework in Figure 6.2 below.

Figure 6.2: Outline of process for developing the model structure within Public Health economic modelling prior to modifications resulting from the diabetes case study



6.5.1 Aligning the framework with the decision making process

Relevant guidance from the draft conceptual modelling framework

Different potential options around process within the conceptual modelling framework are outlined throughout so that the modeller can consider, subject to agreement with the project team and stakeholders, the most appropriate process for developing the model structure. There is no phase within the framework for outlining how it will be employed within the particular project context.

What happened within the diabetes project

Within an initial meeting with the project leads about the project plan (w/c 14/05/12), we discussed how the draft conceptual modelling framework would be used within the diabetes study. The project lead subsequently requested a protocol outlining the project plan which was developed using the draft framework as a basis (w/c 30/07/12) (see Appendix D1 for protocol).

Critical reflection

The draft conceptual modelling framework outlines a methodology with generic scalable processes which can be adapted according to the decision making process and requirements. Reflecting upon the discussion with the project leads, there is a generic need at the start of a project to define the processes according to the project requirements and constraints in order to develop a project plan. Outlining this within a protocol document meant that the project leads could ensure that the project was planned to run appropriately and the project team knew what work needed doing throughout the project and could refer to the timescales and deadlines throughout. Key process decisions that were made during this phase relate to the frequency and timing of stakeholder workshops, the focus of formal literature searches, and the time and resources available for each step of the framework. The constraints of time and resources were also identified within the qualitative research in Chapter 5 as key impacts upon the modelling process, yet these constraints are not explicitly considered within existing conceptual modelling frameworks.

6.5.2 Choosing stakeholders

Recruiting stakeholders

Relevant guidance from the draft conceptual modelling framework

The draft conceptual modelling framework suggests the types of stakeholders to involve to provide advice throughout the project, including customers (patient representatives, lay members), actors (methods experts, clinical and epidemiologic experts) and system owners (policy experts), but it does not suggest how to recruit these stakeholders.

What happened within the diabetes project

Within the diabetes project, stakeholders were identified based upon existing relationships with the project leads, previous NICE PDG members, advice from a diabetes modeller within the project team and searches for specific types of stakeholders on the Internet. I sent emails to potential stakeholders describing the project and what we would require from them in terms of expertise and time (see Appendix D2 for an example email). The majority of the stakeholders recruited within the diabetes project were those who had existing professional relationships with one or more members of the project team. It was much more difficult to recruit experts who did not have a connection within the team.

Critical reflection

Within the diabetes project when recruiting stakeholders I was depending upon altruism or upon experts thinking that they would benefit from their contribution in some way. Checkland discusses the importance of stakeholder worldviews within Soft Systems Methodology (described within Chapter 4).[123] He suggests defining the worldviews of each stakeholder in order to understand conflicts between stakeholders. Upon reflection it may have been useful to understand more clearly the possible worldviews and motivations of each of the potential stakeholders in order to inform the mode of engagement with them. Potential stakeholders may be more willing to be involved if the initial request is phrased in a way which aligns the aims of the project with the expected motivations of the stakeholders. For example, some stakeholders may be more interested in the outcomes of the project than the methods being employed so the initial information provided could describe the potential outcomes of the project. Another potential approach is for a more senior colleague involved in the project who is renowned in their field to contact the experts, potentially raising the prestige of the project and increasing the perceived benefits to the expert of being involved.

Choice of lay members

Relevant guidance from the draft conceptual modelling framework

The draft conceptual modelling framework describes the types of stakeholders to approach. It is suggested that lay members should be involved to ensure that views and experiences of the wider public inform the work.

What happened within the diabetes project

The lay members of the stakeholder group volunteered for the role after contact via Diabetes UK. Both lay members involved within the diabetes project are white, retired/ semi-retired men who are also lay members for a number of other diabetes projects.

Critical reflection

The perspectives provided by the lay members do not necessarily represent those of all diabetes patients/ the general population. In particular, they do not represent the more vulnerable groups within society who are unlikely to volunteer for such a role.[168] Importantly for the diabetes project, they also do not represent ethnic minorities, some of which tend to have a different disease natural history to white British people. If these relevant groups are not represented, then the views and experiences of the wider public may not be heard by the stakeholders and project team. This could lead to unrealistic assumptions about a particular subgroup of the population who behave differently to those represented within the stakeholder group. In addition, according to the theory associated with complex systems discussed within Chapter 3, social networks might impact upon the effectiveness of the interventions. The social networks of those people who are most vulnerable in society are different to those who participate in research, and as a result the interventions are often less effective within these vulnerable groups. By definition 'hard to reach groups' are not easily accessible, but their input is likely to improve model validity.

6.5.3 Use of a causal diagram and associated questions to develop the understanding of the problem

Terminology associated with the causal diagram

Relevant guidance from the draft conceptual modelling framework

The development of a diagram describing the understanding of the problem by representing hypothesised causality is proposed within the framework.

What happened within the diabetes project

During a meeting reviewing the material for the first stakeholder workshop (w/c 17/09/12), Project Lead 1 highlighted that the 'causal diagram' does not necessarily only include causal relationships at this stage. This intermediate stage was also suggested by one of the modellers within the qualitative research (see Chapter 5). As a result, the name of the diagram was changed to 'problem-oriented conceptual model' as defined by Kaltenthaler *et al.*[14] Subsequently, the information specialist/

reviewer on the project team suggested that this term might be too technical for stakeholders, so this was further revised to 'conceptual model of the problem'.

Critical reflection

The review of conceptual modelling frameworks described within Chapter 5 suggests that the term 'conceptual model' has a range of meanings and studies are inconsistent.[8;14;17;123;126] The term 'conceptual model of the problem' was used within the discussion document for the diabetes case study with an aim of being explicit about what the conceptual model represented. Upon further reflection there is an advantage of using the term 'causal' to be more informative about the aim of the diagram, whilst recognising that the analysts will not know whether the factors are truly causal at this stage. Thus, it would be more explicit to use the term 'a conceptual model of the problem describing hypothesised causal relationships'.

Describing the disease natural history

Relevant guidance from the draft conceptual modelling framework

No information is provided within the draft conceptual modelling framework around how to incorporate disease natural history.

What happened within the diabetes project

When developing the conceptual model of the problem within the diabetes case study (see Appendix D3), moving from normal blood glucose levels to having diabetes is not causally related. I therefore represented the disease natural history by arrows from risk factors to blood glucose levels (divided into 'Impaired Glucose Regulation' and 'diabetes') since these are causally related.

Critical reflection

Transitioning from a 'normal' state to the first stage of disease is not directly causally related, but affected by behaviour. As such the causal chain can show the relationship between the behaviour and the disease. Within the diabetes case study, a decrease in physical activity might lead to an increase in blood glucose levels. Following the onset of disease, the disease natural history can be described by probabilistic causation. For example, somebody with impaired glucose regulation has an increased probability of developing diabetes.

Representation of time within the conceptual model of the problem

Relevant guidance from the draft conceptual modelling framework

There is no explicit discussion of how time should be incorporated into the conceptual model of the problem within the draft conceptual modelling framework.

What happened within the diabetes project

Within a meeting before the first workshop (w/c 10/09/12), project lead 2 said that he felt that there was insufficient consideration of time within the conceptual model of the problem, in particular in relation to the disease natural history of diabetes. Since blood glucose levels are on a continuous scale, the trend over time was not captured diagrammatically by causal arrows in the same way as if the disease states were discrete categories. Thus, a small graph was included within the diagram to show blood glucose levels over time (See Appendix D4).

Critical reflection

One of the reasons for developing the conceptual model of the problem is for communication with the project team and the stakeholders. Thus it is important that all relevant issues are clear within the diagram. Experience from the diabetes project suggested that where the disease natural history is not depicted by discrete health states, additional graphical representations are helpful. In addition, literature around causal diagrams for system dynamics models suggests that time lags between discrete factors can be highlighted by adding the term 'delay' to the arrows if there are substantial time delays between cause and effect.[89]

Describing the impact of the determinants of health upon the decision problem

Relevant guidance from the draft conceptual modelling framework

In order to facilitate development of the conceptual model of the problem, a number of questions are proposed for the modeller. One of these questions is:

'*Are the following determinants of health (taken from Dahlgren and Whitehead*[28]*) important in determining outcomes and in what way:*

- *Age, sex and other inherent characteristics of the population of interest?*
- *Individual lifestyle factors?*
- *Social and community networks?*
- *Living and working conditions and access to essential goods and services?*
  (including unemployment, work environment, agriculture and food production, education, water and sanitation, health care services and housing)

- *General socioeconomic, cultural and environmental conditions?*'

What happened within the diabetes project

During the understanding of the problem phase, age, sex, ethnicity and family history of diabetes were incorporated as well as physical activity, diet, BMI, smoking, use of antihypertensive therapy, use of corticosteroids, diagnosed CVD and waist circumference. 'Risk factors of the next generation' were also included which is one aspect of social and community networks, but other aspects were ignored at this stage. Social networks were reconsidered and excluded at the justifying the model structure phase due to insufficient evidence and resources within the project. No factors were included during the understanding of the problem phase regarding *'living and working conditions'* and only the risk factor Townsend Score was included in terms of *'general socioeconomic, cultural and environmental conditions*' (see Figure C4 within Appendix D3). The main reason for the inclusion of some of these factors and not of others is because I had identified several risk equations associated with diabetes and recorded the factors included within these in the conceptual model of the problem. Therefore, at the time of answering the questions within the conceptual modelling framework, I thought that the factors included within the risk equations were sufficient. However, the risk equations were developed in order to easily identify whether a person is at high risk of diabetes rather than to identify all of the determinants of health associated with diabetes incidence. Thus, variables tested for inclusion within the equations tended to be those which could be easily obtained from the patient or their records. This means that there could be additional factors which would affect outcomes which are not captured by the individual characteristics of the person.

Critical reflection

To some extent I had a natural tendency to exclude the broader determinants of health such as social networks from the conceptual model for ease of modelling. A systematic consideration of the social determinants of health is one of the four key principles of the framework because of the importance of these upon outcomes. However, as discussed within Chapter 3, currently these are generally not included within economic evaluations, which is likely to be due to modellers applying the same thinking from modelling clinical interventions to Public Health interventions. Even if time and resource constraints prevent inclusion of the broader determinants of health within the model, the conceptual model of the problem should capture these so that the exclusion of the factor and the reason for exclusion is transparent.[1] Thus, it is worth noting this tendency so that modellers can be aware of it when developing the conceptual model of the problem.

There are so many determinants of health that it is unlikely to be feasible to capture all of them which have a minor impact upon the problem. However, it is important to understand which determinants of health are key drivers of the problem in order to appropriately estimate the difference in costs and effects between the interventions given the dynamic complexity of Public Health systems (see Chapters 2 and 3). This could be facilitated by a literature search based upon relevant theory associated with the problem.

In addition, there are a substantial number of questions to facilitate the development of the conceptual model of the problem and conceptual model development is iterative (as highlighted within Chapters 4 and 5). There is therefore a risk when first answering these questions that they will not be addressed in sufficient depth and so revisiting them throughout development is likely to be useful.

Using the determinants of health to describe the relationship between the interventions and the decision problem

<u>Relevant guidance from the draft conceptual modelling framework</u>

Within the draft conceptual modelling framework, the problem and its consequences are identified and subsequently the types of interventions which might be assessed within the model are incorporated into the conceptual model of the problem. Any potential consequences of the interventions not already included within the conceptual model of the problem are then incorporated. There is an implicit assumption that the impact of the interventions upon the problem can be assessed directly and there is no discussion around the reported outcomes of the interventions or the determinants of health at this stage within the draft conceptual modelling framework.

<u>What happened within the diabetes project</u>

Within the discussion document for Stakeholder Workshop 1, I related BMI to blood glucose levels/ diabetes, but not behavioural outcomes such as fruit and vegetable intake or increases in physical activity (see Appendix D3). When looking at some of the intervention studies, it became clear that BMI and diabetes outcomes were rarely reported, and that most studies reported changes in behaviour. This was also raised within the first stakeholder workshop. Thus the understanding of the problem was expanded to capture these behaviours (see Appendix D4).

Critical reflection

Economic evaluation, as defined by Drummond, is 'the comparative analysis of alternative courses of action in terms of both their costs and consequences'.[2] This definition highlights that the key focus is the alternative courses of action. This is echoed by the findings from the qualitative research within Chapter 5 which suggests that modellers view the purpose of model development to be to help decision makers make decisions about the alternative options, as opposed to trying to reproduce reality. Thus, the factors included within the model should be driven by the interventions being assessed. As such, it is important that the understanding of the problem is sufficiently broad to capture all of the factors associated with the interventions which might be included within the model. Where the outcomes described within the conceptual model of the problem are not those presented within the intervention effectiveness studies, then the additional causal chains associated with the reported outcomes need to be described.

Chapter 3 highlights the importance of social structure upon the effectiveness of an intervention, suggesting that the effects of an intervention should be assessed by considering the impact of the environment and the interaction between the intervention and subsequent behaviour. The determinants of health might be associated with the interventions in a number of different ways. I have divided this into three alternative ways by reflecting upon the diabetes case study and considering whether this is applicable for the other Public Health projects I have worked on. The determinants of health: (1) could be modifiable with the intervention; (2) could define the population for the intervention (including subgroups which may reflect equity considerations); and/or (3) could indirectly affect intervention effectiveness. These are shown in Table 6.2 with examples of each based upon the diabetes case study.

Table 6.2: Implications of the determinants of health

Determinant of health	There is potential for the determinant of health to...		
	Be modifiable with intervention	Define the population for intervention	Indirectly affect intervention effectiveness
Age, sex and other inherent characteristics of the population of interest	No	Yes (eg. South Asians)	No
Individual lifestyle factors	Yes (eg. diet advice)	Yes (eg. BMI > 30)	Yes (eg. BMI reduction might increase smoking)
Social and community networks	Unlikely	No	Yes (eg. obese people with obese social networks are less likely to lose weight)
Living/ working conditions and access to essential goods and services	Yes (eg. workplace meals)	Yes (eg. factory workers)	No
General socioeconomic, cultural and environmental conditions	Yes (eg. fiscal policy)	Yes (eg. low SES)	No

Using the existing 'knowledge' of the project team

Relevant guidance from the draft conceptual modelling framework

The draft conceptual modelling framework does not explicitly describe how to deal with the existing 'knowledge' of the project team.

What happened within the diabetes project

Several of the diabetes project team had previously worked on diabetes projects and had knowledge of varying levels. This existing knowledge was used to identify relevant stakeholders and evidence and to internally validate each stage of the model development prior to it being circulated to stakeholders. However, other than a report to NICE outlining the existing work, this knowledge was not recorded at the start of the project. Any preconceptions of the project team associated with diabetes were not recorded prior to developing the understanding of the problem.

Critical reflection

Within an interpretivist perspective, it is important for the researcher to recognise their initial assumptions, or 'conceptual baggage',[169] in order to consider the impact of them upon interpretations during the research. This theory can be applied to developing the understanding of the problem. Within Public Health it is likely that the project team may have some 'knowledge' about the subject. For example, this may be based upon personal experience, media coverage or previous research. Some of the ‘knowledge’ that the diabetes project team had was quite dated because they had worked on diabetes for a long time and they were slow to move away from established views and respond to new evidence which provided a fundamental shift in how the disease is considered. Checkland describes the importance of worldviews and the dominance upon our thinking of unquestioned worldviews.[123] He suggests that the human mind is more likely to explain new information which is inconsistent with what we know by slightly revising theories rather than making a fundamental shift in our worldview, as was indicated within the diabetes project. This is consistent with several Psychology theories including anchoring, selective perception and confirmation bias.[96] There is thus a need for the project team to question each other’s assumptions throughout the conceptual modelling process. It is important for the modeller to be ready to acknowledge that the beliefs that they had about the system may not be the most appropriate and be willing to alter fundamental assumptions according to new evidence.

6.5.4 Describing current resource use

Relevant guidance from the draft conceptual modelling framework

The draft conceptual modelling framework suggested that resource use should be identified during the understanding of the problem phase. The justification for this was that if stakeholders are meeting, it is a good opportunity to investigate resource use in practice as this can be quite different to that described within the literature. In addition, some knowledge about resource use can help to decide whether specific factors within the diagram can be excluded or should be included.

What happened within the diabetes project

In practice, when developing the discussion document for circulating to stakeholders prior to Stakeholder Workshop 1 (see Appendix D3), it was necessary to establish the general resource processes (for example, diabetes diagnosis and treatment pathways) prior to being able to describe detailed resource use (for example, the amount of each drug provided for diabetes patients). In addition, it seemed inefficient to include detailed information about resource use for each factor within the understanding of the problem phase given that some of the factors may be excluded from the model.

Critical reflection

The general resource processes associated with key components of the conceptual model were described during the understanding of the problem phase and detailed resource use was described during the developing and justifying the model structure phase. The conceptual modelling framework by Kaltenthaler et al., described within Chapter 4, suggests that service pathway models should be developed to describe resource use as part of the problem-oriented conceptual modelling. Service pathway models are flow diagrams of a service with an accompanying textual description that do not describe detailed resource use.[14] This is consistent with the way resource use was described within the diabetes project.

6.5.5 Working with the information specialist to develop the searches

Relevant guidance from the draft conceptual modelling framework

The draft conceptual modelling framework suggests that literature reviews should be undertaken to inform the understanding of the problem and the model structure, but it does not explain how this should be done.

What happened within the diabetes project

A key consideration within the diabetes project was how to describe the disease natural history for which we undertook a literature review. The search was poorly defined because initially we did not have a clear understanding of the types of literature available and what the disease natural history might include. Following a project team discussion of what we initially thought we wanted to achieve, the information specialist undertook some general searching and retrieval of potentially relevant papers. Based upon the content of the papers identified, I suggested a slightly more well-defined specification for the next iteration. The information specialist and I continued to meet regularly, during which I suggested the focus for the next search based upon the literature she had identified. In this way, I constructed an iterative series of predefined search questions, which gradually became more specific, for the information specialist.

Critical reflection

It is not standard practice for the information specialist to help the modeller with the searches for developing the understanding of the problem and the model structure. The PhD thesis by Paisley defined the requirements of a search approach for evidence for developing the model structure.[63] She suggests using 'search techniques that focus on efficiency and maximising the retrieval of relevant information, gathering information a bit at a time from a complex search environment and taking into account the dynamic nature of relevance decisions characteristic of the model development process.'[63] However, the research by Paisley did not define particular strategies or techniques for doing this.

The approach taken within the diabetes project required adjustments in working for both the information specialist and the modeller. For the information specialist, the established methods for reviewing effectiveness evidence are based upon a pre-defined search question.[61] Thus, for the purposes of developing the model structure, the information specialist needed to adopt a new way of thinking and learn new skills to work in a way where they are constantly changing and refining the search according to the evidence identified. It is currently a more challenging way of working for the information specialists because the methods are not fully developed and there is no shared language for these types of searches.[63] In addition, modellers are accustomed to undertaking searches to inform the model structure themselves, although often not transparently or systematically.[63] Thus, I found it difficult not to carry out quick searches whilst I was developing my understanding of the problem. This may also be because of the complexity and subtlety associated with choosing what is relevant and the difficulty in relaying this to another person, and in doing this within a time constrained process.

Paisley highlights the importance of applying information theory in developing information retrieval techniques.[63] Information foraging theory suggests that information retrieval is a set of activities leading to another higher level goal.[63] In this case, the higher level goals are to develop a conceptual model of the problem and subsequently to develop a model structure. The modeller has greater knowledge about the higher level goal, whilst the information specialist holds the searching expertise. Thus, it follows that within the diabetes project information gathering was mainly undertaken by the information specialist whilst information processing was undertaken by both the information specialist and the modeller because this is where the expertise lay.

As discussed within the qualitative research in Chapter 5, time constraints are an important factor when developing a model. The iterations between the systematic reviewer and the modeller are likely to increase the time required for the search. Methods for reducing these iterations such as the modeller and the information specialist working together in real time to identify appropriate search strategies might be useful. In addition, the modeller could undertake searches, providing that they are systematic, meaning that the search should be documented and that the modeller must reflect upon what has been found by the search and the process taken so that alternative potential theories or findings are considered rather than focusing upon the first theory or type of findings identified.

6.5.6 Stakeholder consensus

Relevant guidance from the draft conceptual modelling framework

Within the draft conceptual modelling framework there is no guidance for modellers around how to deal with conflicting advice from stakeholders.

What happened within the diabetes project

Within the diabetes project, generally the stakeholders were in agreement, however where there were disagreements the general consensus was described within the conceptual model of the problem. This approach was not explicit when presenting the diagram. I did not describe where stakeholder consensus was reached and where only one person had suggested an idea.

Critical reflection

There was a natural tendency to limit the understanding of the problem by capturing only those aspects for which there was no disagreement, so that the full set of complexities and nuances were not recorded. For transparency, it could be argued that it is most appropriate to develop the full understanding of the problem with all of the uncertainties associated with this understanding, and then reduce the set of relevance when defining the model structure (as suggested by the first principle of good practice within the draft conceptual modelling framework). However, according to Russo and Schoemaker, too many ideas can lead to information overload for participants.[170] Thus, there is a balance between discussing convergent views and limiting the number of ideas so that they are manageable during communication with stakeholders. Within Strategic Options Development and Analysis (SODA), a problem structuring methodology employing stakeholder workshops, described within Chapter 4, the first stage of the workshop is described as divergent and the second stage as convergent.[139] This means that the key uncertainties can be explored but it is the crucial concepts and issues that are eventually described.[44] This echoes theory from the Delphi approach,[171] also described within Chapter 4, which suggests that the discussion between experts encourages stakeholders to consider issues and perspectives which they may not have previously considered themselves and stakeholders may then revise their perspectives as a result of the discussion. Thus, the theories associated with these methodologies suggest that stakeholder views are likely to generally converge after ideas are shared and thus divergent views will be reduced. Practically, there is a trade off between covering all relevant topics and providing sufficient time to discuss disagreements and explore new ideas within the workshop.

6.5.7 Difficulties with setting up the stakeholder workshops

Relevant guidance from the draft conceptual modelling framework

No guidance around setting up the stakeholder workshops was provided within the draft conceptual modelling framework.

What happened within the diabetes project

Setting up the first stakeholder workshop was time consuming. Many of the stakeholders were busy months ahead by virtue of being so highly regarded in their area. After the date was agreed, some stakeholders who had said they could attend chose not to at a later date due to other priorities. Those stakeholders who said they would like to be involved but could not attend the workshop were asked if they were available to video/ teleconference for any part of the workshop, and if not, they were asked to provide feedback on the discussion document prior to the workshop. A meeting was also held with one of the diabetologists to discuss the key issues when he was visiting Sheffield.

Critical reflection

The variety of approaches for involving stakeholders, whilst relatively time consuming, allowed a range of views to be incorporated which otherwise may have been ignored. It is thus important to have more than one way of communicating with stakeholders and to be flexible with the approach.

6.5.8 Choosing interventions

Relevant guidance from the draft conceptual modelling framework

The draft conceptual modelling framework included a stage for choosing model interventions based upon discussion between stakeholders and the project team of the effectiveness review findings.

What happened within the diabetes project

It was difficult to define the boundary for the effectiveness review due to the broad range of interventions which could potentially be considered within the project scope and the large number of studies available. Several iterative search strategies were used and the results were presented within stakeholder workshops. Stakeholders were more forthcoming to identify interventions that were not included within the review than to limit the interventions being considered. Thus, in order to reduce the interventions to a manageable number, based upon the workshop discussion the project team divided the interventions into key categories and then specified a particular intervention to assess within each category. The excluded interventions from each category were also listed so that stakeholders could subsequently propose alternative interventions for each category without increasing the number of interventions considered, until a set of interventions were agreed.

Critical reflection

As identified within Chapter 4, the current approach for choosing which specific interventions to assess within the model is not well defined, and this is variable between projects. Ultimately, the model is being developed to help decision makers make judgements about which interventions to provide. Thus it seems appropriate for these decision makers to determine which interventions to consider within the model if possible, based upon evidence reviews and input from other stakeholders. As the diabetes project illustrates, it may not be possible to review systematically the effectiveness of all types of potentially relevant model interventions and stakeholders may be reluctant to limit the interventions assessed.

6.5.9 Model boundary and level of detail

Relevant guidance from the draft conceptual modelling framework

The draft conceptual modelling framework describes in the text potential considerations when defining the model boundary and level of detail.

What happened within the diabetes project

After undertaking the conceptual modelling of the problem, I began to consider how to convey to the rest of the project team the next steps of the conceptual modelling framework, without everyone needing to read the draft conceptual modelling framework. I developed a diagram depicting how the reviews feed into the model boundary, level of detail and model type and also a flow diagram for helping to define the model boundary and a box of key considerations for the level of detail. I described these during meetings on 20/11/12 and 11/12/12.

Critical reflection

There is a lot of text within the conceptual modelling framework throughout the developing and justifying the model structure phase and this is not particularly accessible for the project team or stakeholders. As described by the adage ‘a picture is worth a thousand words’, a flow diagram or box describing a summary of the suggestions within the text provided a more accessible way of highlighting the key considerations when conceptualising the model structure.

6.5.10 Stakeholder workshops

Content of workshops

Relevant guidance from the draft conceptual modelling framework

The conceptual modelling framework proposes holding workshops with stakeholders if time and resource constraints allow. However, no guidance about the content of the stakeholder workshops was provided.

What happened within the diabetes project

When developing the diabetes project plan, through discussions with the project leads (w/c 14/05/12) it was agreed that there was sufficient time and resources available to hold stakeholder workshops. I proposed that we should hold three workshops during the project. The first workshop was held within the first few months of the project (05/10/12) to discuss the understanding of the problem, the types of interventions and populations to consider, potential model perspectives and outcomes and resource pathways. The second workshop was to discuss the review of the effectiveness evidence, the model boundary and the key model assumptions (07/03/13). The final workshop will be to discuss the draft model results (in January 2014).

Critical reflection

The decision about the number of workshops to hold during the project was based upon a balance between providing contact with stakeholders at each significant stage of the model development process and minimising the amount of stakeholders' time required, and the two workshops for conceptualisation worked well. The outcome of the discussion around model perspectives, outcomes, potential interventions and populations within the first workshop had the potential to substantially expand the requirements for the modelling. This is because it was initially anticipated that a NHS and PSS perspective would be appropriate, whilst the stakeholders suggested that a societal perspective should be employed, with a breakdown of other outcomes presented. The interventions being considered were also broadened. As a result of the discussion, it was necessary to expand the conceptual model of the problem. Moreover, the model boundary is dependent upon these decisions and if these issues were not discussed at this stage, subsequent modelling decisions would either be delayed or are likely to be incorrectly specified. In addition, these discussions may have encouraged participation by all stakeholders within discussions about the model structure.

Resource requirements

Relevant guidance from the draft conceptual modelling framework

No guidance about the resource requirements of the stakeholder workshops was provided within the draft conceptual modelling framework.

What happened within the diabetes project

The workshops were run by four members of the project team; two gave brief presentations throughout to remind stakeholders of key points from the discussion document and facilitated group discussions; whilst two took notes of the discussions, timed the sessions and wrote the feedback from group discussions onto a whiteboard. Where diagrams or tables were used, these were printed on A3 and handed out to each group so that they could scribble and make notes on them.

Critical reflection

The resource requirements during the workshops were substantial, with four members of the project team playing important roles in running the workshop. This high level of involvement was necessary in order to maintain engagement with the stakeholders, record what was said and process and collate information developed during the workshop to share with the group later within the meeting. The A3 diagrams were a useful tool which encouraged the stakeholders to share ideas and make immediate modifications. It also provided a good record of the suggestions which had been made by the stakeholders.

Introductions within Stakeholder Workshop 1

Relevant guidance from the draft conceptual modelling framework

No information is provided within the draft conceptual modelling framework around introductions of each of the stakeholders within the first workshop.

What happened within the diabetes project

Before the first workshop project lead 2 suggested that it would be useful to allow a substantial amount of time for stakeholders to introduce themselves. Within the workshop, reflecting upon the ideas of different stakeholder worldviews within Soft Systems Methodology,[123] project lead 1 explained that we wanted people to spend 2-3 minutes introducing themselves in order to describe their perspective, what they thought they could give to the project and what they would like out of their involvement.

Critical reflection

Drawing upon Checkland,[123] the worldviews described within the diabetes project allowed us to:

- Explore different views and the reasons for these between the stakeholders within workshops.
- Identify concerns which may not otherwise have been identified. For example, the issue of equality of patient access was raised by two of the stakeholders within their worldviews, which may not otherwise have been identified.
- Assess the stakeholders' potential contribution towards the project rather than our expectation around what they may be able to input.
- Identify who it may be most appropriate to contact to ask specific questions or for clarifications outside of the workshop setting.
- Put what the stakeholders say into the context of their worldview so that any assumptions about the world can be more easily identified.
- Ensure that future workshops and correspondence aims to address the aims and motivations of the stakeholders so that they remain engaged within the project.

They also encourage each stakeholder to feel valued and give each stakeholder chance to talk in order to promote later involvement in discussions.[123]

6.5.11 Response to the use of the conceptual modelling framework by the project team

Relevant guidance from the draft conceptual modelling framework

The draft conceptual modelling framework aimed to be flexible within different decision making processes and to accommodate modellers' preferences because the qualitative research within Chapter 5 suggested that the framework should be sensitive to the time available and the processes followed within the decision making process.

What happened within the diabetes project

One of the project leads who is a health economic modeller implied that he would like to see analysis of datasets at an earlier stage in the project, alongside the understanding of the problem stage, which contravenes one of the key principles of good practice outlined by the framework. The project lead showed some discomfort with the principles and methods of the conceptual modelling framework being followed.

Critical reflection

Within the qualitative research, described within Chapter 5, a finding was that some modellers do not like to follow a specified method for model development. However, this is a larger issue than the one described within the qualitative research as the modeller was not only reluctant to follow the principles and methods of the framework, but he did not seem to believe that they were useful to deliver the model the team were aiming to develop. However, the same modeller also stated after the first stakeholder workshop that he had not thought that it was going to be particularly useful but having attended the workshop and witnessing the discussion he thought it was very worthwhile for the project. This suggests that the conceptual modelling framework may not be readily adopted.

According to Kotiadis and Mingers, in order to combine problem structuring methods with quantitative methods the modeller needs to believe that it is a worthwhile thing to do, to have the type of personality which is able to switch between analysis of quantitative data and facilitating qualitative analysis, and to have understood and practiced the relevant problem structuring methods.[154] There is a certain culture within health economic modelling of developments in quantitative modelling methods increasing prestige and very little interest or knowledge about conceptual modelling methods, as suggested by the qualitative research within Chapter 5. Based upon the background of the health economic modellers within the NICE Technology Assessment Groups, many come from a highly quantitative background and begin working in the profession because they are good at (and may enjoy) mathematics. Conversely, they tend to have no or minimal training in (and may not enjoy or think important) conceptual modelling. Encouragingly, the other project team members did not seem to have had the same reservations about the use of the conceptual modelling framework. Importantly, however, not only does the modeller doing the work have to be convinced that the approach is appropriate and useful in practice, but the project lead also needs to agree to its use. These issues will need to be considered during dissemination and championing of the conceptual modelling framework, as well as within future case studies.

6.6 Chapter summary and implications for methods development

This chapter provides a critical reflection of the use of the draft conceptual modelling framework within a case study assessing the cost-effectiveness of interventions for screening and prevention of type 2 diabetes. In general, the framework was helpful in developing an appropriate understanding of the problem and documenting the transition from that understanding to the model structure. The diabetes case study raised some practical issues which had not been considered within the literature reviews and the qualitative research. These can be incorporated into the final conceptual modelling framework. Based upon these reflections, the key implications for methods development are:

Aligning the framework with the decision making process

1) There should be a first step describing the necessity to align the framework with the decision making process and develop a project plan.

Stakeholder involvement

2) Stakeholder recruitment is not a trivial task and the project team should reflect upon potential stakeholder worldviews to understand their motivation for involvement in order to raise the efficiency of recruitment.
3) Where feasible, it would be valuable to choose lay members to represent different types of people within society where those differences are likely to be important to the topic area (eg. ethnic minorities, lower BMI, lower socioeconomic status).
4) There is a need for flexibility with the approach for involving stakeholders within the model development process and several means of communication may be required. It may be appropriate to try and hold workshops or meetings with stakeholders around relevant conferences or meetings. Whilst workshops have the advantage of allowing issues to be discussed and debated, one-to-one meetings or telephone conversations may be employed in addition to, or instead of, workshops.
5) The substantial resource requirements during the stakeholder workshops should be highlighted within the conceptual modelling framework as an important consideration when choosing whether or not to run workshops. A3 diagrams (eg. of the conceptual model of the problem and resource pathways) are a useful tool for sharing ideas and recording them.
6) Within any workshops, stakeholders should be told that the aim is not necessarily to reach consensus; however after sharing divergent views, it is useful for the project team to limit these to a few key concepts and issues. During the understanding of the problem phase, it would be valuable to provide some sort of description of the degree of consensus/ disagreement between stakeholders.
7) Stakeholders could spend 2-3 minutes at the beginning of the first stakeholder workshop (or a paragraph of written text if not within a workshop) describing their perspective, what they think they can give to the project and what they would like out of their involvement.

Developing the understanding of the problem

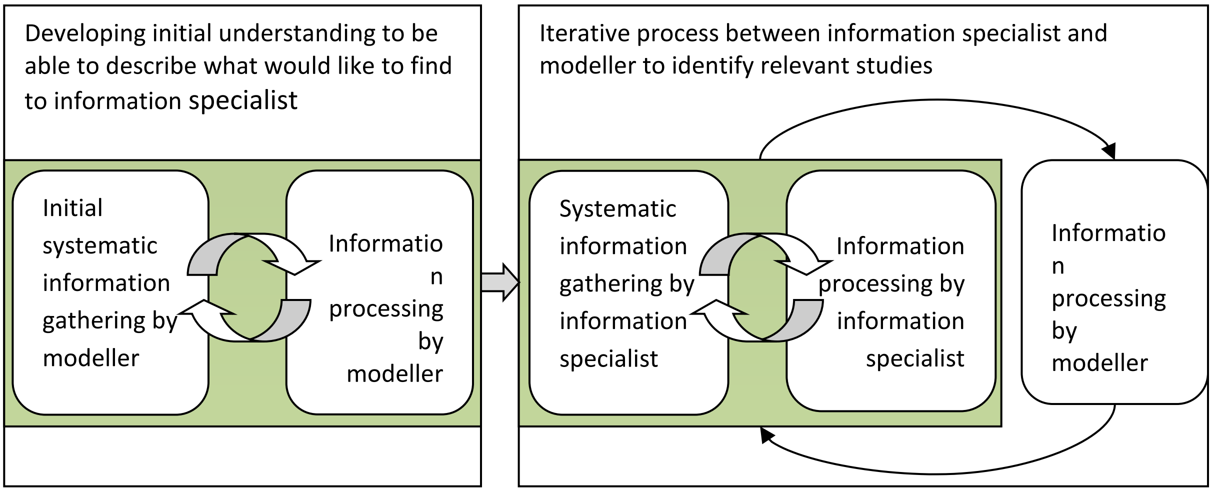
8) The diagram developed within the understanding of the problem phase can be described as a '*conceptual model of the problem depicting hypothesised causal relationships*'.
9) To represent the disease natural history within the conceptual model of the problem, the causal chain can show the relationship between the behaviour and the disease (eg. a decrease in physical activity might lead to an increase in blood glucose levels). Following the onset of

disease, the disease natural history can be described by probabilistic causation (eg. impaired glucose regulation increases the probability of diabetes).

10) Where the disease natural history is discrete rather than continuous, the importance of depicting time within the conceptual model of the problem needs to be highlighted. This can be done by adding a graph to the diagram. The term 'delay' could also be added between cause and effect of relevant model factors.
11) The modeller should be aware of the tendency to oversimplify when considering the impact of the determinants of health and relevant theory should be consulted to inform which determinants of health to consider.
12) The modeller should revisit the questions within the conceptual modelling framework to facilitate the development of the conceptual model of the problem throughout its development.
13) The following additional questions around the determinants of health should be added to accompany the conceptual model of the problem:
    a) When interventions are being added to the conceptual model of the problem:
        - Are there any determinants of health reported by the effectiveness studies which are not included within the diagram?
        - Are there any additional types of potentially relevant interventions given potential impacts upon the problem of interest of individual lifestyle factors, living and working conditions and access to essential goods, and general socioeconomic, cultural and environmental conditions which affect the problem of interest?
        - Are there any substantial impacts of social networks upon intervention effectiveness and of the interventions upon other lifestyle factors?
    b) When the model population is being chosen, in order to incorporate equity considerations:
        - Is there a bigger problem in a particular subgroup or is the intervention more effective in a particular subgroup? These subgroups might be based upon the age, sex and other inherent characteristics of the population of interest, individual lifestyle factors, living and working conditions and access to essential goods, and general socioeconomic, cultural and environmental conditions.
14) There is a need for the project team to question each other's assumptions throughout the conceptual modelling process. It is important for the modeller to be ready to acknowledge that the beliefs that they had about the system may not be the most appropriate.
15) The description of resource use can be undertaken as a two-stage process in order to increase efficiency of model development; first establishing very generally what sort of resource

processes there are for key components of the conceptual model of the problem; and second describing resource use in detail during the justifying and developing the model structure phase.

16) A possible information retrieval approach for developing the understanding of the problem and model structure is shown below. Further development of methods and techniques will be required within future work.



17) It should be suggested that the model perspectives, outcomes, potential interventions and populations are discussed at an early stage of the project, particularly if the project question and scope have been developed by researchers rather than decision makers. If stakeholders broaden the potential interventions being assessed, the understanding of the problem needs to be expanded.

When justifying and developing the model structure

18) Decision makers should determine which interventions to consider within the model, based upon evidence reviews and input from other stakeholders. Discussions between the project team and the stakeholders may be required to limit the breadth of the search for the effectiveness review.

19) A flow diagram or box describing a summary of the suggestions within the text provides a much more accessible way than lots of text for highlighting the key considerations.

Introducing the conceptual modelling framework

20) The introduction of the conceptual modelling framework should clearly and concisely describe why it is beneficial. A discussion about the preconceptions that modellers may have which might be inconsistent with the conceptual modelling framework could also be described. In addition, the key principles and methods within the framework need to be well justified and evidence-based where possible.

Chapter 7: A conceptual modelling framework for Public Health economic evaluation

7.1 Chapter outline

This chapter describes a conceptual modelling framework for Public Health economic evaluation, developed based upon the research presented within Chapters 2 – 6. Throughout this chapter, a green shaded background is used to denote the stand-alone conceptual modelling framework document which was presented to a focus group for evaluation purposes (see Chapter 8 and Appendix E). Non-shaded parts provide justification for each aspect of the framework. Section 7.2 presents the requirements of the framework based upon the findings of Chapters 2 – 6. The conceptual modelling framework is described within Section 7.3. An example to illustrate the methods is included using the diabetes case study described within Chapter 6. This is denoted throughout by the heading 'Diabetes project example'. Whilst suggestions about the processes which may be followed are made within the conceptual modelling framework, it does not aim to provide a specific, prescriptive process. The processes followed will be dependent upon the decision making context, the resources available and the preferences and judgements of the project team. However, process suggestions are included throughout in italics within boxes.

7.2 The requirements of the conceptual modelling framework

<u>Definition of a conceptual modelling framework</u>

There is no agreed definition for a conceptual modelling framework within the literature. Based upon the definition of a conceptual modelling framework by Robinson[137] and the definition of a conceptual model by Kaltenthaler *et al.,*[14] a conceptual modelling framework for current purposes is defined as: *'A methodology that helps to guide modellers through the development of a model structure, from developing and describing an understanding of the decision problem to the abstraction and non-software specific description of the quantitative model, using a transparent approach which enables each stage to be shared and questioned.'*

<u>Aim of the framework</u>

The aim of this framework is to provide a methodology which can be moulded according to different situations by different users[123] to help modellers develop model structures for Public Health economic models. It acts as a tool to help modellers make decisions about the model structure, but it does not provide automated solutions to these choices. It is intended to be used by any modellers undertaking Public Health economic evaluations; for inexperienced modellers it provides a transparent process to follow; for experienced modellers it provides Public Health-specific considerations such as the determinants of health and understanding and describing dynamically complex systems, as well as a standardised approach which will help decision makers/ clients to input into and use the model developed.

Benefits of the conceptual modelling framework

Conceptual modelling is the first part of a modelling project, which guides and impacts upon all other stages. This means that if this is done poorly, all subsequent analysis, no matter how mathematically sophisticated, is unlikely to be useful for decision makers.[49] Key potential benefits of this conceptual modelling framework and what pitfalls these aim to avoid, based upon a review of conceptual modelling frameworks and qualitative research with modellers, are shown within Table 7.1 below.

Table 7.1: Potential benefits of the conceptual modelling framework

Potential benefit	What pitfalls can be avoided
To aid the development of modelling objectives	➢ Answering the wrong (or less useful) question with the model.
To provide tools for communication with stakeholders	➢ Representing a contextually naïve and uninformed basis for decision-making, including misunderstandings about the problem, producing unhelpful model outcomes, and incorporating inappropriate and/ or invalid model assumptions. ➢ Ignoring important variations between stakeholders' views. ➢ Model results which are not trusted by stakeholders.
To guide model development and experimentation	➢ Inefficient model implementation (i.e. repeatedly making structural changes to the implemented model) ➢ Inadequate analyses
To improve model validation (developing the right model)	➢ Answering the wrong (or less useful) question with the model. ➢ Misunderstanding the key issues associated with the problem. ➢ Using the first theories identified from the evidence to develop the model. ➢ Not having a basis for justifying the model assumptions and simplifications.
To improve model verification (developing the model correctly)	➢ Not having an intended model with which to compare the implemented model.
To allow model reuse	➢ Other experts not being able to identify or correctly interpret key model assumptions and simplifications and why these have been made.

Development of the framework

The conceptual modelling framework has been developed based upon the *implications for methods development* identified from the research presented within Chapters 2 – 6. These have been divided into categories according to the type of impact they would have upon the development of a conceptual modelling framework. Some of these relate to what the framework should do which defines the nature of the framework rather than its specific content (framework aims), whilst others relate to the general principles that the modeller should follow and these need to be described as part of the framework (general principles). Some of the identified implications for methods development specify methods which need to be included within the framework (methodological considerations), whilst others outline key issues which the modeller should consider including within Public Health economic models (consideration of relevant issues). Finally, some of the implications for methods development identified within Chapters 2 – 6 are suggestions about processes which may be helpful to the modeller, although alternative processes may be followed (process). Table 7.2 summarises these.

The framework aims have been used as a general guide whilst developing the framework. The four implications relating to the general principles are described within the framework as four key principles of good practice. The methodological considerations have been used to develop the specific steps of the conceptual modelling framework, whilst the consideration of relevant issues have been included directly into the framework. Finally, the process suggestions have been included throughout in grey boxes in italics.

Table 7.2: Implications for the development of the framework based upon Chapters 2 – 6

Framework aims	Based upon Chapter				
	2	3	4	5	6
A conceptual modelling framework specifically for Public Health economic modelling has the potential to provide more guidance about the approach than a generic framework.	Y	Y	Y		
To aid the model development process but not constrain it. It should allow for the variation in requirements of different Public Health economic modelling and be clear that there is scope for further methods development given the early phase of development of a framework within Public Health economic modelling.			Y	Y	
To provide a general outline of the model development process in Public Health economic modelling.				Y	
To provide a tool for communication with the project team and stakeholders.				Y	
To help modellers make decisions about what to include and exclude within a model.				Y	
To help modellers determine appropriate and inappropriate simplifications of the problem.				Y	
To provide a transparent approach for choosing model interventions.				Y	Y
To encourage understanding of the implications of the structural choices that the modellers make.				Y	
To help decision makers make decisions, as opposed to trying to represent reality.				Y	
To facilitate clear reporting of the model structure and the process by which it was developed.				Y	
To encourage modellers to question the assumptions of the experts and decision makers.				Y	
To take into account that modellers have different skill sets and encourage modellers to recognise potential skill set biases and moderate impact.				Y	
To include an example to illustrate the methods.				Y	
To be clear about what the framework can and cannot do.				Y	
To be culturally acceptable and simple to use in practice (use of flow diagrams, tables and boxes rather than large chunks of text).				Y	Y
To clearly and concisely describe why a conceptual modelling framework is beneficial. A discussion about the preconceptions that modellers may have which might be inconsistent with the conceptual modelling framework could also be described. In addition, the key principles and methods within the framework need to be well justified and evidence-based where possible.					Y

General principles: How the modeller should approach the problem	Based upon Chapter				
	2	3	4	5	6
A systems approach is an appropriate approach for modelling Public Health systems, taking a holistic view of the system and focusing upon the relationships between components. This involves understanding the complex causal chains, including feedback loops, and the unintended consequences of the comparators and interventions upon other parts of the system.	Y	Y			
A systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling.		Y			
To involve stakeholders within each stage of conceptual model development in order to encourage learning about the problem, develop appropriate model requirements, facilitate model verification and validation, help develop credibility and confidence in the model and its results, guide model development and experimentation, and encourage creativity in finding a solution.			Y		
To specify modelling objectives and develop a thorough documented understanding of the problem, and subsequently choose model options, determine the model scope and level of detail, and identify structural assumptions and model type, with a different representation for each. This model development process is iterative.			Y	Y	Y

Methodological considerations: Things the modeller should do during conceptual modelling	Based upon Chapter				
	2	3	4	5	6
To consider the use of modelling methods to enable the broader determinants of health to be incorporated such as agent-based simulation and social network analysis.		Y			
To be practical within a decision making context by considering the needs of the decision makers, including the time requirements upon the stakeholders.			Y		
Cognitive mapping, causal diagrams and SSM may be useful for objective setting and developing the understanding of the problem.			Y		
To consider the most appropriate outcome measure and perspective to report to decision makers.				Y	
To consider the choice of experts and the implications of these choices.				Y	
To consider any diagrams, such as logic models, developed by decision makers or other parts of the team on the project.				Y	
To recognise relevant methods guidance (eg. NICE methods guide).				Y	
To consider the likely cost-effectiveness of the interventions in making decisions about model structure.				Y	
To consider the trade off between developing an appropriate structure for the problem versus ability to meet deadlines.				Y	
To consider the trade-off between providing stakeholders with something to critique and limiting their thinking.				Y	
To explore the use of existing models in the same area.				Y	
To consider whether a more exploratory analysis may be more useful given the time and data constraints.				Y	
To suggest that the question of interest, model perspectives, outcomes, potential interventions and populations are discussed at an early stage of the project, particularly if the project question and scope have been developed by researchers rather than decision maker.				Y	Y
To undertake a first step to align the framework with the decision making process and develop a project plan.					Y
To describe resource use as a two-stage process in order to increase efficiency of model development; first establishing very generally what sort of resource processes there are for key components of the conceptual model of the problem; and second describing resource use in detail during the justifying and developing the model structure phase.	Y				Y
For the project team to question each other’s assumptions throughout the conceptual modelling process. It is important for the modeller to be ready to acknowledge that the beliefs that they had about the system may not be the most appropriate.					Y
To revisit the questions within the conceptual modelling framework to facilitate the development of the causal diagram throughout the development of the understanding of the problem.					Y

Consideration of relevant issues: Specific issues for the modeller to consider including within the model	Based upon Chapter				
	2	3	4	5	6
To consider equity and the social gradient.	Y	Y		Y	
To consider non-health costs and outcomes and what is a 'good' outcome (Eg. Is it better to have a baby at age 19 than age 17? Is it a good thing to return employees to work more quickly if they are less productive?).	Y			Y	
To consider stakeholders within the system who might act to reduce or increase the impact of the intervention. (Eg. the smoking industry may increase marketing if smoking is banned from public places).		Y			
To incorporate outcomes dependent upon the determinants of health and consider step-changes in societal behaviour due to sufficient people adopting a type of behaviour.		Y			
To consider assessing population, community and individual-level interventions.		Y			
To consider the culture and politics of the system.		Y			
To consider heterogeneity and whether there are any appropriate subgroups, including socioeconomic status.		Y		Y	
To highlight the difference between causation and association.				Y	
To choose model type according to interactions and heterogeneity.				Y	
To consider intergenerational impacts.				Y	
To explore the population, outcomes and other biases such as trial design associated with the effectiveness studies.				Y	
To encourage understanding of the modelling requirements in other sectors when the scope of the model extends beyond health and wellbeing.				Y	
To think about the constraints of the project scope.				Y	
To encourage modellers to explore the exact meaning of topic specific terminology which also has a lay meaning.				Y	
To consider whether behaviour is being prevented or delayed.				Y	
To encourage reflection upon if there are other consequences (positive or negative) not considered by the effectiveness studies.				Y	
To consider, in some form, each of the following: (i) classifying and defining population subgroups of interest, (ii) identifying and defining harms and outcomes for inclusion in the model, (iii) thinking about modifiable components of risk, (iv) specifying the baseline position on policy variables, (v) estimating the effects of changing the policy variables on the risk factors, (vi) risk functions relating to risk factors to harm, (vii) monetary valuation.				Y	
To describe how to incorporate the disease natural history within the conceptual model of the problem.					Y
To highlight the importance of depicting time within the conceptual model of the problem.					Y
To consult relevant theory to choose which determinants of health to include.					Y
To incorporate additional questions around the determinants of health to accompany the conceptual model of the problem.					Y
To expand the understanding of the problem if stakeholders broaden the potential interventions being assessed.					Y

Process: Suggestions about the process the modeller might follow, although there may be alternative processes which would allow the general approach to be taken.	Based upon Chapter				
	2	3	4	5	6
If the term 'conceptual model' is employed within the framework it needs to be defined and which groups of people might be involved in the model development process should be clear.			Y		
To encourage the use of the model for understanding the effectiveness of the interventions as well as the cost-effectiveness.				Y	Y
To align the stakeholders' expectations of the process and their requirements with the modellers' expectations.				Y	
To highlight that stakeholder recruitment is not a trivial task and that the project team should reflect upon potential stakeholder worldviews to understand their motivation for involvement in order to raise the efficiency of recruitment.					Y
To choose lay members to represent different types of people within society where those differences are likely to be important to the topic area (eg. ethnic minorities, lower BMI, lower socioeconomic status) where feasible. If this is not possible, modellers could consider whether the assumed chains of behavioural causation developed within the conceptual model of the problem are likely to be violated by a particular subpopulation.					Y
To describe a possible information retrieval approach for developing the understanding of the problem and model structure.				Y	Y
The modeller should revisit the questions within the conceptual modelling framework to facilitate the development of the conceptual model of the problem throughout its development.					Y
To highlight that within any workshops, stakeholders should be told that the aim is not necessarily to reach consensus; however after sharing divergent views, it is useful for the project team to limit these to a few key concepts and issues. During the understanding of the problem phase, it would be valuable to provide some sort of description of the degree of consensus/ disagreement between stakeholders.					Y
To highlight that there is a need for flexibility with the approach for involving stakeholders within the model development process and several means of communication may be required. It may be appropriate to try and hold workshops or meetings with stakeholders around relevant conferences or meetings. Whilst workshops have the advantage of allowing issues to be discussed and debated, one-to-one meetings or telephone conversations may be employed in addition to, or instead of, workshops.					Y
To highlight that the resource requirements during the workshops are substantial in order to maintain engagement with the stakeholders, record what is said and process and collate information developed during the workshop to share with the group later within the meeting.					Y
Stakeholders could spend 2-3 minutes at the beginning of the first stakeholder workshop (or a paragraph of written text if not within a workshop) describing their perspective, what they think they can give to the project and what they would like out of their involvement.					Y
The diagram developed within the understanding of the problem phase can be described as a 'conceptual model of the problem depicting hypothesised causal relationships'.					Y

7.3 The conceptual modelling framework

7.3.1 Key principles of good practice

Although modellers within the focus group meeting suggested that the conceptual modelling framework should not be too prescriptive (see Chapter 5), findings from the research presented within Chapters 2 – 6 strongly suggested that in order to develop valid, credible and feasible models there are four key principles of good practice that need to be followed by modellers.

In order to develop valid, credible and feasible Public Health economic models, the four key principles of good practice are that; (1) a systems approach to Public Health modelling should be taken; (2) developing a thorough documented understanding of the problem is imperative prior to and alongside developing and justifying the model structure; (3) strong communication with stakeholders and members of the team throughout model development is essential; and (4) a systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling. These are each described in detail below. Justification should be provided by modellers if these principles are not followed.

Key principle of good practice 1: A systems approach to Public Health modelling should be taken

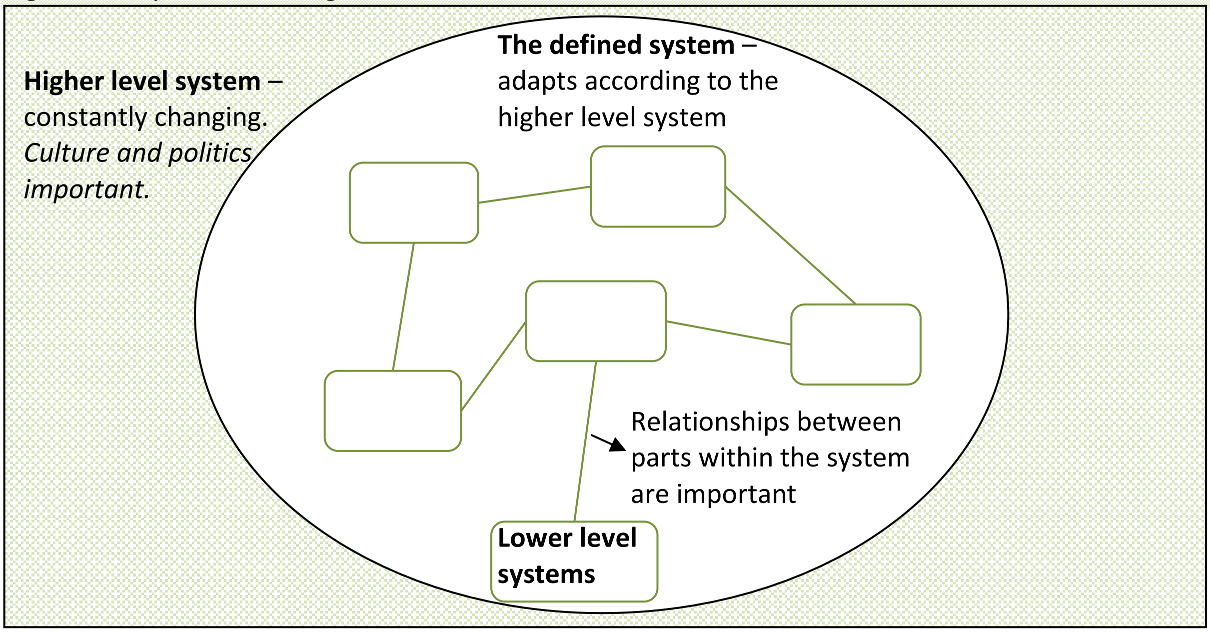
Chapter 3 suggests that Public Health systems are generally dynamically complex and that a systems approach is appropriate for dealing with these types of problems.

Public Health economic modelling generally involves understanding dynamically complex systems.[82] This means that they are non-linear systems where the whole is not equal to the sum of the parts, they are history dependent, there is no clear boundary around the system being analysed, heterogeneity and self-organisation impact upon the outcomes, and people affected by Public Health interventions may learn over time and change their behaviour accordingly.[91]

Within complex systems there may be positive feedback loops, whereby if Factor A increases [decreases], the number of Factor B increases [decreases], which leads to Factor A increasing [decreasing] further, which would lead to exponential growth [decay] if no other factors were present.[91] For example, an increase in population obesity might lead to an increase in population mental illness which in turn leads to an increase in obesity, and so on. There may also be negative feedback loops, where an increase [decrease] in Factor A leads to an increase [decrease] in Factor B which in turn leads to a decrease [increase] in Factor A.[91] For example, an increase in eating will lead to an increase in weight gain (all other things being equal) which may lead to a decrease in eating. The dynamics of complex systems arise from the interaction between positive and negative feedback loops, and this may occur over a long period of time, often producing counter-intuitive behaviour.[91] The economy is an example of a complex system which displays such counter-intuitive behaviour. Within these dynamically complex systems, factors are constantly changing over time, and a sudden change in behaviour may arise as a result of a number of smaller changes, such as a stock market crash. Making assumptions of simple cause and effect may lead to inappropriate results. See the paper 'Learning from Evidence in a Complex World' by Sterman for a good discussion of dynamic complexity.[91]

A systems approach, or systems thinking, is a holistic way of thinking with the philosophy that to understand a problem it is important to understand the interactions between parts within a system and with its environment.[90;172] Figure 7.1 depicts the multiple system levels, whereby the system of interest is subjectively defined and there is always a higher level system within which it belongs and a lower level system which describes detailed aspects. The challenge within health economic modelling is to determine which level will be that of the system of interest (the model), by having sufficient knowledge about the higher level system (the broader understanding of the problem), and subsequently to be able to define an appropriate level of detail for the system of interest. Within systems thinking, the importance of not considering one aspect of a system in isolation is emphasised to avoid ignoring unintended consequences. Soft systems thinking also recognises the impact of culture and politics upon a situation,[123] which is interlocked with Public Health policy evaluation. Culture and politics affect the process by which decisions are made, what is modelled (eg. the identification of the problem, stakeholder involvement, the interventions assessed and the perspectives and outcomes of the analysis) and the effectiveness of the interventions (eg. service provision and the behaviour of individuals and society). Thus, a systems approach is suited to modelling these dynamically complex public health systems.

Figure 7.1: Systems thinking



Key principle of good practice 2: Developing a thorough documented understanding of the problem is imperative prior to and alongside developing and justifying the model structure in order to develop valid, credible and feasible models

The majority of the conceptual modelling frameworks identified within the literature review within Chapter 4 divide into two separate phases; (i) understanding the problem and (ii) making judgements about how to simplify that understanding in order to develop a valid, credible and feasible qualitative description of the quantitative model.[8;14;18;127;129;136] This has a number of advantages.

It is valuable to have an initial understanding of the problem and to document this understanding prior to making simplifications when developing the model structure because of both theoretical and practical reasons. Theoretically, it provides a basis for validation by facilitating the specification of an appropriate scope and structural assumptions and for credibility by supporting stakeholder involvement and producing clear documentation when developing the model structure.[14] We learn by building upon what we already know, and how we see the world or a problem is constrained by our previous 'knowledge'.[89] As such, if a model is data-led and/or based only upon the analyst's interpretation of the data, it may lead to a narrow view of what should be included within the model. Documenting an understanding of the problem prior to analysing available datasets allows that understanding to be reflected upon and shared. This reduces the risk of ignoring something which may be important to the model outcomes, which is particularly important given the potential dynamic complexity of the system. In terms of systems thinking (see key principle of good practice 1), documenting an understanding of the problem (the higher level system) allows the modeller to be able to define the boundary of the system of interest for modelling (see Figure 7.1). This description of the understanding of the problem should also help the modeller to understand the impact of potential simplifying assumptions they are making within the model.

Practically, if the problem is not sufficiently understood an inappropriate model structure may be developed which, if recognised at a later stage of model development, may take a long time to alter within the computer software. This is particularly true if an alternative model type needs to be developed (for example, a DES rather than a Markov model). Thus taking the time at the beginning of the project to understand the problem could actually reduce overall time requirements. Documenting the understanding of the problem also enables communication with stakeholders and the project team (see key principle of good practice 3). An additional benefit is that the documentation of the understanding of the problem could be used (alongside any logic models developed) to help stakeholders understand all of the impacts of the interventions in order to inform the scoping and/or the interpretation of systematic reviews of intervention effectiveness. Finally, documenting the understanding of the problem will enable researchers and policy makers who are not involved within the project to understand the problem and the basis for decisions about the model structure.

Thus, as also proposed by Kaltenthaler *et al.* within the context of clinical economic modelling,[14] it is recommended that the model structure be developed in two phases. The first is to develop an understanding of the decision problem which is sufficiently formed to tackle the above theoretical and practical issues and should not be limited by what empirical evidence is available (see Section C). The second is to specify a model structure for the decision problem that is feasible within the constraints of the decision making process (see Section D).

The understanding of the problem will inevitably continue to form during model development; however this initial documented understanding provides a basis for comparison and any major changes to this understanding can subsequently be documented.

Key principle of good practice 3: Strong communication with stakeholders and members of the team throughout model development is essential for model transparency, validity and credibility

The qualitative research described within Chapter 5 highlighted that the modelling work within Public Health economic evaluation is based around the requirements of the decision makers. The modellers suggested that the model must be easily communicable and credible to the decision makers, and as such the decision makers and other relevant stakeholders should be involved during the development of the model. The review of conceptual modelling frameworks described within Chapter 4 also highlighted the importance of involving stakeholders in model development.

A stakeholder is defined here as 'any person who might impact upon or be impacted upon by the system of interest'. Literature suggests that stakeholders can encourage learning about the problem (including geographical variation of healthcare provision and stakeholders' values and preferences), help to develop appropriate model objectives and requirements, facilitate model verification and validation, help to develop credibility and confidence in the model and its results, guide model development and experimentation, encourage creativity in finding a solution and facilitate model re-use.[1;14;18;125;127-129] Additionally, stakeholders can help to define the meaning of subject-specific terminology which has a different lay meaning. Pidd has used the metaphor of taking a photograph of a scene, whereby each person involved might see different aspects of the scene and frame the photo differently.[44] The more frames provided by people with different interests (which may be affected by culture and politics), the better our understanding of the scene, and differences between perspectives can be discussed explicitly. Section B of the framework describes the types of stakeholders which may be involved.

The modeller is encouraged to question the assumptions of the stakeholders[92] and the project team throughout the model development process in order to uncover inconsistent and invalid assumptions. Within topics where the project team have existing 'knowledge', it is important for them to be aware of the tendency to anchor to initial beliefs and be open to accepting new theories in order to develop valid models.[96;123] Effective ways of communicating information such as using clear diagrams should be used in order to share information and describe assumptions.

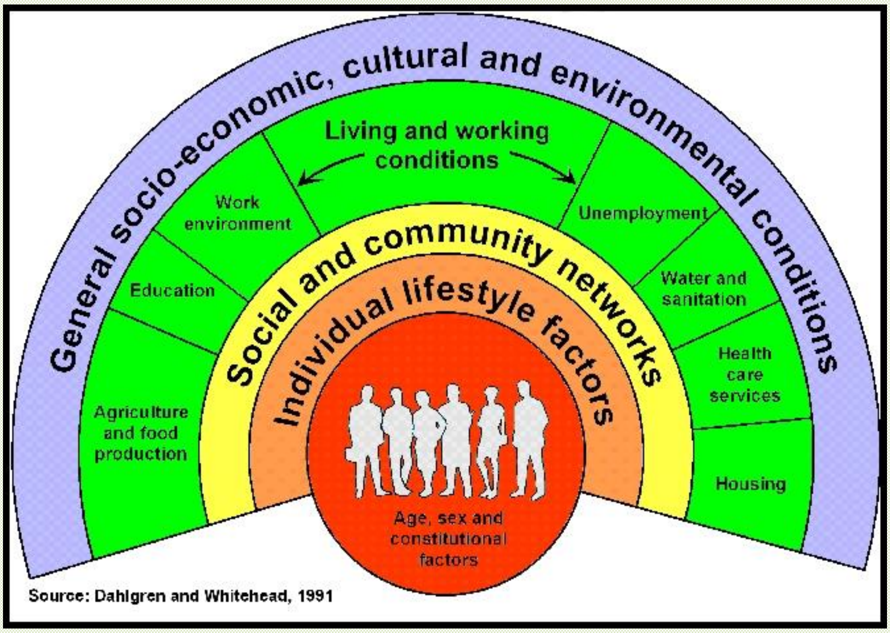
Key principle of good practice 4: A systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling

Chapter 3 highlights the importance of the broader determinants of health for modelling the Public Health interventions and suggests that systems thinking can be applied to the idea that an individual's behaviour cannot be considered in isolation, but that our social structure impacts upon an individual's actions which in turn impacts upon the social structure.[24] As was established within Chapter 3, there are several different classifications of the determinants of health and the determinants of health inequities. The model by Dahlgren and Whitehead is used here because it provides a clear diagram outlining population, community and individual level factors affecting health, and it includes a number of specific categories within each of these which the modeller could consider.[28] Although the diagram does not include the causal mechanisms of the determinants upon health and health inequities, the review presented within Chapter 3 essentially suggested that all factors might impact upon all other factors across the population, community and individual levels.

The determinants of health which include the social, economic and physical environment, as well as the person's individual characteristics, are central in the consideration of Public Health interventions. The determinants of health as described by Dahlgren and Whitehead are shown within Figure 7.2.[28] Individual behaviours (or lifestyle factors) impact upon the broader determinants of health, which in turn impact upon individual behaviours.[27] Thus, it is important to consider these broader determinants of health in order to be able to predict the full impact of the interventions upon health outcomes. In addition, the determinants of health could be used to think through all of the non-health outcomes associated with the interventions that it might be useful to report, such as transport or employment.

Consideration of the broader determinants of health also facilitates identification of potential types of interventions, for example those which might impact upon individual health through making community and population-level changes, such as food production, as well as those which might impact upon health through changing individual lifestyle factors. Similarly, subpopulations that might benefit from the intervention could be identified, given that reduction of health inequities is often an objective of Public Health. Finally, the consideration of social network effects might affect the analytical model type chosen, and subsequently the predicted impact of the interventions.

Figure 7.2: Determinants of health

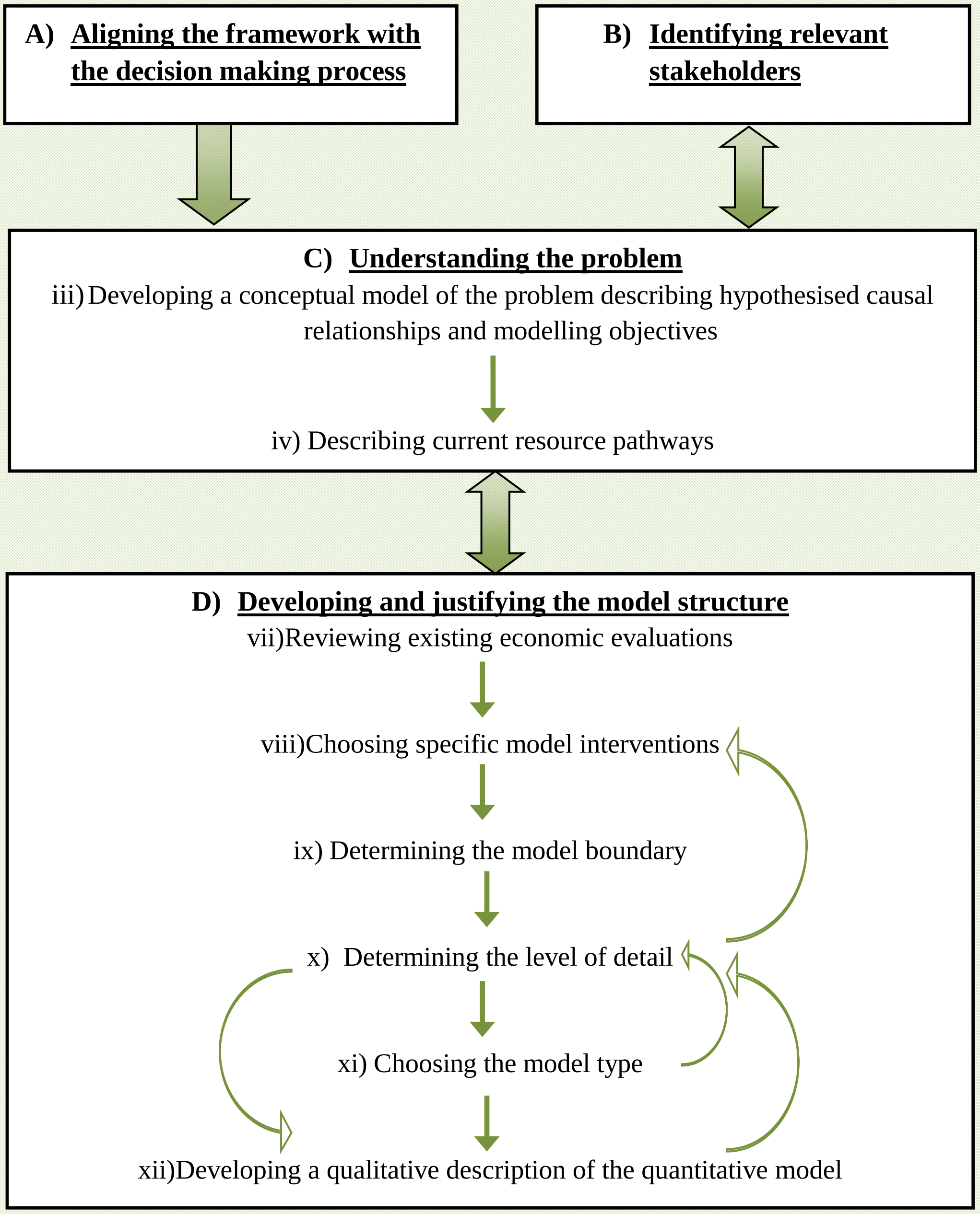


It would not be appropriate or feasible to include all of the determinants of health within the model; however, they should be systematically reflected upon during the understanding of the problem phase to consider which determinants it might be important to include within the model so that all important mechanisms and outcomes of the interventions can be captured.

7.3.2 Overview of steps within the conceptual modelling framework

Figure 7.3 describes an outline of the phases within the conceptual modelling framework, which includes (A) Aligning the framework with the decision making process; (B) Identifying relevant stakeholders; (C) Understanding the problem; and (D) Developing and justifying the model structure.

Figure 7.3: Overview of conceptual modelling framework for Public Health economic modelling



<u>An iterative approach</u>

The research within Chapters 4 - 6 suggests that model development is necessarily an iterative process.

Choosing stakeholders and aligning the framework with the decision making process will generally need to be undertaken in parallel because the choice of stakeholders and their ideal level of involvement will depend upon the decision making process, but the availability of the stakeholders may have a substantial impact upon the process which is followed. It may be necessary to iterate between choosing relevant stakeholders and developing the understanding of the problem since the understanding of the problem step may highlight the need to include stakeholders with specific expertise. Similarly, whilst it is important to develop an understanding of the problem prior to developing and justifying the model structure (see principle of good practice 2), in practice the understanding of the problem is never complete and it may be necessary to transparently revise this understanding at a later stage. These iterations are described by arrows within Figure 7.3. The steps within the developing and justifying the model structure phase are also iterative. Evidence identification is not described as a separate stage within Figure 7.3 (apart from reviewing existing models) since it is an activity required within the majority of the outlined stages. However, iterations are inevitable between appropriate conceptualisation and data collection because there is unlikely to be the exact evidence available that has been specified.

7.3.3 Detailed methods of the framework

A) Aligning the framework with the decision making process

Based upon the findings of Chapters 4 and 5, the Public Health conceptual modelling framework aims to be flexible within the different decision making jurisdictions. Thus the framework outlines a generic scalable approach. Reflecting upon a discussion within the initial meeting of the diabetes project with the project leads (see Chapter 6), there was a need at the start of the project to adjust the processes according to the project requirements and constraints in order to develop a project plan.

The conceptual modelling framework is intended to be flexible for different decision making arenas which means that decisions about how to employ the framework within the process are required. For example, the project team may need to operate differently according to the nature of the engagement with decision makers and clients within the project. If the client is the decision maker, then the scope of the model in terms of the interventions, comparators, populations, outcomes and perspectives may be better defined than if the client is not the decision maker (eg. a research funding body). This may influence the approach to evidence searching (in particular the search for intervention effectiveness evidence) and the time and resources required for model scoping. If the client is not the decision maker, the project team will need to identify the relevant decision makers and include them within the stakeholder group (see part B of the framework).

A protocol document outlining the project plan can be produced using the framework as a basis for discussion between the project team and stakeholders. This helps the clients to understand whether the project is planned to run appropriately and the project team with project planning. Key process decisions to be made during this phase relate to the relevant modes of stakeholder engagement, the approach to evidence searching, and the time and resources available for the modelling project and each step of the framework.

B) Identifying relevant stakeholders

Key principle of good practice 3 highlights the importance of stakeholder involvement and key principle of good practice 1 proposes the use of systems thinking which involves consideration of all relevant perspectives. The range of expertise which might be relevant is described within Chapter 5.

Range of expertise

There are a number of different types of stakeholder within any Public Health project including clinical experts, decision makers and lay members, all of whom provide different expertise. The choice of stakeholders involved with the development of the model will inevitably affect the model developed and the interventions assessed because modelling is subjective. For instance, stakeholders help define the model scope, make value judgements, use their expertise to recommend structural assumptions such as extrapolating short term trial data over the long term, and choose which interventions to assess within the model. These will be affected by what is considered to be culturally and politically acceptable, which is entirely appropriate in order for the model to be useful, but provides an additional reason to obtain input from a range of stakeholders. Within some projects, the experts who inform the model development are chosen by the modelling team, whilst within others a group of experts are chosen by a decision making body, such as within the NICE process (see Section A).

These experts are nominated because of their expertise in a particular area and it may be that stakeholders with views which strongly conflict with the aims and scope of the project may not be chosen to be involved (see Chapter 5). Thus, depending upon how the experts are chosen, they may be less likely to disagree with each other and the decision makers than a randomly chosen group of experts.

There is, however, usually the opportunity to involve additional experts chosen by the project team. A group of experts who will provide different expertise over a range of perspectives can be identified (see below). Practically, the approach to stakeholder communication needs to be flexible and some stakeholders will provide more input than others.

Customers, actors and system owners

Within the review of conceptual modelling frameworks within Chapter 4, few of the frameworks consider how to choose stakeholders. Roberts *et al.* suggest that clinical, epidemiologic, policy and methods experts should be consulted, as well as patient representatives.[18] Within the classification from Soft Systems Methodology (SSM), stakeholders include the people benefiting within the system (the customers), the people performing the tasks in the system (the actors) and the people with the power to approve or cancel the system (system owners, which may overlap with the actors of the system).[123]

Based upon Soft Systems Methodology (SSM)[123] and the conceptual modelling paper by Roberts et al.[18], the types of stakeholders to involve are:

1) Customers which might include patient representatives and lay members;
2) Actors which might include methods experts, clinical and epidemiologic experts for all relevant diseases;
3) System owners which might include policy experts (in addition to some of the people identified as actors).

The relationships between the customers, actors and system owners can be considered in order to think about whether any relevant stakeholders have not been identified. For example, if a general practitioner (actor) has been identified as a stakeholder, this could help identify the non-diabetic lay member (customer). The person with the power to stop the actor giving the customer a service is the local commissioners (system owners). Stakeholders should be involved during the understanding of the problem phase and the development and justification of the model structure phase.

DIABETES PROJECT EXAMPLE

Within the diabetes project, stakeholders that might be involved could be a diabetic patient and a non-diabetic lay member (the customers), a general practitioner, experts in diabetes, cardiovascular disease, microvascular disease, cancer and osteoarthritis and an expert in statistical analysis of longitudinal data (the actors), and local and national commissioners (the system owners).

Process suggestions which may be helpful to modellers

<u>Resource requirements for stakeholder recruitment:</u> It may require substantial time and effort to engage stakeholders. It may be necessary to approach more stakeholders than required as some will not have the time to be involved. Stakeholder workshops are useful if there are sufficient resources within the project budget because they allow stakeholders to debate and question the assumptions and beliefs of each other. Substantial administrative time is likely to be required to organise stakeholder workshops due to the probable busy schedules of the stakeholders. For this reason, it is also likely that any workshops will need to be organised at least two months before they are due to take place.

<u>Stakeholder worldviews and motivations:</u> Checkland suggests defining the worldviews of each stakeholder in order to understand conflicts between them.[123] An understanding of the possible worldviews and motivations of each of the potential stakeholders allows the project team to compare these with the project aims. Potential stakeholders may be more willing to be involved if the initial request is phrased in a way which aligns the aims of the project with the expected motivations of the stakeholders. For example, some stakeholders may be more interested in the outcomes of the project than the methods being employed so the initial information provided could describe the potential outcomes of the project. Another potential approach is for a more senior colleague involved with the project who is renowned in their field to contact the experts, potentially raising the prestige of the project and increasing the perceived benefits to the expert of being involved.

<u>Stakeholder expectations:</u> Stakeholders who are unfamiliar with modelling may not expect to be involved in shaping the modelling work. At the start of the project it is valuable to be clear with all of the stakeholders about the expectations of their involvement throughout the model development process and the importance of their input. Assumptions being made by the decision makers and other stakeholders throughout model development should be questioned.[92]

<u>Lay members:</u> Lay members are involved to ensure that views and experiences of the wider public inform the group's work. Where possible, lay members should represent different types of people within society where those differences are likely to be important to the topic area (eg. lower socioeconomic status). If this is not possible, the project team should be aware that the perspectives provided by the lay members do not necessarily represent those of all patients in that disease area/ the general population. In particular, they may not represent the more vulnerable groups within society who are unlikely to volunteer for such a role.[168] If these relevant groups are not represented, then the views and experiences of the wider public may not be heard by the stakeholders and project team. This could lead to unrealistic assumptions about a particular subgroup of the population who behave differently to those represented within the stakeholder group. Modellers should consider whether the assumed chains of behavioural causation are likely to be different within particular subpopulations.

C) Understanding the problem

One of the four principles of this framework is that developing and documenting an understanding of the problem is at the core of developing an appropriate model structure. This is about understanding what is relevant to the problem, and should not be limited by what empirical evidence is available.[14] The understanding of the problem phase within Figure 7.3 includes: (i) developing a conceptual model of the problem describing hypothesised causal relationships; and (ii) describing current resource pathways.

<u>Potential methods for developing an understanding of the problem</u>

Problem structuring methods are expected to improve understanding of complex decision problems from all stakeholders' perspectives in an exploratory and transparent manner, acknowledging uncertainties.[130] Franco argues that PSMs provide the potential for the quality of the communication between the modeller and the stakeholders to improve by encouraging a dialogue between them rather than debate, persuasion or negotiation.[173] They should allow all stakeholders to be equally included within the communication and they encourage stakeholders to think beyond their current perceptions by considering the perceptions of other stakeholders. Within the review of conceptual modelling frameworks in Chapter 4, the methods presented for understanding the problem included Soft Systems Methodology (SSM), cognitive mapping and developing causal diagrams. Within Chapter 4 a detailed description of these approaches is described, along with discussions about their potential application to Public Health economic evaluation.

<u>Proposed method for developing an understanding of the problem</u>

One way of gaining a shared understanding of the problem is to combine the benefits of each of the above approaches. The advantages and disadvantages of these methodologies are summarised in Table 7.3, and the method developed for the conceptual modelling framework is based upon the features within the left hand column. Diagrams such as that suggested here encourage holistic thinking as they can be taken in as a whole.[123]

Table 7.3: Pros and cons of SSM, SODA and causal diagrams for Public Health economic modelling

Useful aspects for Public Health economic modelling	**Disadvantages for Public Health economic modelling**
SSM	
Allows the entire problem to be understood.	Long process with lots of different steps to follow, which may not be practical for the stakeholders or accepted by the modellers.
Aims to uncover and share the sense making systems of the stakeholders rather than adopting the single worldview of the analyst. Types of potential stakeholders are considered.	Aims to help people within an organisation continue to solve problems; within Public Health economic modelling the aim is not to impart how to solve these problems, but to develop a useful quantitative model.
	Aimed at use within organisations, which are generally focused on shorter term observable outcomes, rather than predicting outcomes which are not directly observable over the lifetime of the relevant population as in Public Health economic modelling.
SODA/ Cognitive mapping	
Allows the entire problem to be understood.	Focuses on how things are managed within an organisation rather than on prediction.
Aims to uncover and share the sense making systems of the stakeholders rather than adopting the single worldview of the analyst.	Aims to help people within an organisation continue to solve problems; within Public Health economic modelling the aim is not to impart how to solve these problems, but to develop a useful quantitative model.
Allows causal relationships to be captured, which is essential within Public Health economic modelling.	Tend to include normative rather than positivist statements which generally cannot be translated into a quantitative model.
The hierarchical structure of goals, actions & options is a useful and intuitive method for thinking through the problem with stakeholders.	
Can be used to establish whether there are any positive or negative feedback loops within the system, and whether there are any clusters of factors which have greater impact upon the goals than single factors.	
Causal diagrams	
Allows the entire problem to be understood.	There is no specific approach for developing the causal diagram.
Allows causal relationships to be captured and each concept within the diagram is a variable which could be used within a quantitative model.	Does not typically help uncover and share the sense making systems of the stakeholders.
Can be used to establish whether there are any positive or negative feedback loops within the system, and whether there are any clusters of factors which have greater impact upon the goals than single factors.	

i) Developing a conceptual model of the problem describing hypothesised causal relationships

This section describes a methodology for developing a conceptual model of the problem by using the notation of causal diagrams, borrowing some of the methods from cognitive mapping,[139] and ensuring that the worldview of each of the stakeholders is considered.[123;139] This provides a systematic approach for developing an understanding of the problem at an appropriate and manageable level of relevance.

A causal diagram depicts the relationships between factors by arrows, using a + or – sign to indicate a positive or negative causal relationship. Causal diagrams allow feedback loops to be described which depict the dynamic complexity of the system. Each factor is a quantity such that one factor leads to an increase or decrease in another factor. For example,

CVD event $\xrightarrow{+}$ Cost and CVD event $\xrightarrow{-}$ Quality of life

mean an increase in CVD events leads to an increase in costs and a decrease in quality of life respectively. The hypothesised causal relationships associated with the problem can be depicted using this notation, bringing together the understanding of relevant diseases, human behaviour and societal influences. Drawing upon cognitive mapping, the ultimate aims can be stated at the top of the diagram (by asking 'why is x a problem?'), with intermediate outcomes below and options for change underneath (by asking 'how can the problem be avoided?').[139] Detailed steps to develop the diagram are described overleaf.

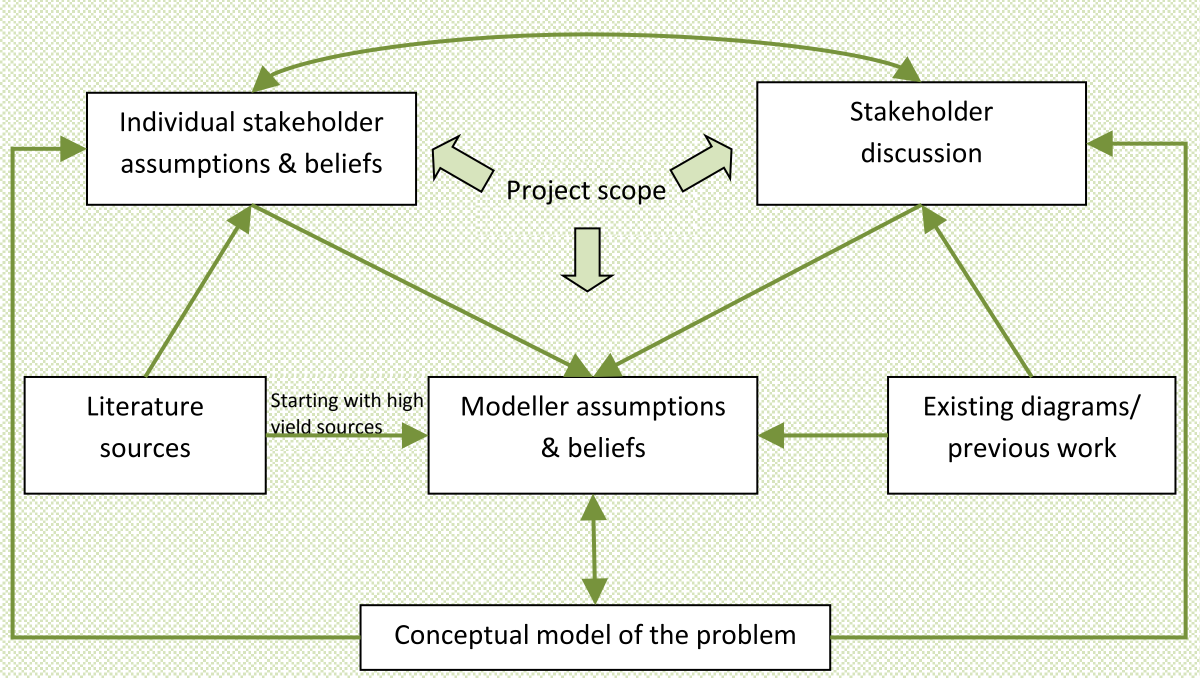
Within cognitive mapping, theoretically a diagram would be developed to represent the background knowledge and judgement of each stakeholder in order to communicate the construct system of each before bringing these together into one diagram (see Chapter 4).[139] Practically, there is unlikely to be time for each stakeholder to develop a diagram of their beliefs and assumptions. It is more feasible in most cases to develop one diagram which aims to describe a set of causal relationships which can be questioned and discussed with stakeholders who have alternative constructs.

Whilst the goal is to develop a causal diagram with positivist factors, it is unlikely that stakeholders will provide all of their input in a form which can be input directly into the diagram, and there will be an iterative process of translating the stakeholder's normative statements into the diagram. However, people do intuitively think in terms of causal relationships because causal reasoning is learnt from a young age, for example, crying causes mum to come and see me.[86] Causal knowledge is gradually built up through personally manipulating variables and from other information sources. Thus, the development of the conceptual model of the problem describing hypothesised causal relationships alongside stakeholders who have not been trained in developing these diagrams should be feasible.

Evidence for developing the conceptual model of the problem

Causal assumptions for policy prediction will necessarily be based upon experience and judgement since observational data can only be used to assess the statistical association between the specified causal relationships.[86] The proposed diagram can provide an explicit description of our hypotheses about causal relationships and the challenge is to be able to justify the causal assumptions made. The diagrams can be developed based upon a range of sources including the project scope, literature, stakeholder input, the team's previous work in the area and any other diagrams which have been developed by the rest of the current project team or the decision makers to depict their understanding of the problem, as described within Figure 7.4 below. By developing the diagram with input from stakeholders, it allows their assumptions and beliefs to be made explicit so that they can be agreed upon or questioned. The iterative process using all of the evidence sources outlined within Figure 6.4 provides multiple opportunities to question and adapt the causal assumptions. Ultimately, the conceptual model of the problem will depict the modeller's assumptions and beliefs about the causal relationships based upon all of these sources of evidence. In doing so, some forms of information may dominate over others according to the modeller's views of the validity of the information.

Figure 7.4: Sources used for developing the conceptual model of the problem



Step 1: What is the problem?

The first step, based upon cognitive mapping,[139] is to ask 'what is the problem?' This is the key problem from the decision makers' perspective and could be based upon the project scope if available. The cause of the problem described should include a potentially modifiable component. The importance of defining the modelling objective is highlighted by many researchers.[1;123] The model objective is likely to be (although not necessarily) to assess the effectiveness and cost-effectiveness of interventions which might decrease this problem. Beginning the development of the diagram by identifying the key problem encourages a focused boundary around the understanding of the problem.

DIABETES PROJECT EXAMPLE

What is the problem?

Blood glucose levels/ diabetes

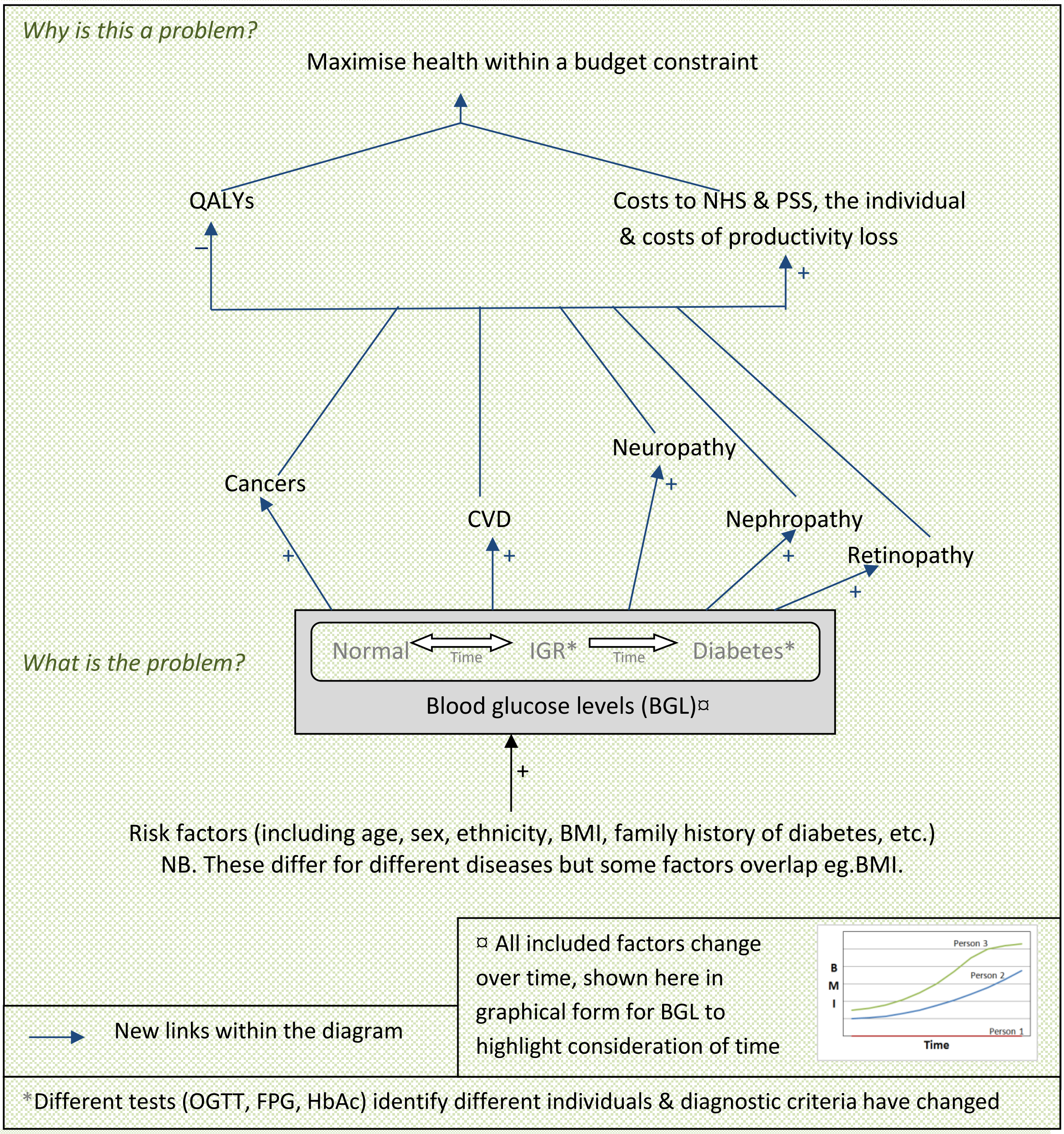
↑ +

Risk factors (including age, sex, a measure of physical activity and diet, family history of diabetes, ethnicity, etc.)

Step 2: Why is this a problem?

The modeller can then ask 'why is this a problem?', and continue to ask 'why?' or 'what are the implications of this?' until no more factors are identified, again based upon the methods of cognitive mapping.[139] Within Public Health economic modelling the goal may be to maximise net benefit by maximising health and minimising costs or equity may be considered of primary importance.

DIABETES PROJECT EXAMPLE



Step 3: Developing additional causal links

A set of questions have been constructed which may be useful to help develop the diagram further. These are based upon the findings of Chapters 2, 3 and 4 and ensuring all considerations within the taxonomy used to help choose the most appropriate model type are reflected upon (see part D of the framework). Many of the questions draw upon systems thinking (key principle of good practice 1) by considering unintended consequences and feedback loops.

These are shown in Box 7.1. The development of the understanding of the problem is iterative, and hence it may be useful to continually revisit these questions.

<u>Incorporating disease natural history</u>

Any relevant disease natural histories will not be causal in that having a 'normal' health state does not cause a disease to develop. For example, moving from having normal blood glucose levels to having diabetes is not causally related. However, the interventions being assessed within Public Health tend to be those which reduce morbidity and mortality by aiming to change behaviour. Thus where there is a disease natural history, it is likely to be affected by behaviour and as such the causal chain can show the relationship between the behaviour and the disease. For example, a decrease in physical activity might lead to an increase in blood glucose levels. Following the onset of disease, the disease natural history can be described by probabilistic causation. For instance, somebody with impaired glucose regulation has an increased probability of developing diabetes.

<u>Defining factors for inclusion</u>

The arrows between the factors within the diagram would ideally be definable by one relationship. For example, if the relationship between risk factors and stroke and risk factors and heart disease is known to be different, then it is preferable for these factors to be separated out within the diagram rather than being combined within the factor CVD. If this is not possible in order for the diagram to remain clear, then a note could be added to describe the different subsets within that factor.

Box 7.1: Questions about the decision problem to help with developing the diagram

A1. Questions relating to the disease and the determinants of health include:

- Have any relevant disease natural histories been captured?

  Example: Disease natural history associated with diabetes

- Are the following determinants of health (taken from Dahlgren and Whitehead) important in determining effects and in what way:
  - Age, sex and other inherent characteristics of the population of interest?
  - Individual lifestyle factors? (incl. diet, physical activity, smoking, alcohol/ drug misuse)
  - Social and community networks? (incl. friends, family including intergenerational impacts, wider social circles)
  - Living and working conditions and access to essential goods and services? (incl. unemployment, work environment, agriculture & food production, education, water & sanitation, health care services, housing)
  - General socioeconomic, cultural and environmental conditions? (incl. economic activity, government policies, climate, built environment including transportation, crime)

  Example: Relationship between age, ethnicity, BMI, smoking and blood glucose levels

A2. Questions to help ensure the understanding of the problem is sufficiently broad include:

- Are there any other (positive or negative) consequences of each concept?

  Example: Increases in BMI may also lead to increases in osteoarthritis incidence.

A3. Questions to ensure that the dynamic complexity of the system has been captured are:

- Could there be any other factors which explain two outcomes, for links which may not be causal, but correlated.

  Example: BMI may help explain both CVD incidence and increased blood glucose levels rather than CVD causing increased blood glucose levels directly.

- Are there any other possible causal links between the factors? (with the aim of establishing whether there are any feedback loops)

  Example: increased BMI leads to increased diabetes incidence which leads to an increase in mental illness which may lead to increased BMI.

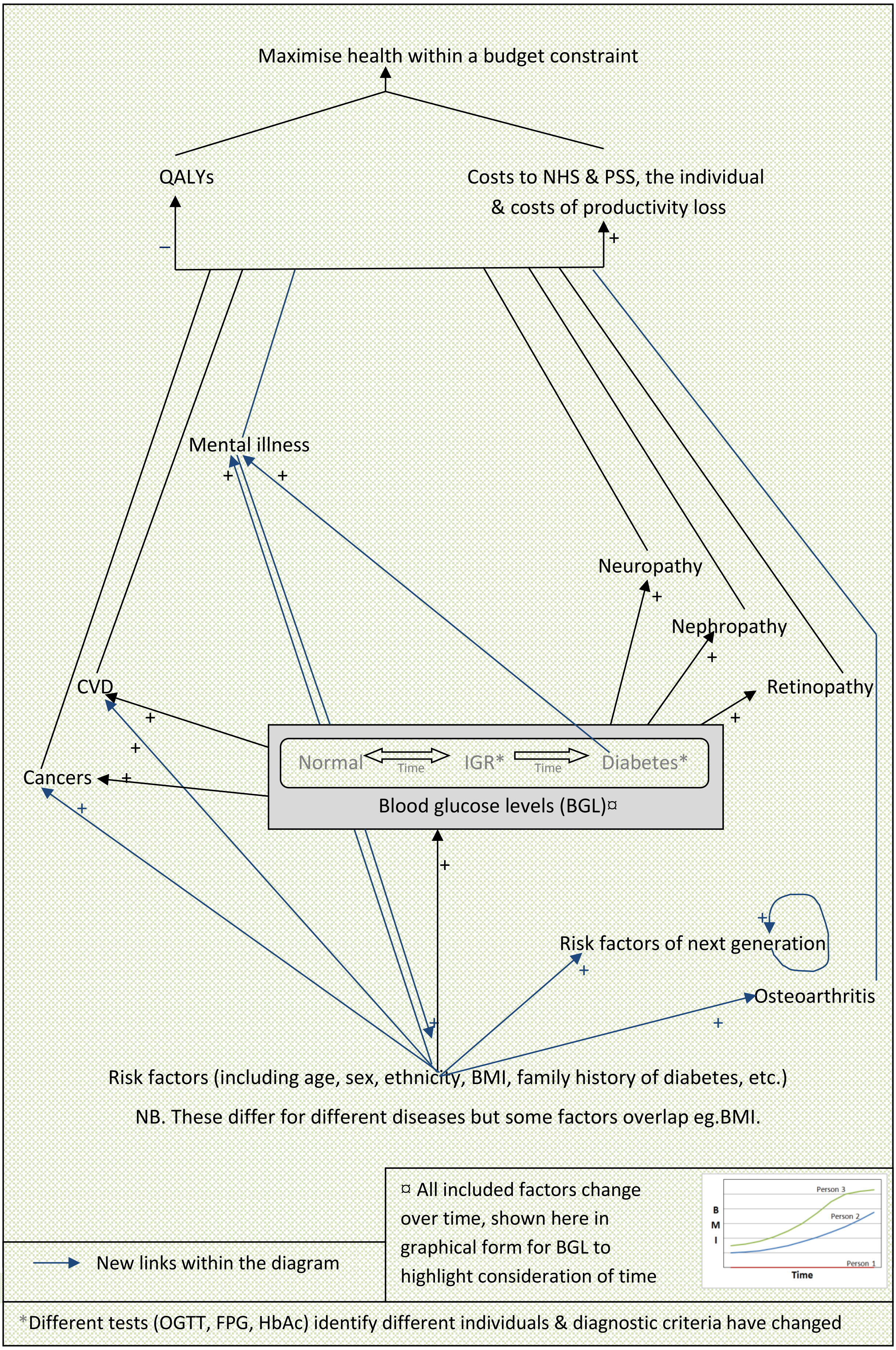
- Are there interactions between people which affect outcomes? (see social networks above)

  Example: People interacting with friends and family with higher BMI are more likely to have a higher BMI.

- Is timing/ ordering of events important?

  Example: Timing and type of CVD events may affect other disease outcomes.

DIABETES PROJECT EXAMPLE



Step 4: Incorporating types of intervention

Within dynamically complex systems like Public Health systems, the possible points at which interventions might affect outcomes associated with the decision problem may not be easily definable at the start of the project prior to developing a sufficient understanding of the problem. Thus, how to avoid or reduce the impact of the described problem should be considered in order to identify potential types of interventions. It is useful to firstly know what is considered to be current practice. Intervention types can be categorised by the population they target and their impact. Combinations of individual, community and population interventions may be considered, since a combination is likely to be most effective. These different potential types of interventions can be added to the conceptual model based upon the project scope, any effectiveness studies identified, and by considering within the diagram where interventions may be beneficial. One way of doing this is to consider which of the potentially modifiable determinants of health (individual lifestyle factors; living and working conditions and access to essential goods; and general socioeconomic, cultural and environmental conditions) affect the decision problem. It is not expected that the final specific interventions being assessed within the model will have been chosen at this stage. However, it is important to define the types of interventions which might be assessed within the model so that their impact upon model factors, including those not already incorporated into the diagram, may be considered.

A set of questions have been constructed which may be useful for considering the impacts of the interventions, shown in Box 7.2.

These are based upon the findings of Chapters 2, 3 and 4.

These should be considered in the context of each type of intervention potentially being assessed within the model.

Box 7.2: Questions about the interventions and their impacts

B1. Questions relating to the constraints of the decision making process are:

- Are there constraints on the project scope? (eg. are we constrained by the types of interventions we are assessing? What about the population?)

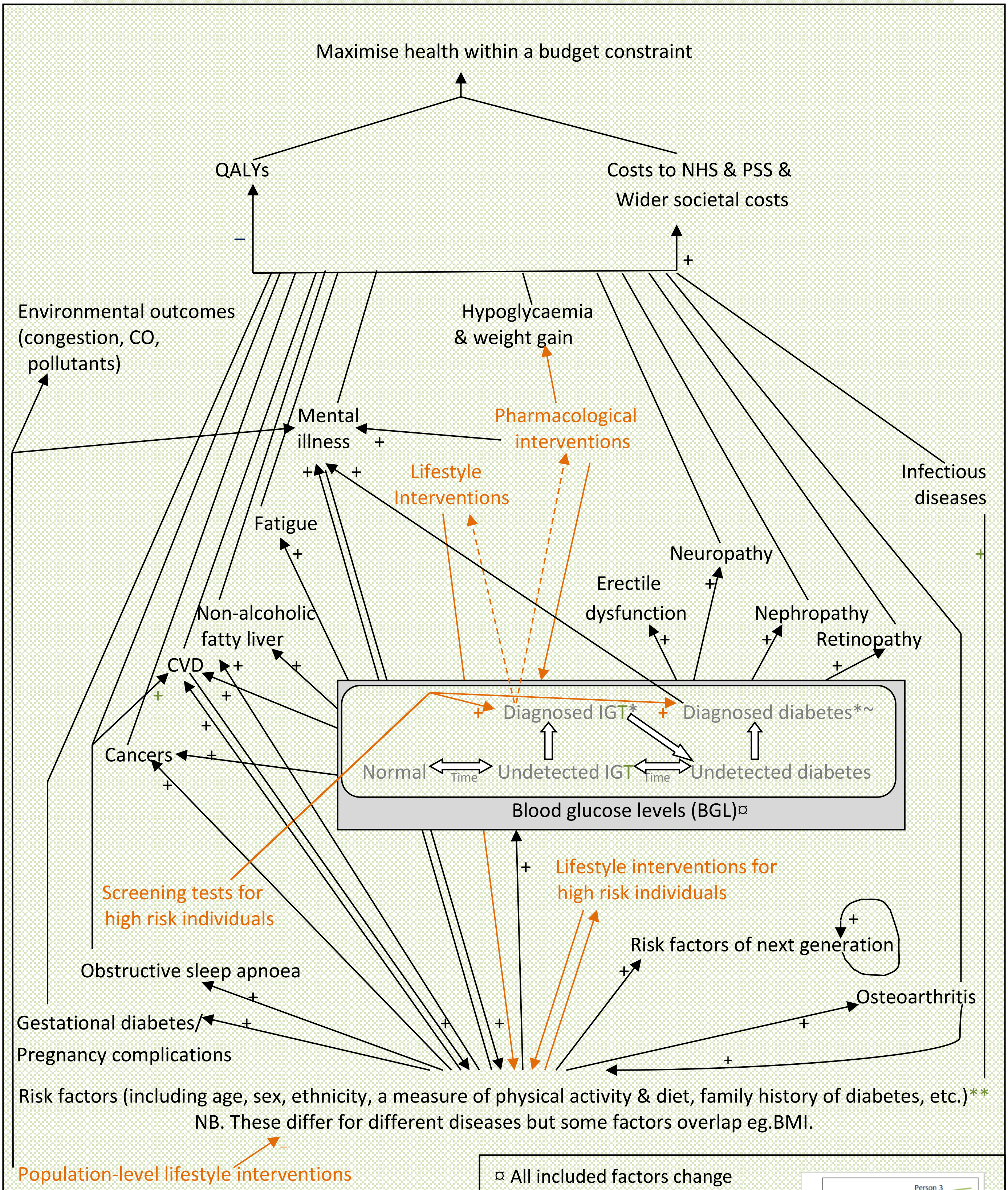
B2. Questions relating to the goals and mechanisms associated with the interventions are:

- What is considered to be a good outcome?
  Example: Would it be a good outcome if the intervention led to people understanding the benefits of healthy behaviours but chose not to adopt them?
- What would happen in the absence of the interventions versus as a result of the interventions – would negative outcomes be prevented or delayed?
- *Example: Would there be fewer diabetes and related-disease outcomes in total or would they simply be delayed by x years? What might x be?*
- What evidence exists to describe the outcomes of the intervention/ comparator over time? Are behavioural outcomes important? If so, do any relevant models of behaviour from psychology, sociology or behavioural economics exist to help describe the behaviour resulting from the intervention or the comparator? This will require additional targeted literature searches.
- Are there any determinants of health reported by the effectiveness studies which are not included within the causal diagram? Can such a relationship be described?
  Example: Access to healthy foods may be reported rather than diet, physical activity or weight-related outcomes.

B3. Questions relating to the dynamic complexity of the system are:

- Might a third party act to reduce the impact of interventions?
  Example: Might fast food restaurants increase advertising if sales drop as a result of the intervention?
- Are there any substantial impacts of social and/or community networks upon intervention effectiveness? Will these impacts be captured over the long term within the effectiveness evidence?
  Example: The intervention may be more effective if friends and family are also receiving it.
- Are there any substantial impacts of the interventions upon other lifestyle factors?
  Example: Healthy eating could also be linked to reduction in binge drinking.
- Might the interventions have other impacts not already considered?
  Example: Walking/ cycling interventions may be associated with environmental outcomes.

DIABETES PROJECT EXAMPLE

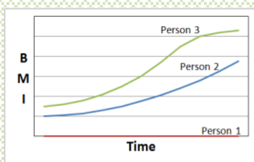


Potential interventions

Affects usage of alternative intervention

*Different tests (OGTT, FPG, HbAc) identify different individuals & diagnostic criteria have changed

¤ All included factors change over time, shown here in graphical form for BGL to highlight consideration of time



~This leads to screening for CVD & microvascular complications which will affect these outcomes. If BGL are decreased, the risk of complications may decrease even if the individual is still termed 'diabetic'.

**Risk factors may be worse in the future as lifestyles become more sedate

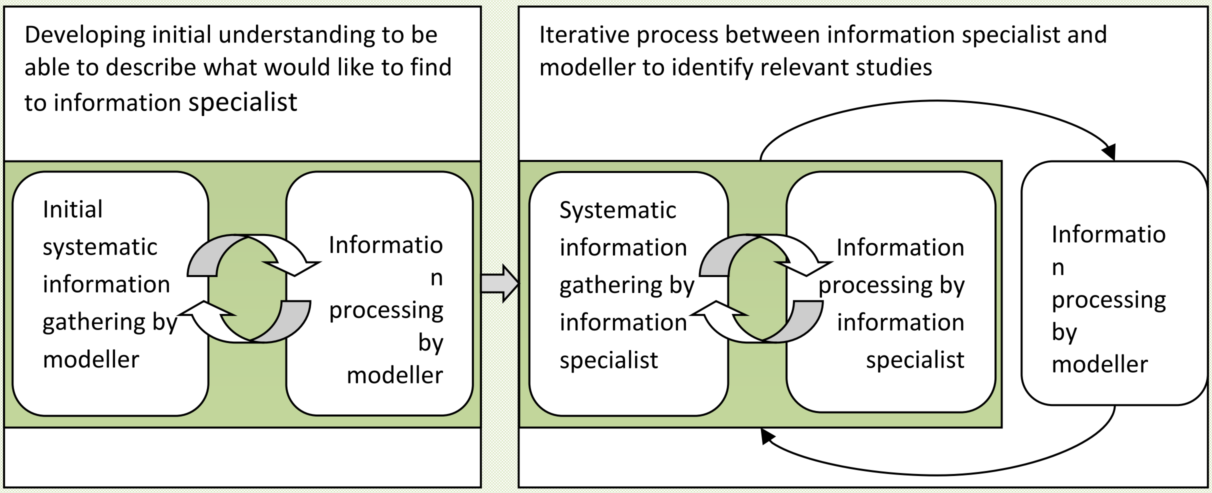
CVD, retinopathy & hypoglycaemia may affect driving ability

Process suggestions which may be helpful to modellers

<u>Literature searching for developing the conceptual model of the problem:</u> There is a dearth of defined methods associated with searching for evidence to inform the understanding of the problem and model development. A doctoral thesis by Paisley investigates how evidence to inform clinical intervention model development might be identified.[63] This thesis suggests that a range of methods are likely to be required, which may include using known sources of information such as a previous model (direct acquisition), a formal literature search to identify specific information (directed acquisition) and/or identifying information on one topic during a search for information on a different topic which allows new ideas and options to emerge, as well as evidence which may not be picked up by a standard search such as grey literature (indirect retrieval).[63] This process will be cyclical in that literature will increase the modeller's understanding of the problem which will in turn direct where to search next for data. The modeller may begin this cyclical process by thinking about which sources of information may provide an initial high yield of information about the decision problem.[63] For example, the modeller might begin by examining previous similar models and undertaking a broad search for reviews of the topic area. It is useful during this process to flag any literature which is identified which may be useful in specifying the structure of the model or model parameters.[63]

Paisley suggests that literature search strategies should focus on maximising the retrieval of relevant information using an efficient, dynamic approach such as Berry Picking or Information Foraging.[63] It is important to work closely with information specialists and reviewers and ensure that there is a shared understanding of what is required, particularly due to the dynamic nature of this type of search. The modeller has greater knowledge about the higher level goal, whilst the information specialist holds the searching expertise. Thus, a possible approach to information retrieval for understanding the problem and developing the model structure, based upon information theory, is described by Figure 7.5 below. Methods for reducing the iterations between the systematic reviewer and the modeller, such as the two working together in real time to identify appropriate search strategies, might be useful.

Figure 7.5: Information retrieval for developing the understanding of the problem and model structure



Use of existing economic models: One of the sources of evidence for understanding the problem may be existing economic models since they can provide useful information about the problem in an efficient way. It is important to be mindful that these may have been developed for a slightly different problem/ context. Moreover, it is important to understand the current decision problem in its own right without being led by how others have modelled the topic.

Mapping review for potential interventions: A useful approach which has been employed within the School of Health and Related Research at the University of Sheffield to facilitate the identification of potential types of interventions is to undertake a mapping review.[174] This involves carrying out an initial broad search to understand what sort of evidence is available for interventions which fall into the project scope in order to define a more specific search. If there are too many possible types of interventions to assess within the constraints of the decision making process, decisions about which types of interventions to focus upon should be made through discussion with the stakeholders. If stakeholders broaden the potential types of interventions being assessed, the conceptual model of the problem may need to be expanded accordingly to capture any additional impacts of the interventions.

Use of existing diagrams of the problem: The decision makers or other parts of the project team may have developed diagrams of their understanding of the problem. For example, within the NICE process, logic models are developed by the decision makers to describe the relationships between actions and outcomes, incorporating relevant theory, in order to inform the project scope, including highlighting areas for potential interventions.[5] The conceptual model of the problem may therefore build upon any other diagrams which have been developed by the rest of the project team or the decision makers, and importantly it should be consistent with them. If these diagrams were inconsistent, the reasons for these differences should be explained. Where such diagrams have not been developed, the conceptual model of the problem could be used for a similar purpose in terms of identifying potential interventions (according to potentially modifiable determinants of health) and informing the searches for intervention effectiveness evidence.

Stakeholder involvement: The extent to which stakeholders can be involved in the development of the conceptual model of the problem will depend upon the specific project as discussed previously, but it could be developed or validated during a workshop with experts and decision makers (as in Strategic Options Development and Analysis[139]). Group judgements tend to be more accurate than individual judgements, particularly if a facilitator ensures that all people have chance to input.[96] By each stakeholder sharing their beliefs and assumptions these can be questioned and discussed.[139] However, practically it is likely that more than one way of communicating with stakeholders and a flexible approach will be necessary. For example, if holding stakeholder workshops, those that cannot attend the full workshop may be able to join for part of it by tele- or video-conference, and/or to provide comments upon circulated documents so that these can feed into the workshop. It may be appropriate to hold workshops/ meetings around relevant conferences or meetings to *increase attendance. One-to-one meetings, telephone conversations and/or email communication may be employed in addition to, or instead of, workshops.*

<u>Stakeholder introductions:</u> Drawing upon Checkland,[123] understanding the worldviews of the stakeholders can help to:

-Explore different views and the reasons for these between the stakeholders;

-Identify concerns which may not otherwise have been identified;

-Assess the stakeholders' potential contribution towards the project rather than our expectation around what they may be able to input;

-Identify who it may be most appropriate to contact to ask specific questions or for clarifications;

-Put what the stakeholders say into the context of their worldview so that any assumptions about the world can be more easily identified;

-Ensure that future workshops/ correspondence aims to address the aims and motivations of the stakeholders so that they remain engaged within the project.

Thus, it may be valuable for each stakeholder to describe their perspective, what they think they can give to the project and what they would like out of their involvement either for 2-3 minutes at the start of the first workshop or within a paragraph of written text and for the modeller to refer back to these throughout the project. Within workshops, a 2-3 minute introduction also encourages each stakeholder to feel valued and gives each stakeholder chance to talk in order to promote later involvement in discussions.[123]

<u>Handling stakeholder disagreement:</u> Throughout this process it is important to question the assumptions of the stakeholders involved. If discussion does not resolve any disagreements between stakeholders, and there is no evidence to suggest a preference, then it may be due to value judgements, in which case it would be most appropriate to incorporate all alternatives within the understanding of the problem.

<u>Suggested processes if running workshops - project team requirements:</u> Providing some sort of description of the degree of consensus/ disagreement between stakeholders could help with model validity and credibility. A3 diagrams (eg. of the conceptual model of the problem at various stages of development) are a useful tool for stakeholders to share ideas and record them within workshops. When choosing whether or not to run workshops, the project team should be aware that the resource requirements during the workshops are substantial in order to facilitate, maintain engagement with the stakeholders, record what is said and process and collate information developed during the workshop. If the conceptual model of the problem is developed during the workshop, it could be developed using specialist computer software such as Group Explorer (which allows each member of the group to anonymously add to the diagram) or using a pen, post-it notes and a white board.[139]

<u>Suggested processes if not running workshops:</u> If resources, time requirements and/or availability of stakeholders do not allow for a workshop to take place, then it would be possible for the modeller to develop a

diagram of their perception of the problem based upon background reading and any previous diagrams developed for the project, and then circulate the initial version of the conceptual model of the problem for comment from the stakeholders.

<u>Causal assumptions:</u> It is likely that several versions of the conceptual model of the problem will be developed due to the iterative process of building up the understanding of the project team and stakeholders. Some evidence may suggest, or stakeholders may perceive, factors as causal (where one factor directly causes another) when in fact they are correlated (there may be a third factor which causes both outcomes so that they appear to be causal but are not). Causality might be well established for some relationships, such as the relationship between CVD events and mortality. For other relationships, background knowledge and literature should be used to be able to justify the causal assumptions made (see Figure 7.4). Econometric studies (for example, least squares regression, instrumental variables, structural equation models, propensity score matching) can be used to establish the statistical association between these specified causal relationships. Causality could be graded according to the strength of evidence which might be done visually within the diagram, for example, by varying the width of arrows as was done within the Foresight map of obesity.[41] In contrast to facilitation for problem structuring methods where the main benefits might be in terms of the learning that takes place whilst developing the diagram rather than the output of the diagram, the modeller needs to complete a diagram which will be useful for specifying and justifying the quantitative model structure.

<u>Depicting time:</u> Time lags between discrete factors could be highlighted by adding the term 'delay' to the arrows if there are substantial time delays between cause and effect, as for causal loop diagrams within system dynamics.[89] An illustrative graph depicting time could also be incorporated where time effects are unclear from the causal structure.

<u>Reporting the conceptual model of the problem:</u> Different colours, dotted lines or types of arrow can be used to depict different characteristics of the problem. More detailed notes can accompany the diagram. If the diagram becomes too unwieldy the ultimate aims could be removed and considered within a separate diagram or table since many of the factors are likely to link to these. The conceptual model of the problem can be input into the final report. The understanding of the problem may change; however, the diagram of the group's initial understanding provides a foundation for comparison should the understanding of the problem change at a later stage within the project, and this can then be documented.

As Roberts *et al*. suggest, the policy context of the modelling project needs to be clear, particularly in terms of the funder, the policy audience and whether the model is planned to be for single or multiple use.[18]

ii) Describing current resource pathways

Two conceptual modelling frameworks, by Kaltenthaler *et al.* and Roberts *et al.* were identified within the review in Chapter 4 which were specific to health economic modelling. They both explain the need to describe current practice in order to be able to make a comparison between the intervention(s).[14;18] Roberts *et al.* do not provide an explanation of how to describe current resource use; however Kaltenthaler *et al.* state that describing current practice is a complex information requirement which is unlikely to be fulfilled by doing one single search for evidence, and for which empirical effectiveness studies, expert advice and routine data may be consulted.[63] The description of current practice was also recognised within the qualitative research (see Chapter 5) as one of the pieces of information which may be obtained from stakeholders. Kaltenthaler *et al.* suggest developing a service-pathway model which is a diagram of the treatment pathways of the population being considered.[14] Within Public Health systems, resource use may be broader than healthcare, and thus such a flow diagram may or may not be appropriate. Based upon the critical reflection of the diabetes case study presented within Chapter 6, there should be two phases; first establishing very generally what sort of resource processes there are for key components of the conceptual model of the problem; and second describing resource use in detail during the justifying and developing the model structure phase.

The conceptual model of the problem phase can be used to inform what resources might need to be considered. This does not need to be a detailed description of resource use at this stage, since some factors within the conceptual model may be excluded from the quantitative model and hence it would be inefficient to collect detailed information. It also means that the general pathways can be validated with stakeholders prior to collecting detailed information. Flow diagrams, tables and/or a textual description of the resource pathways can be useful to inform assessments of the impact of the factors within the conceptual model of the problem upon the model results. This can be used to help choose which factors to include and exclude from the model as is discussed within the model boundary stage of the framework (see Section D(iii)).

DIABETES PROJECT EXAMPLE

For the diabetes case study, a number of flow diagrams were used from existing NICE guidance to describe the different elements of screening and treatment of disease.

C) Developing and justifying the model structure

This section aims to outline an approach for specifying an appropriate model structure for the problem which is feasible, valid and credible to develop into a quantitative model. As described within Figure 7.3, this includes: (i) reviewing existing health economic models; (ii) choosing model interventions and comparators; (iii) determining the model boundary; (iv) determining the level of detail; (v) choosing the model type, and (vi) developing a qualitative description of the quantitative model. This may be described as the design-oriented conceptual modelling phase, as defined by Kaltenthaler *et al.*[14]

The stages described above were chosen based upon the review of conceptual modelling frameworks (see Chapter 4), with an additional stage for reviewing existing health economic models based upon a finding of Chapter 5.

<u>Terminology</u>

Terminology used within other conceptual modelling frameworks, as described within Chapter 4, has been reviewed here. The term 'model interventions' has been employed rather than 'model options' since the former is the terminology which tends to be used within Public Health economic evaluation. In addition, the term 'model scope' has been replaced with 'model boundary' because the term 'scope' within health economic evaluation is so synonymous with defining the Population, Interventions, Comparators and Outcomes (or PICO), which is more narrow a consideration than is intended here.

Determining the model boundary involves deciding what factors are included within the model rather than being part of its external environment. The level of detail is defined as the breakdown of what is included for each factor within the model boundary and how the relationships between factors are defined. The model type is the analytic modelling technique employed, for example a decision tree, a Markov model, a DES, an ABS or a system dynamics model.

<u>Development of methods for developing and justifying the model structure</u>

The implications developed from the research undertaken within Chapters 2 – 5 (outlined within Table 7.2) provide a weaker theoretical basis upon which to develop methods for justifying and developing the model structure compared with developing the understanding of the problem phase. The analysis undertaken within the qualitative research (see Chapter 5) and the thesis by Paisley provide an indication about why this might be. The decisions made when choosing what is relevant for including within the model structure are complex and subtle and the criteria by which these judgements are made are unlikely to be known to the modeller.[63] Thus, whilst some of the methods proposed are based upon published evidence or the qualitative research described within Chapter 5, a substantial proportion of the methods within this phase are based upon reflecting upon previous Public Health projects, testing and reflecting upon this within the diabetes case study (presented within Chapter 6) and subsequently developing them further.

i) Reviewing existing health economic models

It is standard practice within health economic evaluation to undertake a systematic review of existing health economic models in the same area. Existing models may have been used to develop the understanding of the problem, but a systematic review at this stage can be used in a number of ways[175]:

- To determine whether there is already a model which could be used, either in part or as a whole, based upon your understanding of the problem;
- To consider the strengths and limitations of existing economic evaluations, which can be used to inform the model development, including considering the strengths and limitations of different model types in that area;
- To compare and contrast how other modellers have chosen to structure the model and estimate key variables, and how the model results differ based upon these choices. This may involve considering the use of mathematical relationships such as risk equations or parameters which have been included within previous models if their source and justification has been appropriately explained;
- To identify which variables are important in influencing model results (including any which have not been highlighted during the understanding of the problem phase) and which do not substantially affect the differences in outcomes between the interventions and comparators;
- To provide an insight into the sort of data available which may inform the level of detail included within the model.

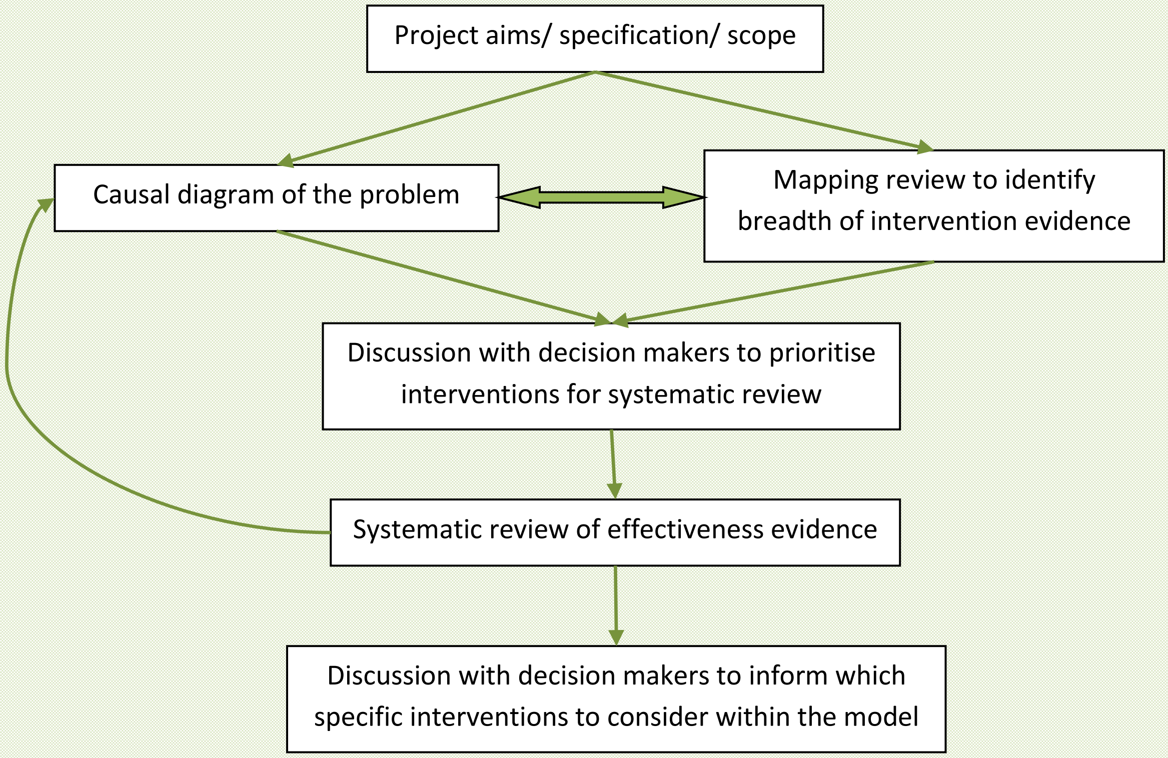
ii) Choosing model interventions and comparators

As identified within the review of conceptual modelling frameworks and the qualitative research (see Chapters 4 and 5), the current approach for choosing which specific interventions to assess within the model is not well defined, and this is variable between projects. Based upon the critical reflection within Chapter 5, it seems appropriate for decision makers to determine which interventions to consider within the model if possible, based upon evidence reviews and input from other stakeholders.

Method for choosing interventions to assess within the model

Specific interventions to be modelled can be defined from the types of interventions identified within the understanding of the problem phase. The decision makers (with consideration of the clients' needs if they are not the decision makers) should define which specific interventions to model grounded within the results of an evidence review and according to expertise from other stakeholders. Figure 7.6 shows how the specific interventions may be chosen based upon the project aims, the understanding of the problem and the intervention evidence review. Not all stages may be required depending upon the breadth of the study. If it was not possible to systematically review all potentially relevant interventions, then decision makers may have been asked to prioritise interventions to determine the inclusion and exclusion criteria for the systematic review at the understanding of the problem phase. The decision makers may use the systematic review of effectiveness evidence to further limit interventions by discussing trial populations, outcomes and other possible biases such as trial design associated with the effectiveness studies. It is possible that one good study or a number of studies can be used to estimate the short term effectiveness, depending upon the evidence available. As far as possible, the comparator can be based upon the same studies as the interventions if this is representative in practice. If practice is substantially different, then an adjustment on the effectiveness estimate would be required. Given that economic evaluation is a comparative analysis, the model results are only meaningful in relation to the comparators chosen.[18]

Figure 7.6: Choosing model interventions



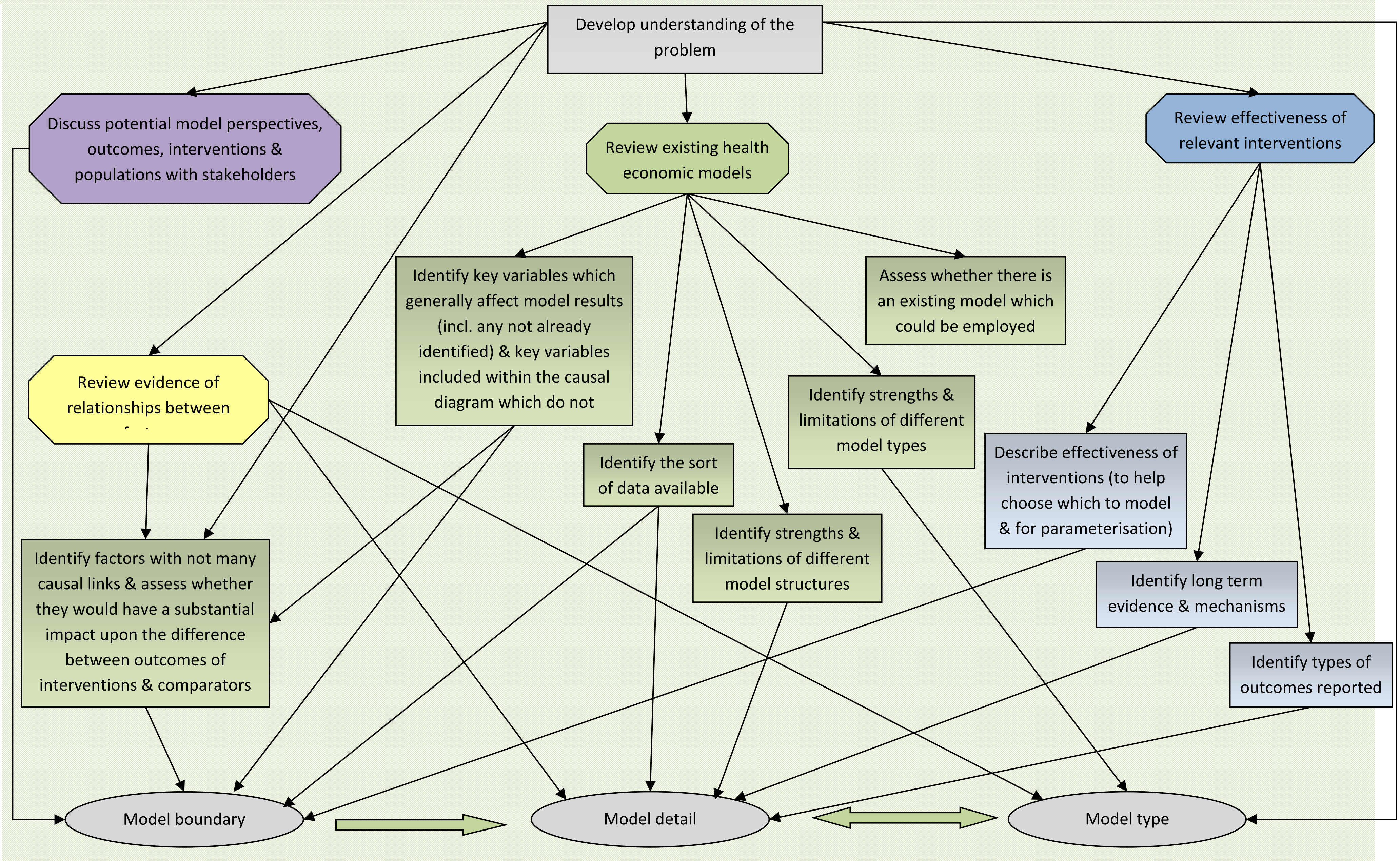
Extrapolation of study outcomes

Which outcomes the effectiveness studies report will guide the development of the model structure. For example, within the diabetes project, if all of the studies reported disease outcomes rather than physical activity/ diet outcomes, it may be appropriate to exclude these behaviours as explicit factors from the model structure. If the intervention has an effect, the mechanism behind the effectiveness can be discussed to develop assumptions for extrapolating these effects beyond the trial data (see level of detail section).

Use of the reviews to develop the model boundary, level of detail and model type

The review of existing economic evaluations and the review of intervention effectiveness can be used to facilitate decisions around the model boundary, level of detail and model type as shown within Figure 7.7 below.

Figure 7.7: Defining the model boundary, level of detail and model type



iii) Determining the model boundary

Determining the model boundary is about deciding, based upon the understanding of the problem, what factors should be judged as relevant for inclusion within the model and which can be excluded given the constraints of the decision making process. The boundary of the model structure must differ from the boundary of the understanding of the problem in order to be able to make informed judgements about what it is important to include within the model structure (see Figure 7.1). It is important to define the boundary of the model such that all important interactions between the elements of the system identified within the understanding of the problem are captured.[92]

Model perspectives and outcomes

Based upon the reflections of the diabetes study (see Chapter 6), the model perspectives, outcomes, interventions and populations/ subgroups should be discussed with stakeholders at an early stage of the project, particularly if the project question and scope have been developed by researchers rather than decision makers. Within Chapters 2 – 6, no methods were identified for choosing appropriate model outcomes and perspectives, thus a method for doing this has been developed based upon reflections of personal modelling experience, informal discussions with other modellers and application and reflection within the diabetes case study.

Often within health economic evaluation, the NHS and PSS perspective is employed.[3] However, within Public Health economic modelling, other perspectives are likely to be relevant because substantial costs and benefits may extend beyond these sectors. Alternative perspectives include (but are not limited to) a societal perspective, a Public Sector perspective or the perspective of the particular agencies involved within the system. The system owners identified within Section B of the framework can be used to identify key perspectives for consideration. For example, if employers are considered to be system owners, then it is likely to be useful to consider an employer perspective. It should be noted that there are currently unresolved issues around using these alternative perspectives in terms of (i) whether it is possible or desirable to make social value judgements associated with the value of health relative to the value of other costs and benefits and (ii) the practicality of transferring costs and benefits between sectors.[66] Nonetheless, if substantial costs and benefits are expected to fall outside of the NHS and PSS, presenting these alternative perspectives is likely to be informative for decision makers.

In order to be able to compare interventions across different populations in terms of health costs and outcomes, the incremental cost per QALY may be employed, based upon New Welfare

Economics.[2] Where the model boundary extends beyond health, it may be valuable to understand the modelling requirements in other sectors so that relevant outcomes may be presented. One way of presenting multiple outcomes for different sectors is to present a cost-consequence analysis alongside the cost-effectiveness analysis.[64;65;70] Decision makers can suggest which model outcomes it would be useful to report. For both perspectives and outcomes, the modeller should follow any specific requirements of the decision makers such as the use of the NICE Public Health Methods Guide. The method for choosing model outcomes and perspectives has been outlined in Figure 7.8.

Figure 7.8: Method for choosing appropriate modelling perspectives and outcomes

1) Consider what is theoretically appropriate and what is required under a reference case if applicable for (a) perspectives and (b) outcomes.
When considering (b) model outcomes, how do the model perspectives affect this?

↓

2) Consider by whom the results of the research will be used to consider whether additional (a) perspectives and (b) outcomes may be useful.

↓

3) Discuss with stakeholders those perspectives and outcomes identified within (1) and (2) and ask if there are any additional (a) perspectives and (b) outcomes that it might be useful to consider.

DIABETES PROJECT EXAMPLE

	NHS & Personal Social Services (PSS) perspective	**Employer perspective** *(given the number of workplace-based interventions)*	**Societal perspective**
The cost of…	The intervention and its delivery to the NHS and PSS	The intervention and its delivery to the employer	All costs of the intervention and its delivery (including to the patient)
	Diagnosis, treatment and follow up of the relevant diseases (for each disease) to the NHS and PSS		Diagnosis, treatment and follow up of the relevant diseases (for each disease) to the NHS and PSS and patients and carers (including travel costs)
		Lost productivity	Lost productivity
			Lost leisure time
Outcomes	Life years (LY) of the patient		Life years (LY) of the patient
	Quality-adjusted life years (QALYs) of the patient and carers		Quality-adjusted life years (QALYs) of the patient and carers
	Incremental cost per LY gained		Incremental cost per LY gained
	Incremental cost per QALY gained		Incremental cost per QALY gained
			Environmental outcomes

Model population and subgroups

The model populations can be discussed with the stakeholders, informed by the populations within the studies identified by the effectiveness review. The modelling team and the stakeholders could consider whether there is a bigger problem in a particular subgroup or whether the intervention is more effective in a particular subgroup and if there is sufficient data to undertake any subgroup analysis. These subgroups might be based upon the determinants of health outlined within Figure 7.2 including age, sex and other inherent characteristics of the population of interest, individual lifestyle factors, living and working conditions and access to essential goods, and general socioeconomic, cultural and environmental conditions.

DIABETES PROJECT EXAMPLE

The populations and subgroups of interest were:

- General population;
- Local communities;
- High-risk individuals including
  - Non-diabetic hyperglycaemic;
  - Women with gestatational diabetes;
  - South Asian individuals.

Additional model boundary considerations

Robinson defines four criteria for helping to determine the model boundary (see Chapter 4).[8] These include validity and credibility (the modeller and client's perceptions that the designed model will be sufficiently accurate for the purpose), utility (the client and modeller's perceptions that the designed model will be useful for the purpose) and feasibility (the client and modeller's perceptions that the designed model can be developed given the time, resource and data available). This criterion was used, alongside development and reflection within the diabetes project, to develop an algorithm to help modellers choose the model boundary.

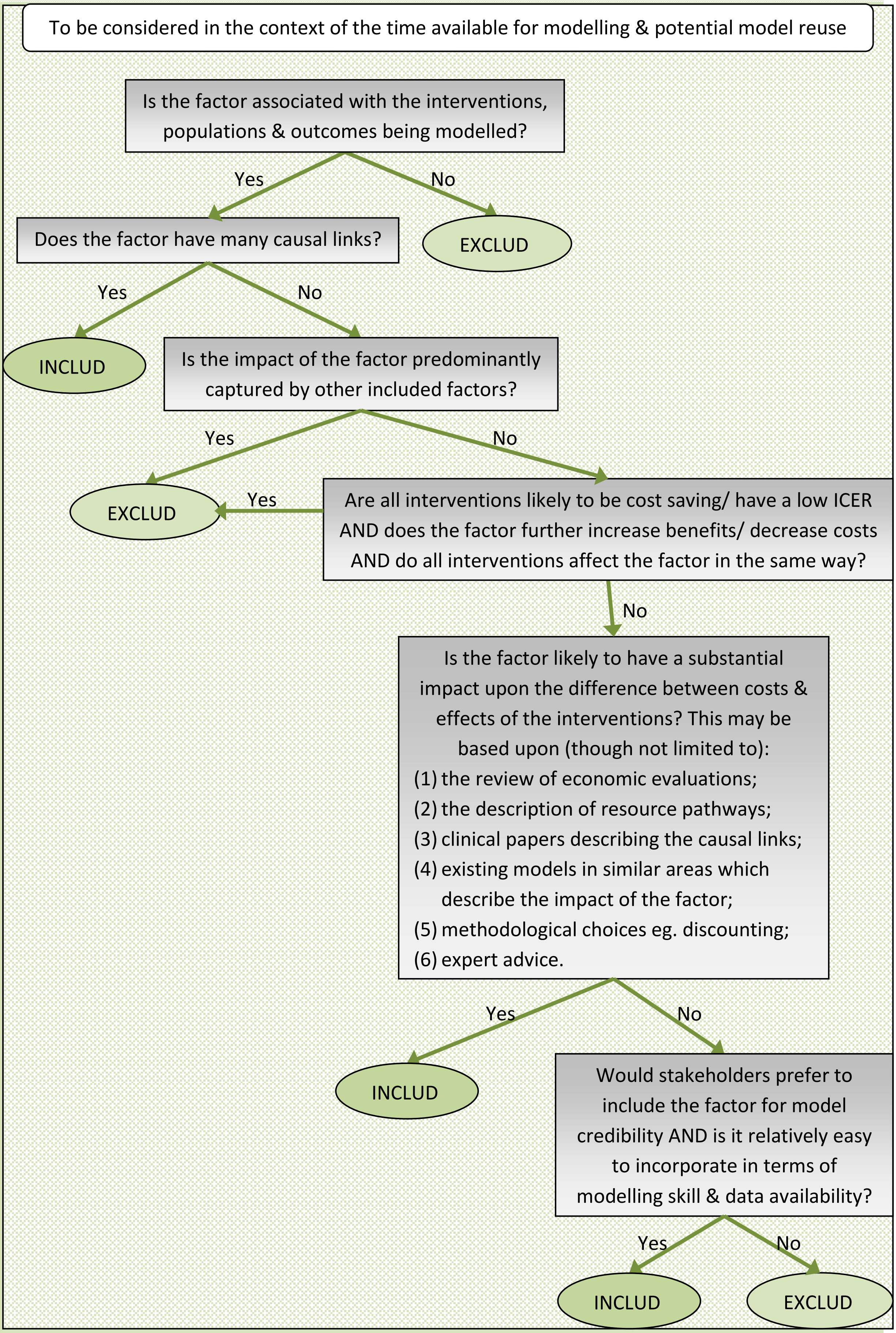
An algorithm to help define the model boundary is shown within Figure 7.9 and can be considered for each factor within the diagram. Within Figure 7.9, the question 'does the factor have many causal links?' aims to identify which factors are central and should be included within the model, even in the absence of data (lots of links), and which factors are less important (not many links to other factors). This can be done formally within computer software if preferred.[139] The question around whether the impact of a factor is substantially captured by other factors attempts to exclude any double counting within the understanding of the problem phase (for example, including fatigue and diabetes) as far as possible from the quantitative model.

It is valuable to predict very approximately the results of the model to facilitate model verification. These predictions can also help with defining the model boundary. Figure 7.9 encourages the modeller to think about whether it is worthwhile including non-central factors given the expected results of the model and the anticipated direction of effect of the factor upon those results, as well as the differential impacts of the interventions upon that factor. If different interventions impact the factor by different mechanisms, then including or excluding the factor may lead to different conclusions based upon the incremental analysis.

In terms of the question within Figure 7.9 around whether the factor is likely to have a substantial impact upon the difference between costs and effects of the interventions, this entails having an understanding of the magnitude of the cost and outcomes associated with the factor and the extent to which the interventions might change these. These subjective judgements will inevitably be considered in the context of the time available for modelling and the potential future uses of the model. Whether or not the factor will impact substantially upon the model results is a subjective judgement which, practically, may be influenced by the time available to develop the model. However, the model boundary stage should not be overly dependent upon the evidence or time available as this can be accommodated for by the level of detail incorporated. It is likely to be more appropriate to crudely include a factor which is expected to substantially affect the model results than to exclude it from the model completely.

Finally, in order to maintain the credibility of the model, stakeholders can be asked whether they are happy, given the above justifications, with the exclusion of factors. One way of reporting this stage is to produce a table of the excluded factors and the justification for exclusion as suggested by Robinson.[8] An example of this is illustrated below Figure 7.9.

Figure 7.9: Defining the model boundary



DIABETES PROJECT EXAMPLE		
Factor	Include/ exclude	Reason for inclusion/ exclusion
Risk factors	Include	Key component.
Blood glucose levels/Diabetes	Include	Key component.
Gestational diabetes	Include	As a subgroup of the population who will be given intervention.
Osteoarthritis	Include	From a random sample of 3664 members of the Dutch population aged >25 years, Tukker reports that 'for each unit increase in BMI respondents were 8% more likely to report OA or chronic pain' and the Foresight report highlights the high prevalence of osteoarthritis within the UK population. In addition, the report by Gillett et al. suggests that the cost of osteoarthritis is comparable to the cost of diabetes.
Risk factors of next generation	Exclude	Within the high risk group, only a minority of people will parent a young child due to the age of the people affected. Within the general population, Whitaker et al. suggest that parental obesity more than doubles the risk of adult obesity among their children, but because these costs and outcomes would occur so far in the future, by applying a discount rate to both costs and effects, there would be minimal impact upon the model results.
Hypoglycaemia & weight gain	Include (but not as a separate factor)	The quality of life implications of hypoglycaemia and weight gain will be captured within the quality of life of people with diabetes. The costs of hypoglycaemia will be explicitly included within the cost of diabetes treatment.
Non-alcoholic fatty liver	Exclude as a seperate factor	This is likely to be implicitly included within the costs and quality of life estimates associated with diabetes and obesity.
Fatigue	Exclude as a separate factor	The quality of life implications of fatigue are likely to be captured within the quality of life of people with disease. There will be minimal additional costs associated with fatigue above those associated with treating disease.
Nephropathy	Include	Key outcome associated with diabetes.
Retinopathy	Include	Key outcome associated with diabetes
Neuropathy	Include	Key outcome associated with diabetes.
Erectile dysfunction	Include (but not as a separate factor)	This is likely to be included within the costs and quality of life impacts of neuropathy.
Infectious diseases	Exclude	Relative to other model factors, this is likely to have a smaller impact upon the model outcomes.
Cancers (post-menopausal breast cancer, colorectal cancer)	Include	The report by the World Cancer Research Fund (WCRF) Panel on Food, Nutrition, Physical Activity and the Prevention of Cancer suggests that BMI and physical activity is associated with colorectal cancer, postmenopausal breast cancer and endometrial cancer. Prevalence of colorectal cancer and post-menopausal breast cancer within the UK population is high and they are associated with substantial impacts upon costs and quality of life.
CVD	Include	Has a substantial impact upon both costs and effects.
Mental illness (incl. dementia)	Include	The relationship between mental illness and diabetes is complex and currently not completely understood. Evidence suggests that approx. 18-28% of diabetics have depression (Egede 2005), which is substantially higher than within the general population and this has substantial impacts upon costs and QALYs.
Obstructive sleep apnoea	Exclude as a seperate factor	The relationship between risk factors and CVD is expected to capture those events resulting from obstructive sleep apnoea.
Environmental outcomes	Exclude	Majority of the interventions would not substantially affect this outcome; focus upon health-related outcomes.

iv) Determining the level of detail

The level of detail is defined as the breakdown of what is included for each factor within the model boundary and how the relationships between factors are defined.

Existing evidence for determining the level of detail

Within the review of conceptual modelling frameworks (see Chapter 4), limited consideration was given to making judgements associated with the model level of detail, and only two of the studies provide clear guidance. Kaltenthaler *et al.* provide a list of questions to help understand data requirements and data availability in the context of the decision problem, to encourage the modeller to think about requirements for extrapolation of trial evidence and consider what simplifications might be made and their implications.[14] Robinson suggests that the level of detail should be determined by the model inputs and outputs and the level of accuracy required.[8]

The decision about which parts of the model are likely to benefit from a more detailed analysis can be made *a priori* in order to avoid situations in which the modeller focuses upon specific parts of the model because they are more easily dealt with and subsequently run out of time to develop other parts in detail. Essentially, determining the level of detail involves a mini cost-benefit analysis within which modellers can weigh up, based upon the documented understanding of the problem and the defined model boundary, whether the time required to do one analysis at a specific level of detail within the model is likely to have more of an impact upon the model results compared with the same time period spent upon other analysis, given the current evidence available and the overall time constraints.

Key types of model assumptions and simplifications

Four key types of model assumptions/ simplifications were identified from the qualitative research (Chapter 5) and during the diabetes project (Chapter 6):

a) The relationship between the included factors over time;
b) The extrapolation of study outcomes;
c) The level of detail used to describe each included factor including the outcomes (eg. costs and utilities) associated with each;
d) How interventions will be implemented in practice.

For each of these, key questions for the modeller were identified based upon the types of judgements modellers make according to the qualitative research within Chapter 5 and my reflections upon the diabetes project.

Box 7.3 summarises key questions for the modeller to help choose an appropriate level of detail.

Box 7.3: Questions to help in making judgements about the model level of detail

General

1) Is the time required to do the analysis at a specific level of detail likely to have more of an impact upon the model results than the same time period spent upon other analyses, given the evidence available and the overall time constraints?

To describe the relationship between the included factors over time

- What outcomes are reported within the review of intervention effectiveness? (to help choose which causal links to include)
- What evidence is available to model the causal links and the outcomes of the factor? (to avoid relying on the first available evidence)
- What do other economic evaluations suggest are the strengths and limitations of different mathematical relationships between model factors?
- Which determinants of health are key drivers of the problem according to relevant theory?

To extrapolate study outcomes

- What outcomes are reported within the review of intervention effectiveness?
- What evidence is available for long term follow up?
- Is there sufficient evidence and time available to model social networks given the expected impact upon model results (based upon the understanding of the problem)?

The level of detail used to describe each included factor

- Which are the specific aspects of each factor that are likely to have a substantial impact upon the model results?
    - Is all costly resource use captured?
    - Are all substantial benefits and disbenefits captured using measures acceptable to the decision maker given the available evidence?
- Are impacts included within both costs and benefits where appropriate?

How interventions will be implemented in practice

1) What do the effectiveness studies describe?
2) What do stakeholders suggest would happen in practice and is this likely to lead to different estimates of effectiveness to those within the study?

Distinction between model assumptions and simplifications

Robinson highlights the distinction between model assumptions and simplifications; model assumptions 'are made either when there are uncertainties or beliefs about the real world being modelled' and model simplifications 'are incorporated in the model to enable more rapid model development and use, and to improve transparency'.[137] Thus, model assumptions are uncertain and alternative plausible assumptions can be tested within the model, whilst model simplifications are chosen because they are likely to have limited impact upon the model results. It is important to be explicit about both of these when describing the level of detail and highlight model assumptions which could be tested within sensitivity analyses.

Searching for evidence

Data for inclusion for specifying the model structure and for the parameters will need to be identified at this point if it has not been already. This could be based upon literature identified during the development of the conceptual model of the problem for which specific literature was noted as useful, although additional specific searches may also be required. Data collection and the development of a description of the level of detail for the model will be a highly iterative process. Sufficient evidence is required to be able to justify why the modelling choices have been made.[63] It is important to note that elements for which there is a lack of empirical data which are considered to have key differential impacts upon the comparator(s) and the intervention(s) may be informed by expert elicitation. One consideration at this stage is likely to be the derivation of the disease natural history parameters which may be taken from existing studies or calibrated using statistical methods such as the Metropolis Hastings algorithm.[176]

Reporting level of detail

The simplifications and assumptions should be described and explained, initially for communication purposes with stakeholders and the project team to develop model validity and credibility, but also to facilitate future modelling projects in the same area. A document can be developed which specifies all of the key model simplifications and assumptions for discussion with stakeholders, ideally within a second stakeholder workshop (see Appendix D5 for example from the diabetes project). This can help to identify the most appropriate evidence for the model and also improve model validity and credibility. Writing down all of the key simplifications and assumptions and their justification provides a mechanism for systematically questioning them within project team discussions and with the stakeholders; thus enhancing the appropriateness of the model simplifications and assumptions.

Expressing structural uncertainty

It may be that where there is more than one plausible assumption it is appropriate to develop model structures for each assumption in order to undertake posterior analysis of structural uncertainty, for example model averaging. This would be undertaken by creating a parameter to be included within the probabilistic sensitivity analysis to represent the probability of each structure being appropriate. This parameter and its distribution could then be estimated by elicitation with experts.[12]

The level of detail will be affected by the model type chosen, and hence it will be an iterative process between identifying an appropriate level of detail and choosing the model type.

v) Choosing the model type

Within the qualitative research described within Chapter 5, modellers suggested that it may not be possible or necessary within the constraints of the decision making process to develop the model type identified by a taxonomy based upon the characteristics of the problem. Based upon Chapters 4 and 5, six key issues have been identified which may affect the type of model structure developed:

- The most appropriate method for the characteristics of the problem;
- The requirements of the decision maker including time/ resources available;
- Data availability;
- The availability of and access to the use of existing relevant good quality economic models which could be used as a starting point;
- The expertise and previous experience of the modeller;
- The likelihood of the intervention being cost-effective in combination with the requirements of the model for future use.

These have been used to develop a method for helping the modeller choose the model type.

Most appropriate method given the characteristics of the problem

It is important to understand the most appropriate method given the characteristics of the problem, even if it is not practical to develop this model type, so that the modeller can understand the simplifications they are making. A number of existing papers outline taxonomies for deciding upon appropriate model types given the characteristics of the problem for health economic modelling.[124;134;135] The taxonomy developed by Brennan *et al.* is used here,[124] although others may be employed. It can be summarised by asking whether interaction, timing and stochasticity are important, and whether there is sufficient data for an individual level model rather than a cohort model, each of which leads to a preferred model type (see Table 7.4 over page). Whilst decision trees and Markov models are most often employed within Health Technology Assessment,[135] because of the complexity associated with Public Health systems it is likely that alternative model types may be more appropriate.

Agent-based simulation (ABS) is not included within the taxonomy by Brennan *et al.* (or any other health economic modelling taxonomies identified); however it may be useful for modelling dynamically complex Public Health systems and so has been added to the taxonomy. ABS is an individual-level simulation modelling approach and is compared with the individual-level simulation approach DES which is included within the taxonomy. DES is a top-down approach where the behaviour of the centralised system is defined by the modeller and entities within the model are passively affected by the rules of the system. Conversely, ABS is a bottom-up approach where the behaviour of the system is a result of the defined behaviour (based upon a set of rules) of individual agents and their interactions within the system.[122] These agents can learn over time. Therefore, DES may be preferable when the interaction between the agent and the environment is important (for example, a person has surgery which changes the probability of subsequent outcomes); whilst ABS may be preferable when the interactions between heterogeneous agents are important in addition to their interactions with the environment (for example, infectious disease modelling). Importantly, ABS more easily allows the analyst to capture spatial aspects in order to model appropriate interactions (for example, family and friend networks for transmission of a contagious disease).[122] Studies have shown such social network impacts of Public Health behaviours such as physical activity and diet.[177] Table 7.4 shows a revised version of Brennan's taxonomy with an additional row incorporated for ABS.

Table 7.4: Revised version of Brennan's taxonomy

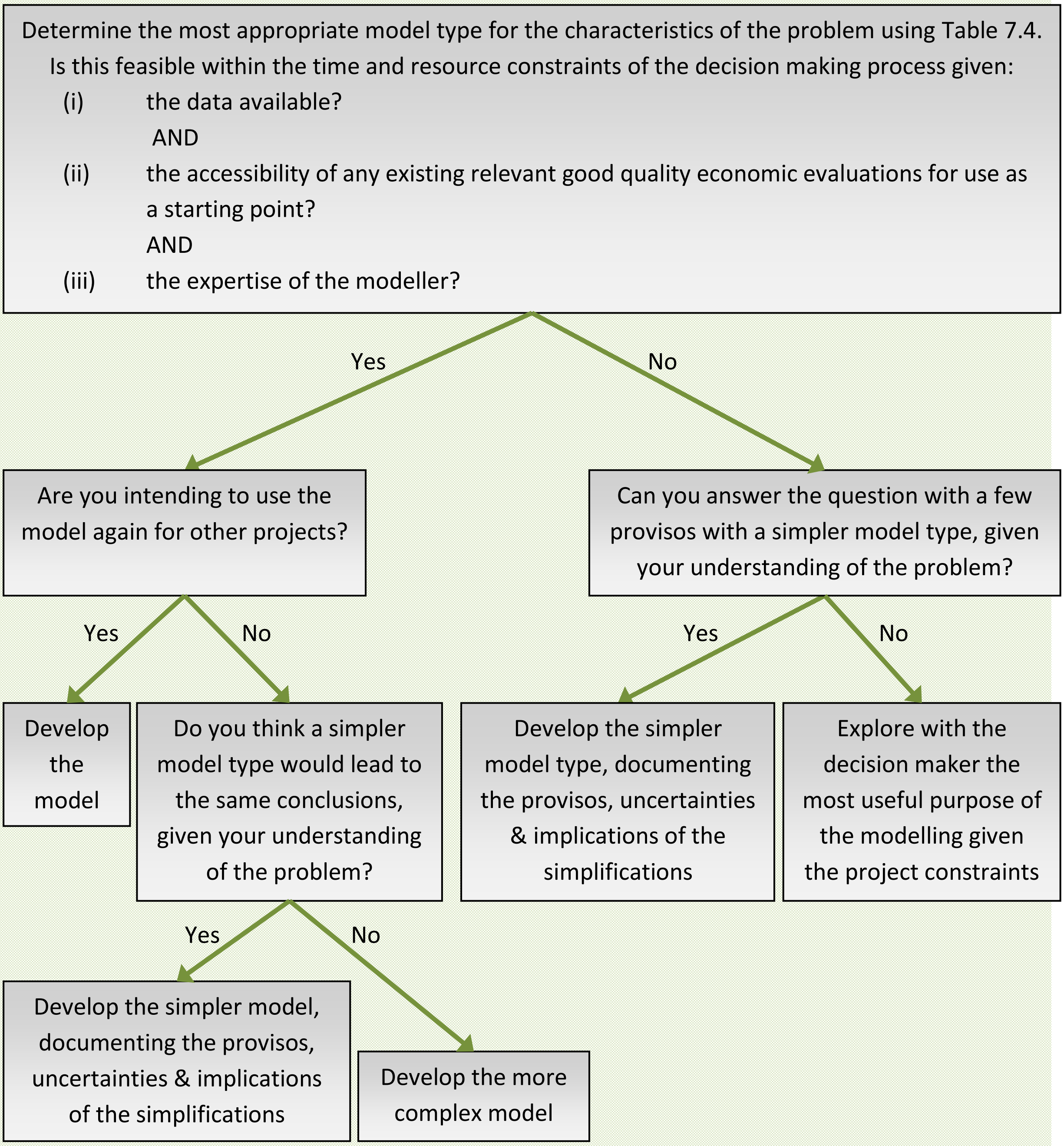
			A	B	C	D
			Cohort/ aggregate level/ counts		Individual level	
			Expected value, continuous state, deterministic	Markovian, discrete state, stochastic	Markovian, discrete state	Non-Markovian, discrete state
1	No interaction	Untimed	Decision tree rollback	Simulation decision tree	Individual sampling model: Simulated patient-level decision tree	
2		Timed	Markov model (deterministic)	Simulation Markov model	Individual sampling model: Simulated patient-level Markov model	
3	Interaction between entity and environment	Discrete time	System dynamics (finite difference equations)	Discrete time Markov chain model	Discrete-time individual event history model	Discrete individual simulation
4		Continuous time	System dynamics (ordinary differential equations)	Continuous time Markov chain model	Continuous time individual event history model	Discrete event simulation
5	Interaction between heterogeneous entities/ Spatial aspects important		X	X	X	Agent-based simulation

It is important to note that the choice of model type is not completely clear cut.[124] For example, it would be possible to incorporate some timing into a decision tree or to develop a system dynamics model with some individual level behaviour; however many of these ‘work arounds’ often become more time consuming to program than employing the more complex model type.

Most appropriate model type based upon broader considerations

It may not always be practical to employ the model type which is most appropriate for the characteristics of the problem. Figure 7.10 provides an outline of how the modeller might decide on the most appropriate model type according to broader practical issues.

Figure 7.10: Choosing the model structure



DIABETES PROJECT EXAMPLE

Within the diabetes project, the most appropriate model type, based upon the understanding of the problem and the revised version of Brennan's taxonomy was an agent-based simulation model. However, given the constraints of the project, a discrete event simulation was considered to be most appropriate and the provisos, uncertainties & implications of not modelling the social network effects of obesity were documented and highlighted as areas of further research.

vi) Qualitative description of the quantitative model

A qualitative diagram of the quantitative model alongside the development of the model structure can facilitate clear communication of the final model structure to stakeholders, other members of the team and people who may want to understand the model in the future. This will depend upon the model type developed but may take the forms outlined in Table 7.5.

Table 7.5: Suggested diagrams to represent the implemented model

Model type developed	Suggested diagram
Decision tree	Decision tree diagram
Markov model	State transition diagram
System dynamics	Influence diagram / stock and flow diagram
Individual event history model	State transition diagram
DES	Activity cycle diagram
Agent based model	A flow diagram

Whilst the design-oriented conceptual model can be specified prior to the quantitative model development, the conceptual model may be iteratively revised according to data availability and/or inconsistencies identified during the development of the quantitative model.[8;14;127;129] These modifications should be documented throughout so that there is transparent justification for the final model developed.

7.4 Chapter summary

This chapter collated the implications for methods development from Chapters 2 – 6 of the thesis and presented the conceptual modelling framework resulting from this research and the justification for the methods developed. The conceptual modelling framework used for evaluation within Chapter 8 (green shaded sections from this chapter) is presented within Appendix E.

Chapter 8: Evaluation of the conceptual modelling framework

8.1 Chapter outline

My research question is 'What might a conceptual modelling framework for Public Health economic evaluation comprise and what could its potential be to improve model quality?', where quality is defined as providing a tool for communication with stakeholders, aiding the development of modelling objectives, guiding model development, experimentation and reuse, and improving model credibility, verification and validation. This chapter aims to critically assess whether this research question has been addressed by:

1) Reflecting upon the theoretical basis of the conceptual modelling framework developed, including considering whether the framework might be associated with any negative implications for model quality;
2) Presenting the analysis of a second focus group of modellers providing their views on the utility of the framework.

The response of modellers and health economists to the conceptual modelling framework presented at a Health Economics Study Group meeting is also presented as an informal evaluation. Sections 8.2 and 8.3 present the methods and results of the evaluation respectively. A discussion of the evaluation is presented within Section 8.4 and Section 8.5 provides a chapter summary.

8.2 Methods of evaluation

A traditional positivist approach is not considered to be appropriate for the evaluation of this research, as discussed within Chapter 4. The review of conceptual modelling frameworks within Chapter 4 suggested that the most appropriate approach may be theory-based evaluation, alongside other forms of evaluation such as a case study and/or feedback from modellers or stakeholders. Therefore, the conceptual modelling framework is evaluated by the following methods: (i) a reflection on the theoretical basis of the framework; (ii) analysis of a second focus group of modellers which aimed to provide views on the framework developed; and (iii) as an informal evaluation I also consider the response of modellers and health economists to the conceptual modelling framework presented at a Health Economics Study Group (HESG) meeting. These methods are outlined in more detail below.

As discussed in Chapter 1, this thesis has focused upon the development of the conceptual modelling framework based upon the MRC guidelines that highlight the importance of adequate development of a complex intervention.[60] The methods described below aim to provide an initial evaluation of the framework. Further evaluation, reporting and implementation can be pursued within subsequent research and dissemination following this work. Future research may involve qualitative research collection and analysis from stakeholders and other modellers following their use of the framework within case studies. Throughout this chapter, I have adopted the first person so as to be explicit about my role within the evaluation.

8.2.1 Theory-based evaluation methods

The theory-based evaluation has four components;

1) My reflections upon the strengths and limitations of the methods employed to develop the conceptual modelling framework;
2) I consider how the key issues identified within Chapters 2 – 6 (see Table 7.2) have been incorporated and whether there might be further scope for consideration of some of these issues within the framework;
3) I describe the potential benefits of the framework by considering how it might help modellers to avoid the potential pitfalls described in Chapter 7 (Table 7.1, developed from Chapters 4 and 5);
4) I reflect upon the potential weaknesses of the conceptual modelling framework.

8.2.2 Qualitative research methods

<u>Data collection</u>

The qualitative research element of the evaluation of the conceptual modelling framework involved holding a focus group meeting with five health economic modellers. A focus group meeting was chosen for data collection as it can provide a range of views relatively quickly and encourages discussion and debate of different perspectives.[17] Participants were chosen and recruited as for the focus group which contributed to methods development described within Chapter 5. I identified different experts to those invited to the earlier focus group since it could be argued that the people who contributed to the development of the framework are less likely to be critical. The focus group was arranged to take place in Birmingham due to the ease of access for all participants. Further research ethics approval was obtained. In order to reduce coercion and for participants to be able to openly provide their views about the conceptual modelling framework that I had developed, I invited a colleague who had previously undertaken both health economic modelling and qualitative research to facilitate the meeting. I introduced the framework at the start of the meeting, but subsequently left the room; although I was in the next room in case anybody had any questions. The conceptual modelling framework was circulated three weeks before the meeting so that participants could read the document prior to attending. I developed a topic guide to inform the general structure of the session which was designed to facilitate critical assessment of the research question, including questions exploring the key benefits and issues of the framework and whether it has the potential to improve model quality, in what circumstances and for whom the framework might be beneficial and the requirements for successful implementation (see Appendix F for topic guide). The information sheet and consent form were similar to those developed for the qualitative research within Chapter 5. As for the earlier focus group, the meeting was audio recorded. The recording was transcribed by a transcription specialist and then checked for accuracy by me listening to the entire audio recording whilst reading the transcript.

<u>Thematic analysis and open coding of data</u>

As for the analysis of the earlier focus group data described within Chapter 5, I undertook thematic analysis.[159] Each sentence from the focus group transcript was copied across to an Excel spreadsheet into categories. These categories were developed gradually as I went through the transcript sentence by sentence, having already familiarised myself with the content by reading it through. All data were open coded in this way,[160] apart from any parts of the transcript considered irrelevant to the aims. This meant that all perspectives were included within the analysis. After open coding was complete, similar categories were grouped together into themes. The original transcript was also used within the analysis to note where participants had agreed or disagreed with each other, and how the quotations related to each other. For each open code, key points were identified and for each of these a quotation was selected according to whoever had made the point being described in the most succinct way.

8.2.3 Paper presentation at the HESG meeting

The HESG annual meeting was held the week following the focus group meeting. Unlike typical conferences, at HESG, all people attending the session are expected to have read a pre-circulated paper (shown in Appendix F) and another health economist or modeller will give a 20 minute Powerpoint presentation describing it. The author will then have 5 minutes to clarify any issues, followed by a 35 minute discussion with the other attendees. This discussion was not recorded due to ethical reasons, but it allowed an informal yet useful additional evaluation of the framework which I briefly reflect upon.

8.3 Results of the evaluation

My reflections regarding the four components of the theory-based evaluation of the conceptual modelling framework developed (See Section 8.2.1) are presented within Sections 8.3.1 – 8.3.4. The results of the qualitative research are described within Section 8.3.5 and my consideration of the HESG meeting feedback is presented within Section 8.3.6.

8.3.1 Strengths and limitations of the methods employed to develop the framework

Whilst quantitative and qualitative data analysis requires different types of evaluation, most researchers would agree that data analysis should be done in a valid (or credible) and reliable way.[58;156] Validity relates to whether the study measures what it is supposed to be measuring, whilst reliability has been defined as the extent to which research findings can be replicated.[58]

Validity/ credibility

Many qualitative researchers argue that it is not possible to validate qualitative data due to the difficulty of ascertaining the truth within the social world. However, they recognise that some way of assessing the quality of the research is required and suggest terms such as 'credibility' and 'plausibility' rather than 'validity'.[58]

The literature reviews followed an iterative approach to searching, although a clear aim was stated prior to undertaking the searches. There was more than one starting point for each review to avoid identifying studies in only one small area of the relevant literature, and citation, reference and author searches were undertaken for each relevant paper. Within the qualitative research, the combination of interviews and a focus group provided a pragmatic approach to obtain both depth and diversity. I chose participants purposively based upon their varied experience within Public Health economic modelling from different key centres around the UK so that the views presented would be relevant and comprehensive. For example, some participants had undertaken projects for NICE whilst others had not, and one participant was an expert in infectious disease modelling. I audio recorded the interviews and focus group meetings to obtain accurate data and checked the transcriptions by reading them whilst listening to the recordings. I attempted to identify alternative meanings for each piece of data and actively looked for data which might suggest opposing views. I also used literature sources to assess the validity of my findings where available, although due to the limited research in this area this was not possible for many of the findings. The cyclical learning process of diagnosis, planning, analysis and reflection taken throughout the research encouraged me to question my findings and adjust my subsequent activities accordingly.

The conceptual modelling framework was developed via a range of methods including two literature reviews, qualitative research involving analysis of my own notes, interviews and a focus group, and critical reflection of pilot use within a diabetes prevention case study. Since each method is associated with different potential biases, this methodological triangulation is useful to strengthen the validity of the results where they overlap.[58] Moreover, I actively looked for findings from the different methods of data collection which contradicted each other and no key inconsistencies were identified. The methodological triangulation also provides a more comprehensive analysis of the justification and requirements of a conceptual modelling framework for Public Health economic modelling. The variety of methods enabled analysis of both what modellers think and what modellers do in practice, derived from the qualitative research and the case study respectively.

Reliability

There has also been much debate about reliability in qualitative research. Some researchers argue that findings could not and should not be replicated because of the complexity and dynamic nature of the social world.[178] Seale suggests that complete replication is more of a practical problem than a philosophical issue.[160] For example, if the same respondents are asked the same questions again they are unlikely to provide the exact same responses. Lewis and Ritchie suggest that in order to assess the reliability of the analysis, qualitative researchers should describe the procedures which have led to the study's conclusions through reflexivity and carry out internal checks on the quality of the data and its interpretation.[156] Similarly, Mason suggests that researchers should focus upon the bigger issues of quality and rigour.[58]

I have endeavoured to document the systematic and reflexive approach taken throughout the development of the conceptual modelling framework so that the methods and choices can be questioned and justified (mirroring one of the aims of the conceptual modelling framework). For example, the literature reviews were undertaken using a systematic search strategy (see Appendix A and B) and a data extraction form was used to obtain information from the identified articles. For the qualitative research, I systematically coded each sentence of the transcripts in order to develop themes. I also described each change I made to the draft conceptual modelling framework resulting from the diabetes case study using critical reflection. I have described my position as a researcher throughout and the potential impact I might have upon the analysis.

A potential weakness of the qualitative research was that it may not have reached theoretical saturation and it was not possible to continue collecting data due to time and resource constraints (see Chapter 5 for further discussion of the methods). However, the point of saturation is a contested concept which is not precisely defined.[179] There was substantial overlap between the views within the depth interviews and the focus group meeting and some ideas were repeated within the focus group meeting, suggesting that sufficient data was collected to enable a reasonable analysis. Finally, it was not possible for a second researcher to check my coding within the qualitative research or to check study inclusion for the literature reviews.

Generalisability

The intention of the conceptual modelling framework is that it should be possible to employ it across any Public Health economic modelling context; however the generalisability has not been tested within this research. In addition, the conceptual modelling framework has not been used by other modellers who were not involved in its development. These are key areas for further research.

Further applicability of the framework

It has been suggested that the framework may be useful beyond the Public Health field. There is limited methodology for developing health economic models more broadly[17] and whilst this framework includes some aspects which focus upon Public Health (such as the broader determinants of health), they may be applicable in some clinical contexts and not all aspects of the framework need to be employed. Thus, whilst the intention of the framework is that it will be employed for helping modellers to develop Public Health economic models, it may be useful in other health economic projects. This would need to be tested within future case studies.

8.3.2 Verification that the requirements of the framework are addressed

Within Chapter 7, Table 7.2 specifies the requirements of the conceptual modelling framework based upon the implications of the research within Chapters 2 – 6. Each of these is considered in turn to assess how they are incorporated into the framework in order to verify that they are all addressed. This is tabled in Appendix F and suggests that all of the features which were identified as important within the research in Chapters 2 – 6 are incorporated within the framework. However, there are several areas where revisions to the framework or further research might be useful to improve the conceptual modelling framework.

Firstly, the version circulated to the focus group participants does not state that it is intended that the framework will continually be revised as appropriate, although this is stated within the discussion section of the HESG paper. Secondly, one of the requirements identified from Chapter 5 was that it is important to be clear about what the framework can and cannot do. This is broadly specified when describing the aim of the framework; however more detail could be added based upon the analysis of the focus group data and any future evaluation. The focus group evaluation highlights the potential for modellers to misunderstand the purpose of the framework and hence the importance of clearly describing the purpose (see Section 8.3.2). Similarly, the qualitative research within Chapter 5 highlighted that the framework should be culturally acceptable and simple to use in practice; however the qualitative research presented within this chapter suggests that there is currently too much text (see Section 8.3.2 for discussion of the format of the framework).

I would suggest that one of the weakest areas of the framework is in helping modellers determine appropriate and inappropriate simplifications of the problem. Within the conceptual modelling framework, Box 7.3 provides a set of questions which might help modellers think about the appropriate level of detail based upon the understanding of the problem and the model boundary. However, these questions only help the modeller to think about relevant tradeoffs rather than providing an approach to help the modeller make judgements about the level of detail. This may be because it is not possible to develop any useful algorithms to help choose an appropriate level of detail because there is such a broad and subtle range of factors affecting these decisions, and thus the most useful approach is to have a good understanding of the problem and consider the outlined questions within the framework. However, it may be that a better approach could be developed if the process of making these judgements about the level of detail could be better understood across a broad range of projects. It would be useful to investigate this within further research.

It is highlighted within the framework that equity might be an important aim within Public Health, however there is no further discussion of this from a Public Health perspective which may be helpful to modellers within future versions of the framework. The research within Chapter 3 suggested that the framework should consider heterogeneity as it is particularly important within complex Public Health systems. Questions around the determinants of health which highlight heterogeneity are included within the understanding of the problem phase and the benefits of including social network effects within the modelling and of using patient-level simulation are considered. In addition, the identification of subgroups for the modelling is considered within the *Determining the Model Boundary* stage of the framework. However, due to the potential importance of heterogeneity upon the model results, more detail could be provided around how this might be incorporated into the model. The framework suggests that modelling approaches such as agent-based simulation might be used to model the social determinants of health; however in practice the application of such modelling methods in Health Economics is absent. This means that most modellers would need more training and guidance around how to undertake these modelling approaches, which was considered outside of the scope of this work. Publishing work of the methods and application of methods which enable the social determinants of health to be incorporated such as agent-based modelling and social network analysis would be useful to help modellers when considering these approaches.

8.3.3 Potential benefits of the conceptual modelling framework

Two existing conceptual modelling frameworks for health economic modelling have been identified within the review presented in Chapter 4,[14;18] however both were developed for the economic modelling of clinical interventions. As discussed within Chapter 2, Public Health economic modelling is generally more complex than economic modelling of clinical interventions. The conceptual modelling framework developed within this research provides a systematic approach to developing a Public Health model structure, and in particular, systematic consideration of the broader determinants of health, dynamic complexity (feedback loops, unintended consequences), and the transition from an understanding of the problem to a description of the model structure. It also provides an approach for choosing and involving stakeholders. The framework provides new methods for:

A) Developing an understanding of the problem;
B) Defining the model boundary;
C) Defining the level of detail;
D) Choosing the model type.

A table of potential benefits and pitfalls which might be avoided by the use of a conceptual modelling framework was previously developed based upon the review of conceptual modelling frameworks presented within Chapter 4 and the qualitative research within Chapter 5 (Table 7.1). Table 8.1 overleaf provides an extended version of this table with an additional column describing the mechanism within the developed framework which addresses the potential pitfalls. An additional row has also been included to represent the benefit outlined within Chapter 1 that a conceptual modelling framework might help to characterise structural uncertainties and identify primary research needs. Table 8.1 suggests that the framework has the potential to prevent possible pitfalls in each of the areas in which they were identified in order to improve model quality.

Table 8.1: How the conceptual modelling framework helps modellers avoid potential pitfalls

Potential benefit	What pitfalls can be avoided	Mechanism within the framework
To aid the development of modelling objectives	➢ Answering the wrong (or less useful) question with the model.	➢ A method for developing a conceptual model of the problem which begins with the key problem and is subsequently developed alongside stakeholders to describe relevant hypothesised causal relationships, including specifying relevant outcomes.
To provide tools for communication with stakeholders	➢ Representing a contextually naïve and uninformed basis for decision-making, including misunderstandings about the problem, producing unhelpful model outcomes, and incorporating inappropriate and/ or invalid model assumptions. ➢ Ignoring variations between stakeholders' views. ➢ Process/model results not trusted by stakeholders.	➢ An approach for considering all stakeholder types, encouraging capture of different perspectives. A method for developing a conceptual model of the problem describing hypothesised causal relationships, beginning with the key problem and linking this to relevant outcomes and systematically considering the broader determinants of health, followed by a transparent approach to describing the model structure based upon the understanding of the problem. ➢ Highlighted as a consideration within the understanding of the problem phase. ➢ The approach presented is transparent for stakeholders to follow.
To guide model development and experimentation	➢ Inefficient model processes (eg. repeatedly making structural changes to the implemented model) ➢ Inadequate analyses	➢ A method for documenting the understanding of the problem based upon hypothesised causal relationships, with accompanying questions for the modeller to help identify relevant issues including feedback loops, interactions and the broader determinants of health, and then considering model structure with stakeholder input prior to developing the quantitative model. ➢ The recommendation to involve stakeholders during both the understanding of the problem phase and the model structuring phase to produce useful analyses.
To improve model validation (developing the right model)	➢ Answering a less useful question with the model. ➢ Misunderstanding the key issues associated with the problem. ➢ Using the first theories identified from the evidence to develop the model. ➢ Not having a basis for justifying the model assumptions and simplifications.	➢ See row 1 of table. ➢ Documenting the understanding of the problem so that it can be questioned and discussed by stakeholders and the project team. ➢ The framework specifically warns against this. Documenting the difference between the understanding of the problem and the model structure encourages modellers to think about these judgements. ➢ Documenting the understanding of the problem provides a basis for justifying the model assumptions and simplifications.
To improve model verification (developing the model correctly)	➢ Not having an explicit description of the model with which to compare the implemented model.	➢ Documenting the model structure, through: (1) tabling the perspectives and outcomes and describing the interventions, comparators and populations to assess; (2) tabling what is included and excluded within the model (and why) compared with the understanding of the problem; (3) recording key model assumptions and simplifications with justification; (4) Providing a diagram of the model structure.
To allow model reuse	➢ Other experts not being able to identify key model assumptions/ simplifications and why these have been made.	➢ A transparent reporting process from documenting the understanding of the problem to describing the model structure.
To help characterise structural uncertainties and identify primary research needs	➢ Ignoring structural uncertainties. ➢ Not improving the evidence base for future decisions.	➢ The conceptual model of the problem should highlight any areas of disagreement between stakeholders which can be used to highlight primary research needs.

8.3.4 Potential weaknesses of the conceptual modelling framework

Drawing upon systems thinking, it is important to consider whether there might be any unintended negative consequences of the framework. As suggested by the qualitative research within Chapter 5, model development is necessarily constrained by the time and resources available within the decision making process. Using the proposed conceptual modelling framework takes time; in particular, communicating with stakeholders throughout model development and providing explicit documentation around the understanding of the problem and the justification for the model structure may increase time requirements compared with current practice. Whilst the modeller is spending time on these, they are not spending time on other modelling activities. In order that the framework does not lead to negative outcomes, the benefit of undertaking these conceptual modelling activities must be at least commensurably large. Section 8.3.3 highlights the many potential benefits of the conceptual modelling framework which indicates that the opportunity cost associated with these activities is likely to be lower than that associated with other modelling activities. In addition, Robinson highlights the importance of conceptual modelling as the first part of a modelling project, which guides and impacts upon all other stages.[49] Moreover, the framework includes an explicit phase, Phase A (aligning the framework with the decision making process), for considering how much time might be spent upon each modelling activity. Previously, this process may not have been undertaken *a priori*. This phase highlights that the time spent on conceptual modelling activities should be flexible such that the modeller can consider how the framework should be used according to the decision making context. See Section 8.3.5 for further discussion of this within the evaluation focus group analysis.

As with any guidance, the conceptual modelling framework may be subject to misuse. An example of this is the Liverpool Care Pathway for which a 2013 review suggested that the core principles were appropriate for improving quality of care but that the implementation led to a reduction in quality.[180] The review criticised the fact that the document was treated as a 'tick box exercise' which takes insufficient account of individual circumstances and that the document is not a substitute for staff training. Similar issues could arise from the use of the conceptual modelling framework; indeed the comments from the focus group participants around reducing the document to a checklist (see Section 8.3.5) indicated a propensity for movement in that direction. A checklist may promote a sense of complacency whilst an intention of the conceptual modelling framework is that it will help modellers to think about their approach and avoid making assumptions without questioning them. Thus, it is important to be clear about the aims of the framework and how it should be used, and this could be improved within the current version (as also discussed within Section 8.3.2).

8.3.5 Results of the qualitative research

Three key themes were identified from the focus group data analysis; (1) The potential of the conceptual modelling framework to improve the quality of models; (2) Current format of the conceptual modelling framework; and (3) Specific comments on the content of the conceptual modelling framework. These themes are considered in turn within this section. The modellers within the focus group made an assumption that because they were presented with this document that the framework would be disseminated in this way. Thus, much of the discussion is focussed around the current format of the conceptual modelling framework, with the participants expressing that the document needs to be more user friendly.

Theme 1: The potential of the conceptual modelling framework to improve the quality of models

My research question is 'What might a conceptual modelling framework for Public Health economic evaluation comprise and what could its potential be to improve model quality?', where quality is defined as providing a tool for communication with stakeholders, aiding the development of modelling objectives, guiding model development, experimentation and reuse, and improving model credibility, verification and validation. The focus group participants considered whether the conceptual modelling framework developed does have the potential to improve the quality of Public Health economic model structures. The definition of quality specified above was not described by the facilitator; however all of the above aspects of quality were considered to some extent by the participants. Aiding the development of modelling objectives is considered within Theme 2. The subthemes are not directly aligned with these attributes of quality because of the way participants raised the issues. The six subthemes are: (i) Difficulties with assessing the quality of models; (ii) Guiding model development; (iii) Model justification; (iv) Model communication; (v) Applicability to different contexts; and (vi) Dissemination.

Difficulties with assessing the quality of models

All of the focus group participants said that the conceptual modelling framework had the potential to be useful. However, the difficulty with assessing the quality of models, discussed within Section 8.2, was reiterated by the participants when they were asked in what ways the conceptual modelling framework might improve model quality.

> *Modeller 9: "Well I think your question supposes that we know a way that we can measure successfulness of Public Health models, and I'm not sure that we do. How do we measure whether a model is an effective model or not?"*

The participant is highlighting the difficulty of assessing model quality, and hence the problem with evaluating the conceptual modelling framework developed. The use of the term 'measure' suggests that the modeller believes that the only way to assess quality is quantitatively, but as participant 12 says, "*you don't know the truth"*, implying that it would not be feasible to compare model results with real data. Modeller 9 uses the terms 'successfulness' and 'effective' when asked about model quality, which implies their interpretation of model quality is to produce a model which will help decision makers make the right decision. This echoes the participants of the first focus group who emphasised that model development was not an end in itself but a tool for facilitating decision making. It would suggest that model quality might alternatively be assessed by retrospectively assessing whether the right decision was made based upon the model; however this too would not be feasible due to the absence of a comparator. Whilst the participants do not suggest a viable approach for assessing model quality, they do begin to make some inferences about how the conceptual modelling framework might be useful.

Guiding model development

Many of the modellers highlighted that the conceptual modelling framework could help with guiding model development in terms of helping to identify the key issues.

> *Modeller 9: "I think a document like this can certainly be important in encouraging people to think about the key issues that they should be thinking about to produce a decent model... ...it could be useful in encouraging us to be more critically aware of some of the key aspects of how we produce models and what things need to be included."*

This participant suggests that models are developed habitually rather than the modeller thinking about the conceptual modelling process consciously. They imply that there is no existing document outlining the conceptual modelling process for Public Health economic evaluation and that documenting how models might be produced could enable modellers to critique that process. This relates to the discussion within Chapter 1 about whether modelling is an art or a science. If the conceptual model development process for Public Health economic evaluation is not written down it makes it difficult to critique the model development process. The conceptual modelling framework document provides a starting point for modellers to be able to discuss the model development process in Public Health economic evaluation, even if they would want to make revisions to the conceptual modelling framework developed.

Modeller 8 highlights that a benefit of the conceptual modelling framework would be consistency across projects.

> *Modeller 8: "I guess it would introduce some sort of consistency and you'd know that people were considering the same issues as they were developing these models, so that would be one advantage. I guess that there is quite a lot of variability depending on who is doing these things."*

This participant implies that there is a lot of variability in approaches. They suggest that modellers may not consider all relevant issues when developing Public Health economic models and, as also suggested by Modeller 9 above, the conceptual modelling framework could help modellers to identify these.

Model justification

Model justification may improve model validity, verification and credibility and facilitating model reuse.[1] Modeller 10 suggests that the conceptual modelling framework could help with justifying the model assumptions and structure.

> *Modeller 10: "And also the justification for everything else, in terms of the assumptions, the structure, I think that's important as well... …one of the comments here that I thought was very important but I didn't really know what it meant was to document your understanding."*

This modeller recognises that justification of the model structure and assumptions is important. They do not go on to say why justification is important, perhaps because the advantages of this are considered to be obvious. Modeller 10 also recognises that part of the model justification stems from documenting the understanding the problem; although, it is of concern that they do not know what this means given that much of the document outlines a method for documenting that understanding. This may be related to the current form of the document not being user friendly (see Theme 2). However, modeller 8 implies that they do know what it means to document the understanding of the problem (see Model communication subtheme).

Modeller 8 agreed that justifying the model structure is important, but that they may not do this for an uncontroversial model within a time constrained process.

Modeller 8: "It (justifying the model) is obviously good practice, I mean, I think perhaps to me [what] didn't come out as much in this document as it could do is, there's obviously, there's ideal practice, I mean it's like the how detailed does your model need to be, you can have an ultra detailed model but a lot of detail's unnecessary; I think that it's also the same with how much effort one goes into justification of the model you know. [In] some circumstances, for a straight forward model, with time limitations, [it] makes sense to do something fairly brief. With other models, where perhaps it's more controversial, then it's more necessary to adopt those processes."

The modeller suggests, as highlighted within the qualitative research in Chapter 5, that there are typically time constraints around the decision making process and if the modeller is spending time justifying the model structure, they are not spending time on other modelling activities. This is an important practical consideration as discussed within Section 8.3.4. The modeller is suggesting that as model controversy increases, the benefits of justifying the model assumptions increases. I would suggest that if there is less controversy, then model justification is likely to take less time (for example, less time is required to understand and document the problem, the data is likely to be more consistent, existing models may show what factors are likely to be important within the model, there may be well established causal relationships, and so on). Thus, time requirements associated with model justification are likely to be relative to the benefits of doing this. Moreover, Phase A of the conceptual modelling framework highlights that the framework should be adapted according to the specific requirements of the project. Thus, I would suggest that model justification is always good practice, but that the same level of justification is not required for each model developed.

Model communication

All of the participants agreed that the conceptual modelling framework might help with communication of the model developed.

Modeller 9 suggests that the conceptual modelling framework would "*allow communication within the team and to help the project manager time things so that they are in the right place."* In addition, several of the modellers highlighted that it would be useful for communication with stakeholders.

Modeller 11: "And I think this sort of framework is also quite useful, building on your point really, for communication as well isn't it, for stakeholders and people like that because you can *actually show what processes you have gone through to get to where you have got to. Where it is often quite difficult you know to explain things sometimes to clinicians and stuff. That would actually help make you think about why did I make that decision, or why am I doing it like this."*

This modeller implies that it is useful to be able to justify the model that is developed to stakeholders, which may be difficult, and the framework provides a way of doing this. They do not explicitly specify why this is useful, but imply that it is related to model credibility. They also suggest that by documenting the conceptual modelling process this in itself will help the modeller critically evaluate why they are making the decisions they are. Modeller 8 agrees with this and highlights that conceptual model documentation would be useful for model reuse to avoid repeating work.

Modeller 8: "I mean it obviously is useful to write things down and perhaps one is not always very good at it, because in the early stages I think it is easy to think along certain ways and perhaps be driven a bit by the literature that you find in terms of the associations so it obviously is good practice to write down, explicitly, why you've selected what you have selected, and what you have ruled out, if nothing else if somebody else is there looking at that work and wanting to build a model in that area they can say, yes although this isn't in the model they explicitly ruled it out because, rather than oh they didn't think about it, I need to go and investigate whether it's necessary."

This modeller suggests that whilst it is obviously good practice to write down the process the modeller has followed, it is not necessarily done in practice. They imply that by writing down why things are done it will encourage modellers to explore alternative model assumptions rather than using the first structural assumption identified. This also indicates that this modeller has an appreciation of the approach for documenting the understanding of the problem in contrast to modeller 10 (see Model Justification subsection).

The same modeller expresses that documenting the conceptual modelling process would also help the modeller that has developed the model know what they have done and why in the future.

Modeller 8: "And to help yourself remember, you know sometimes these projects can go on for some time and you know 8 or 9 months down the line you're asked why didn't you include this and you sort of think... (group laughter) and I am sure we have all been there!"

This modeller implies that it is common practice not to be able to answer questions about why the model is structured as it is after the project has finished because it has not been formally documented. The laughter implies identification from the other modellers with this problem.

Applicability to different contexts

One of the requirements of the conceptual modelling framework developed from the qualitative research presented within Chapter 5 was that it should clearly specify what it can and cannot do. Modeller 11 suggests that one potential weakness of the conceptual modelling framework is that it is quite theoretical because it has to apply to such a range of topics which constitute Public Health.

> *Modeller 11: "I agree with you that to get something generic is extremely difficult because of all these examples are very varied. And that's why we have a document like this, that's quite abstract, because how do you get to specifics when, you know, it's very, very difficult. And [with] the examples I've done it's very hard to see similarities across [them], you know, they are very, very different from each other. And I don't know how you get round that; that's why at the beginning I said that this is extremely ambitious because to get something that's useful it sort of has to apply to all the different areas, and to achieve that, I don't know, it's very hard."*

The participant implies that it is appropriate that the conceptual modelling framework aims to apply to the broad and varied area of Public Health economic modelling in order to be useful rather than having a framework for a particular Public Health topic. However, they suggest that this is a difficult task and perhaps the current version of the framework has not quite achieved this. This may relate to the current format of the framework discussed within Theme 2, where one solution would be to include more examples. This could be tested within future research within different case studies.

The participants also highlighted the diversity of Public Health decision making contexts. Modeller 9 thought that the framework could be useful in a range of contexts by applying it in different ways.

> *Modeller 9: "Going to the other example of the work with Public Health that we have done, it was very different from that where we talked to the Public Health Intelligence Team. They didn't have a clear question, they knew they had a kind of issue that they wanted to tackle, but they didn't specify it clearly. So, you know, I think that there are many, many different contexts*

under which you might want to do an economic model in public health and in some of those contexts this framework might be extremely useful... ...I think that it could potentially be useful in either situation but it could be applied in very different ways and the flavour of the framework that you might need in those different situations might vary."

This modeller provides an example of different contexts in terms of the status of model specification, but they imply that there are lots of ways that the context may vary, and that how the framework is used can be adjusted accordingly. In contrast, another modeller questioned whether it is the role of the modeller to help define the interventions given that they had previously been given a scope which precisely defined the interventions. A discussion highlighted that the participants had different experiences of this in different contexts, but within this discussion the modellers did not recognise that the conceptual modelling framework is designed to be moulded according to the particular decision making context as described within Phase A of the framework. Again, this may be due to the current format of the conceptual modelling framework (see Theme 2). There was also a debate between two of the modellers around whether the conceptual modelling framework could be used for infectious disease modelling.

Modeller 12: "No no, that (infectious diseases) is completely different. I want to rule that one out from this stuff here anyway, that's a different question."

Modeller 10: "I'm not sure if it is because we do cover issues like, I mean we have got a model where what happens to one patient impacts on the next patient because as soon as you have got patient interaction you are beginning to think in terms of the techniques used in infectious diseases... ...I think one of the things that is very, very important actually is on page 42; the revised version of Brennan's taxonomy... ...it covers these issues of interaction and that's what it is really, this issue of interaction."

Modeller 12 states that infectious disease modelling is a different sort of question, whilst modeller 10 argues that it is not distinct because as soon as there are patient interactions it is a similar type of problem. He supplements this with an example within the framework of where patient interactions are considered. Thus, modeller 10 presents a strong argument for why the framework is appropriate for use within infectious disease modelling.

When asked about the use of the conceptual modelling framework for modellers with different levels of experience, modeller 8 suggested that the framework "*could be useful to anybody"*.

Dissemination

The modellers proposed different ways of encouraging the use of the conceptual modelling framework; one is to use it and publish its use, the other is to get it cited in the NICE Public Health methods guide. There was agreement that the latter of these options would be effective quickly, certainly in the NICE context, if it was possible, although both options could be attempted.

> *Modeller 10: "I think that I would use it and acknowledge its use, say that we have used this, and that would be one way, and that would be a very slow drip process of doing it, I mean what's one publication, but I think that it's important that if you use these things you acknowledge them because, over time, it does add credibility to what you are doing."*
>
> *Modeller 11: "The other thing is to get it cited in the NICE method Public Health guide."*

Modeller 10 refers to the credibility of the framework and suggests that this could be increased by having published examples. This implies that the framework must have been shown to be useful before modellers will adopt it. Thus, further work could involve the application of the conceptual modelling framework within different case studies and the publication of this work.

Theme 1 Summary

The modellers agreed that the conceptual modelling framework has the potential to improve the quality of Public Health economic models although, as will be discussed within Theme 2, perhaps not in its current format. The modellers did highlight difficulties associated with assessing the quality of these models, as highlighted within Section 8.2. When describing aspects of the conceptual modelling framework which might be beneficial to model quality, the modellers made some assumptions which were not questioned about why this ultimately might be. For example, the modellers highlighted that the conceptual modelling framework might improve model justification, although they did not explain why this is important. The modellers suggested that the framework might guide model development by helping the modeller to identify key issues, which would also introduce some sort of consistency. They also highlighted that the conceptual modelling framework would provide a tool for communication with stakeholders, the project team, themselves, and anybody wanting to develop a similar model in the future. The modellers also suggested that the framework might improve model justification, which could lead to improved model validity, verification and credibility.[1]

The modellers stated that the framework is currently quite theoretical, which may relate to the current format of the framework discussed within Theme 2, where one solution would be to include more examples. There was general agreement that the framework could be applied in a range of contexts by modellers with varying levels of experience. The modellers suggested that in order for the framework to be used, its application within case studies would need to be published to demonstrate its usefulness or it would need to be citied in the NICE Public Health methods guide.

Theme 2: Current form of the conceptual modelling framework

Much of the focus group discussion focussed upon the current format of the conceptual modelling framework document. It is important that the framework is presented in a form that will encourage modellers to use it. Two subthemes were identified; (i) Multiple versions of the conceptual modelling framework; and (ii) The use of examples.

Multiple versions of the conceptual modelling framework

All modellers agreed that the document was too long in its current form to be used by modellers in practice and some of the participants suggested that there might be two documents; one shorter document, perhaps in checklist form, which references a longer document.

> *Modeller 10: "There is a lot of justification for this framework in this document so I think that is absolutely fine, but when you are actually coming to use it I think that there is going to be a separate document, there is going to be this and there is going to be some kind of checklist which is a two page thing, which actually makes it useable. Because in this form it is not useable, I don't believe it's useable. I believe all the ideas are great, but you can't use a 47 page document on your desk, to actually use it to assist you, but I did think that a lot of the points in it were very good, and I completely agree with the idea of the checklist."*

Modeller 10 suggests that he thinks that the content of the framework is good, but that the longer conceptual modelling framework could be referenced within a shorter two-page checklist which would be more user-friendly. As discussed within Chapter 1, checklists for good modelling practice allow modellers to review a model and check that **what** is done is reasonable; but they do not describe **how** models might be developed. The aim of the conceptual modelling framework is to describe how model structures might be developed. Modeller 8 suggested that there is too much text within the framework and that the diagrams are more useful. This was echoed by Modeller 9.

> *Modeller 8: "I mean a lot of it is buried in the text and I thought that some of the sort of diagrams, some of the decision diagrams etc you know are more useful because if you've got a sentence buried in the text you're not going to find it."*

The use of the word 'buried' here suggests that the modeller finds the value of the different parts of text variable and that less useful text to this modeller is hiding the more useful text. Modeller 8 suggested that an index page would be useful.

Whilst I would argue that the conceptual modelling framework cannot be reduced to a checklist, a shorter good practice document which references a longer document may be more useful to modellers (see Section 8.3.6 for the informal feedback from the shorter document presented at the HESG meeting). Based upon the modellers' comments, I think signposting could also be improved in order for the framework to be accessible to different modellers, including the use of a contents page and a 'how to use this framework' introduction. As suggested by a member of HESG, I think a user-friendly way of presenting the framework could be to develop it into an online tool, where the modeller would click on links for further detail, to be used as a reference and educational tool.

The use of examples

There was general agreement within the focus group that it would be more helpful to move the example to an Appendix than to have it integrated throughout the text.

> *Modeller 8: "I think that it would have been better if the example had just been maybe given in an Appendix at the end so you see how it followed through, because you get a little bit and then it sort of stops doesn't it and then you get a bit more, and you don't really get the feel for the example."*

The modeller suggests that it is difficult to follow the example as it is currently presented in sections. The modellers also agreed that ideally more examples would be helpful.

> *Modeller 8: "But I think that the example is also, the way her thesis was structured she's followed one project through, so the example is almost there because that was the one that*

she was following rather than because it elucidates what she said in the text, and from the point of view of this it would be more useful to have examples which illustrate the point she's making in the text and I think the diabetes examples aren't always particularly useful for that."

Modeller 9: "I would just like to echo the point about [having more] examples, because I think that is a major weakness of that, as it stands. There is nothing like good case study examples to make things more real and to bring out some of these issues in much more vivid ways, so I would agree with that."

Modeller 8 suggests that by having more than one example, where the diabetes example does not illustrate a point well, there would be another example that does do so. Modeller 9 uses the terms 'real' and 'vivid' to describe some of the advantages of having more examples, implying the framework is currently too theoretical with just one example, as also highlighted within Theme 1.

By integrating the diabetes example within the framework I was intending to illustrate the methods so that the practical application is clear. However, the consensus within the focus group that the example would work better if it were collated persuades me that this format would be preferable. I agree that additional examples would be useful to illustrate the methods since the diabetes example does not precisely illustrate all of the key issues.

Theme 2 summary

The modellers generally suggested that the current format of the conceptual modelling framework is too long to be useful, and that it would be preferable if there were two versions of the document; a shorter document which is simple to use which references a longer document. The modellers discussed the use of a checklist which brings into question their understanding of the purpose of the document. The modellers were also in agreement that the diabetes example should be collated and put into an Appendix. They suggested that having more than one example would illuminate, and be more illustrative of, some of the issues.

Theme 3: Specific comments on the content of the conceptual modelling framework

The modellers generally thought that it was the format of the conceptual modelling framework which required modification rather than much of the content, with modeller 10 expressing that they "*believe all the ideas are great".* However, each modeller had feedback about the content of specific parts of the framework. Some modellers suggested including topics that were already in the framework, for example, ‘review of existing models’, which may be because the framework is currently too long (see Theme 2). Other content suggestions have been divided into four subthemes: (i) Defining the research question; (ii) Use of problem structuring methods; (iii) Addressing the key features of Public Health economic modelling; and (iv) Comparison with existing practice.

Defining the research question

The modellers recognised that the conceptual modelling framework helped to define the modelling objectives. However, modeller 10 suggests that the research question should be made more explicit within the overview diagram of the conceptual modelling framework (Figure 7.3).

> *Modeller 10: “I think it (the research question in Figure 7.3) needs to be more explicit. I think that’s the most important… it’s so so important.”*

The modeller states that they think that defining an appropriate research question is the most important part of model conceptualisation. This echoes one of the findings of the literature review of conceptual modelling frameworks within Chapter 4. Within Figure 7.3 in the framework document, this is captured within ‘developing a conceptual model of the problem describing hypothesised causal relationships’, as highlighted by some of the other focus group modellers in response; however as this modeller suggests, the process of defining the research question is not explicitly stated within Figure 7.3. I agree with modeller 10 that the overview diagram of the conceptual modelling framework would be improved by explicitly stating where the research question is defined.

Use of problem structuring methods

One of the participants highlights that the use of problem structuring methods can help to understand the nuances of the problem which is often important in decision making for issues which are not included within the model.

> *Modeller 12: “Actually I’m not sure that they’ve (problem structuring methods) had a lot to do with the modelling but when it comes to making the decisions they’re often the most crucial... ...all the things to do with the soft sciences and so on, they all get brought in because that’s where most of the richness is, they can’t easily be modelled, but they are part of the decision making process and very often most of the recommendations are based on that.”*

The participant highlights the difference between the boundary of the understanding of the problem and the mathematical model and suggests that a key benefit of the conceptual modelling framework is in describing the understanding of the problem to help with the decision making because of the 'richness' which it is difficult to capture within a model.

Addressing the key features of Public Health economic modelling

Some of the modellers highlighted key features of Public Health economic modelling which they did not think the conceptual modelling framework fully captures.

> *Modeller 9: "I'm not convinced that she's pulled out all the distinctive features of what makes public health different from other areas of health care... ... the outcome measures are very hard to define very often in Public Health and very rarely measured... ...because it's to do with things like behaviour and attitude and you know and specifying that and trying to quantify it and then quantify how all those changes in behaviour impact on likely further events and consequences, which you know, if you're trying to measure it in QALYs you often get totally stuck because, how do you go from there to QALY outputs, it's very difficult."*

This modeller raises one of the key issues identified within Chapter 2 of the thesis. They assume that QALYs would be the outcome of interest which may not always be the case.[66] Within the conceptual modelling framework there is limited suggestion of how to value health because the outcomes of interest would be dependent upon the particular decision making context and valuation issues were considered to be beyond the scope of this work. The same modeller also suggests that the framework does not address the issue of differential intervention effectiveness according to the context within which they are provided.

> *Modeller 9: "There's another distinctive feature which I think we've omitted is the diversity of context that you get with Public Health interventions that comes into play in a way that it doesn't with clinical interventions... ...if you're planning an intervention in Public Health you might be planning it in a rural environment or a metropolitan environment and what's effective and what isn't effective might vary very differently dependant on those contexts."*

Within the conceptual modelling framework there is a section about identifying the model population and subgroups. It also states that 'if practice is substantially different, then an adjustment on the effectiveness estimate would be required'. However, the framework does not specify an approach for adjusting the effectiveness estimates to allow for different contexts if there are no relevant studies in each context. To review methods for doing this is beyond the scope of this work since this relates to the parameter inputs rather than the model structure.

These comments of modeller 9 highlight that what the conceptual modelling framework does not do is to specify all of the key features which are specific to Public Health economic modelling compared with economic modelling of clinical interventions. I think it may be useful within future work to include a supplementary document which tables all of the key features associated with Public Health economic modelling based upon the review in Chapter 2 of the thesis and how they are dealt with in the framework, including referencing ongoing research in each area. For example, Chapter 2 considers issues such as whether the QALY is the most appropriate measure for Public Health interventions, as recognised by another focus group participant, and how costs and outcomes to non-health sectors should be dealt with. It would be informative to include the references to this existing research within a supplementary document to the framework in future versions.

Another participant highlights that other issues which are specific to Public Health are captured within the conceptual modelling framework.

> *Modeller 8: "I thought the other public health issues apart from outcomes [are considered]; the model boundaries I think is quite often much more of an issue than the clinical one and in the framework it does discuss that, you know, thinking about how to tackle that."*

The modeller uses the example of defining the model boundary to suggest that other issues specific to Public Health are considered within the framework. The modeller also recognises that the framework proposes 'how' to tackle these issues and not just 'what' to do (see Theme 2).

Comparison with existing practice

Modeller 8 highlights that developing the model boundary table, which is based upon an approach by Robinson for operations systems,[8] is something that they would not normally do.

> *Modeller 8: "I think that this is something that I wouldn't normally do but I thought was a great way of summarising your thoughts and what you thought about and what decision you've made."*

This modeller considers only the reporting aspect of this stage, rather than the method for helping make those judgements. Generally, the modellers did not recognise the new methods presented. One of the modellers suggested that the conceptual modelling framework describes what they would normally do. Later on within the discussion, other modellers said that the most novel thing about the framework is that it brings all of these things together rather than providing new methods for the modellers.

> *Modeller 8: "This conceptual framework very much describes what I would say is sort of routinely what I would do. I think that there is arguing for more explicit sort of recording perhaps of that than I would probably do, so I find it quite difficult to sort of comment in the sense that a lot of this is what I do already. So having the conceptual framework here wouldn't make very much difference except, as we have already discussed this, it would be quite useful to have a checklist to make sure that you have considered everything as you should really."*

> *Modeller 9: "I think probably the most novel thing is that it's an attempt to do something that not many people have tried before, so although the component parts of what she writes about may not be novel at all, putting them all together in one place might be a new thing."*

The modellers recognised that the conceptual modelling framework brings together diverse information. However, they also suggest it would simply be used to check that all of the key issues have been considered and perhaps encourage more transparent reporting of the model structure, rather than recognising new methods. See Theme 2 for a discussion of the use of a checklist.

I would argue that there are new methods included within the framework which are listed within Section 8.3.3. In addition, an alternative framework does not currently exist which means that there is substantial variability in practice, as highlighted within Theme 1. Furthermore, the conceptual modelling framework aims to highlight key considerations which may otherwise be overlooked, including the broader determinants of health and the dynamic complexity of the system. Literature shows that these issues are not generally considered appropriately, if at all (see Chapter 2). Yet the modellers within the focus group suggested that they were already doing much of this. I would suggest potential reasons for this incongruence may be because (i) the modellers did not appreciate all of the aspects of the conceptual modelling framework because of the current format of it (see Theme 2); (ii) modellers tend to obtain what they think they need quickly from the literature and discard the remainder, so they may have applied this technique to their reading of the framework;

(iii) the participants want to avoid showing any potential shortcomings in the presence of colleagues (which would be a weakness of the methods used); and/or (iv) as suggested within the qualitative research within Chapter 4, there may be reluctance to adopt new methods so modellers may (probably unconsciously) ignore these aspects of the framework. The psychology theory of selective perception might help to explain the latter. Plous presents a number of experiments suggesting that "when people have enough experience with a particular situation, they often see what they expect to see."[96] There are a number of other reasons which may also help to explain this phenomenon including that we are creatures of habit, that we may have insecurities about new approaches, and that we may feel that we have no spare resource for innovation.[181] The same issues will apply if people attempt to use the conceptual modelling framework in the future; thus it is important to attempt to address it within future versions. Modifying the format of the framework and including multiple examples to illustrate the methods (as discussed within Theme 2) may help to address these issues and encourage its use.

Theme 3 Summary

The modellers expressed that they were generally happy with the content; however they suggested that: (1) identifying the research question should be explicitly shown within Figure 7.3 of the framework; (2) one of the benefits of problem structuring methods is that they might help with decision making directly as well as via helping to develop the mathematical model structure; and (3) a discussion of outcome measures and a discussion of the impact of different settings upon intervention effectiveness should be incorporated.

The modellers suggested that the conceptual modelling framework describes an approach which is similar to existing practice. I would argue that whilst some of what is described is based upon existing practice there are new methods within the framework. Two key potential reasons that these may not be recognised are because of the current format of the framework and due to selective perception. This could potentially be addressed by improving the format of the framework and incorporating more examples to illustrate the methods.

8.3.6 Feedback from the HESG meeting

The feedback from the HESG meeting was generally much more positive compared with that of the focus group. A higher than average number of participants attended the session (approx 50 people) which implies interest in the topic. The discussant who presented the framework described it very succinctly and showed a clear grasp of the aim of the framework and the proposed methods. Within an email in response to me asking for a copy of his Powerpoint slides, he said that 'the paper was so comprehensive (and comprehensible) that you didn't leave me much to say'. Many of the participants attending the session provided very favourable comments about the framework such as 'This is great' and 'Thank you for doing this', with a general atmosphere of interest which highlighted the timeliness of the work. There was some constructive feedback including that there could be more consideration of equity and that the methods could be illustrated by an example (since the diabetes example was not included within the HESG paper). The discussant highlighted that there is limited description of the methods used to develop the framework within the document. One of the participants suggested that the framework might be applied more broadly than Public Health, including assessing the cost-effectiveness of clinical interventions. Finally, there was a brief discussion about how the conceptual modelling framework might be published so that it is used by modellers and one participant suggested making it into an online tool.

<u>Potential reasons for the differences in feedback between the focus group and HESG</u>

This more positive feedback could potentially be due to the culture of each group, my presence or the differences in the format of the document. Firstly, HESG is for academics to help each other with developing ongoing work and hence the feedback tends to be constructive, whilst the focus group aimed to critically evaluate the framework and it may be that the focus group participants thought that it was more useful to highlight weaknesses than to acknowledge positive features. Related to this, my presence at HESG may have made it more difficult for people to be critical of the work, although within such an academic environment critical assessment of the work is standard practice. Finally, a different version of the conceptual modelling framework document was presented at the HESG conference because the specification was that the document must be no more than 20 pages excluding the abstract and references and no more than 7,500 words. This was achieved by:

- omitting the diabetes example and stating that it was available on request;
- omitting the process boxes (shown in italics) and stating that they were available on request;
- decreasing the left and right margins;
- omitting the figure for the method of choosing model interventions;

- omitting two paragraphs, a couple of sentences and revising the model type section by considering whether every sentence was essential, so that each section fitted onto 1 or 2 pages and the next section began at the start of the next page.

The other differences between the two documents were that the HESG paper had an abstract, a slightly revised introduction and the addition of a discussion. This revised document for HESG addressed most of the issues discussed within Theme 2 within Section 8.3.5 (apart from having several examples), even though it was submitted prior to holding the focus group meeting. Both the document for the focus group and the document for HESG are shown in Appendix F for comparison.

8.4 Discussion

<u>Validity and reliability of the framework</u>

The theory-based evaluation suggested that the methods used to develop the framework were generally valid and reliable, that it meets the requirements which were developed within Chapters 2 – 6 and that it contains features which aim to prevent the pitfalls highlighted within Chapter 4. However, several areas of improvement were identified. Upon critical reflection I suggested that one of the weakest areas of the framework is in helping modellers determine appropriate and inappropriate simplifications of the problem. It may be that a better approach could be developed if the process of making these judgements about the level of detail could be better understood across a broad range of projects and it would be useful to investigate this within further research.

<u>Generalisability</u>

The intention of the conceptual modelling framework is that it could be employed across any Public Health economic modelling context; however the generalisability has not been tested within this research. In addition, the framework has not been used by modellers who were not involved in its development. These are key areas for further research. Whilst the intention of the framework is for it to help modellers to develop Public Health economic models, it may be useful in other health economic projects; however this would need to be tested within future case studies.

<u>Potential weaknesses of the framework</u>

A key potentially negative impact of using the conceptual modelling framework, identified by both my critical reflection and one of the focus group participants, is that whilst the modeller is spending time undertaking the conceptual modelling they are not completing other modelling activities. Thus, the time taken to undertake these activities should be flexible according to the decision making process and the particular project, which is considered within Phase A of the framework. In addition, as with any guidance document, it has the potential to be misused. Thus, it is important to be clear about the aims of the framework and how it should be used, as highlighted by the focus group data.

Format of the conceptual modelling framework

The focus group participants were generally happy with much of the content of the conceptual modelling framework, but suggested that the format of the conceptual modelling framework is not currently useful. They suggested that it should be much shorter, referencing a longer document, and that a number of case study examples would be useful to illustrate the methods. The HESG participants were generally much more positive about the conceptual modelling framework than the focus group participants and this may be because of the differences in the culture of the groups or the differences in the format of the document, including that it is shorter. Based upon the comments of the focus group participants, it is clear that the conceptual modelling framework needs to be in a form which is easily accessible and importantly, as highlighted above, that the aim of the document needs to be made extremely clear. Within the document circulated to the focus group participants, the aim of the framework was described as ‘to provide a methodology to help modellers develop model structures for Public Health economic models’. However, it did not provide a clear description of how it might be used. I would envisage modellers understanding the entire conceptual modelling framework and following it throughout the project as appropriate. Once familiar with the framework, a shorter version to remind modellers of the overall process and key methods for making judgements might be useful. As suggested by a member of HESG, a user-friendly way of presenting the framework may be to develop it into an online tool, where the modeller would click on links for further detail, and this version could be used as a reference document and educational tool. Based upon the modellers’ comments, signposting could also be improved in order for the framework to be accessible to different modellers, including the use of a contents page and a ‘how to use this framework’ introduction. It would be useful to modify the format of the document and reassess its use in future research.

How the framework might improve the quality of Public Health economic models

The focus group participants suggested that the framework has the potential to improve the quality of Public Health economic models by helping to: (1) identify modelling objectives, (2) guide model development by helping to identify key issues, which would also introduce some sort of consistency, (3) provide a tool for communication with stakeholders, the project team, themselves, and anybody wanting to develop a similar model in the future, and (4) improve model justification which may enhance model validity, verification and credibility. There was general agreement that the framework could be applied in a range of contexts by modellers with varying levels of experience.

<u>The inclusion of new methods</u>

Whilst the focus group participants thought that it was novel to have brought all of the information together within a conceptual modelling framework, they generally did not recognise new methods within the framework. This may be due to selective perception which suggests that "when people have enough experience with a particular situation, they often see what they expect to see,"[96] thus reinforcing further the importance of future work to improve the user friendliness of the conceptual modelling framework and of illustrating the methods with examples.

<u>Capturing features which are specific to Public Health</u>

Several focus group participants suggested that some features which are particularly important within Public Health economic modelling such as valuing health outcomes and the impact upon intervention effectiveness of different contexts should be considered further within the conceptual modelling framework. These were considered to be beyond the scope of the work since the framework aims to provide methods for modellers to develop the model structure rather than considering methods for estimating parameters. However, a supplementary document could accompany future versions of the framework which tables all of the key features associated with Public Health economic modelling based upon the review in Chapter 2 and how they are dealt with in the framework. Other key suggestions by the participants which I would propose incorporating into the framework were that the identification of the research question should be explicitly shown within Figure 7.3 and that one of the benefits of the understanding the problem phase is that it might help with decision making directly as well as via helping to develop the mathematical model structure. Importantly, the conceptual modelling framework document provides a starting point to enable modellers to discuss the model development process in Public Health economic evaluation, even if they would want to make revisions to the current version of the conceptual modelling framework. It could also encourage additional methods to be developed by setting out the process so people can see where new methods might be useful.

8.4.1 Strengths and limitations of the methods employed to evaluate the framework

The combination of theory-based evaluation, focus group analysis and informal analysis of the HESG meeting provide complementary approaches of evaluating the conceptual modelling framework. The theory-based evaluation allowed me to verify that the framework follows the requirements which I had set out based upon Chapters 2 – 6 (see Table 7.2 within Chapter 7). It also provided a critical assessment of how the conceptual modelling framework might help modellers to avoid potential pitfalls which were identified from the literature. However, this type of evaluation does not consider the views of other people who might potentially use the framework. The focus group meeting and the HESG meeting allowed a range of views to be discussed and debated.

Data collection

Checkland suggests that one way to test a new methodology is to aim to refute it, rather than finding evidence only to support it.[123] Within the qualitative research some of the questions specifically aimed to question the usefulness of the conceptual modelling framework. The use of an impartial facilitator to run the focus group was preferable in order that participants did not avoid making contributions of a negative nature about the framework and to ensure that the questions could be posed in an impartial way. However, this also meant that the participants may not have been asked questions which provided the types of information required from the meeting, despite having a topic guide, because of the fast-paced nature and flexibility required of running a focus group when less familiar with the topic. Many of the statements by the participants were not followed by probes in order to gain more depth. In particular, the participants often did not express why they made a statement which makes what they have said difficult to interpret in depth. This is one of the potential weaknesses of focus groups and may have occurred had I or another facilitator taken this role. Within the focus group there were expected to be seven participants, but one participant could not attend due to other priorities and one participant had problems with the trains which meant that she missed the meeting. The discussion with five people was perhaps not as diverse as if more participants had attended.

Data analysis

Because I have been working on this thesis for almost three years, the initial response during evaluation was naturally to be defensive of what I have developed. However, in order to present an objective evaluation, I followed the systematic process described within Section 8.2.2 and when analysing each quote I spent time reflecting upon it rather than presenting any initial emotive responses. It was not possible to incorporate feedback from the HESG meeting into the formal evaluation because I did not collect a sufficiently detailed record of the discussion; however the informal consideration of this meeting helped to strengthen the overall evaluation by providing feedback from a larger group of potential users of the framework.

Further evaluation

Given more time and resources for the evaluation, it would have been preferable to undertake several focus group meetings to investigate if any new ideas emerge. Due to time and resource constraints of the PhD this was not possible; however the purpose of the focus group was to provide a forum for discussion of the framework and it was not essential that this was exhaustive at the current stage of evaluation. The informal evaluation of the feedback from the HESG meeting provided a larger number of modellers' views of the framework; however it is currently unclear whether the more positive feedback from HESG was due to the culture of the group, my presence or the revised format of the conceptual modelling framework. The next step is to make the modifications suggested to the format and test its use within case studies.

8.5 Chapter summary

This chapter aimed to provide an initial evaluation of the conceptual modelling framework, with the intention to undertake more substantial evaluation via its use within case studies in future research. The difficulty of evaluating a conceptual modelling framework has been highlighted and the methods and results of the theory-based evaluation and qualitative research described. Throughout the development of the framework a process of cyclical learning has been undertaken of diagnosis, planning, analysis and reflection. This evaluation forms the final stage for the purposes of this thesis but it is intended that future work will continue this cycle in order to improve the conceptual modelling framework.

Key areas of further work resulting from the evaluation include:

- The modification of the current format of the framework to make it more accessible by:
    - Reducing the length;
    - Increasing signposting;
    - Increasing the number of examples and moving them to an Appendix.
- Within the framework adding:
    - More text to clarify the purpose of the framework;
    - A discussion of the importance of equity from a Public Health perspective;
    - An explicit statement to identify the research question within Figure 7.3;

    - That a benefit of problem structuring methods is that they might help with decision making directly as well as via helping to develop the mathematical model structure;
    - A discussion of the impact of different settings upon intervention effectiveness;
    - More discussion about how intervention heterogeneity might be incorporated into the model;
    - The inclusion of a supplementary document which tables all of the key features associated with Public Health economic modelling.
- The potential development of an online tool for reference and educational purposes.
- The development and publication of more case study examples.
- The use and evaluation of the conceptual modelling framework by other modellers and the evaluation of the conceptual modelling framework by stakeholders.
- Research to develop a better understanding of the process of making judgements about model level of detail across a broad range of projects.
- Publication, training and guidance for modellers around methods which allow the social determinants of health to be incorporated into models.

Chapter 9: Discussion, conclusions and further research

9.1 Chapter outline

This chapter aims to provide a discussion of the research presented within this thesis and outlines the conclusions and recommendations for further research. Section 9.2 describes the contribution of each chapter of the thesis in the context of existing research, with a particular focus upon the contribution of the conceptual modelling framework presented within Chapter 7. Section 9.3 outlines the strengths and limitations of the research. Sections 9.4 and 9.5 outline further research recommendations and the conclusions about the role and value of the research respectively.

9.2 Contribution of this work in the context of other research

Current status of research in this area

When this research began, there were no publications about conceptual modelling within health economic evaluation. While conducting this research the lack of guidance about conceptual modelling has been recognised as an issue within the Health Economics community; the ISPOR-SMDM Joint Modeling Good Research Practices Task Force has developed guidance to inform conceptual modelling for health economics and a Technical Support Document has been developed for the NICE Decision Support Unit for identifying and reviewing evidence to inform the conceptualisation and population of cost-effectiveness models.[14;18] Both of these are reviewed within Chapter 4 of the thesis. I was involved within the development of the Technical Support Document; however the ISPOR-SMDM guidance was developed independently. This parallel development highlights the importance and timely nature of this work. The conceptual modelling framework developed here complements and adds to these existing frameworks by focusing upon Public Health economic modelling.

Chapter 2

Chapter 2 reviewed the literature around the key methodological challenges within Public Health economic modelling. Economic evaluations within Public Health are generally different to economic evaluations of clinical interventions since they usually require the development of models of multi-component interventions with complex causal chains operating within dynamically complex systems, dependent upon the social determinants of health, as against models of simple interventions which generally do not depend upon human behaviour operating within relatively clear system boundaries. It is also often much less clear what a 'good' outcome of a Public Health intervention is. In addition, a key objective of Public Health is often to reduce health inequities rather than to maximise health. The review highlighted the many issues with the conceptualisation of the model; however none of the papers considered methods for this conceptualisation process. The review highlighted key issues to be explored further within Chapter 3.

Chapter 3

Chapter 3 considered, in more depth, some of the issues raised within the literature review in Chapter 2. Drawing upon literature within the fields of complexity theory and systems thinking, this chapter described what a dynamically complex system is and concluded that Public Health systems tend to be dynamically complex. A key finding was that due to this dynamic complexity of most Public Health systems, a systems approach is expected to be appropriate for modelling Public Health interventions, taking a holistic view of the system and focusing upon the interactions between variables. The Public Health literature around the social determinants of health was also reviewed and it was found that whilst there are a large number of different classifications, many of them comprise similar factors. Many of the papers reviewed highlighted that there are causal effects between many of the determinants of health and that due to the interaction between the individual, community and population level, interventions and their outcomes should be considered at all levels simultaneously. Finally, models of behaviour from other disciplines such as Psychology and Sociology were found to be potentially useful for Public Health economic modelling; the use of these models within this context is highlighted as a further research recommendation.

Chapter 4

Chapter 4 reviewed the literature relating to existing conceptual modelling frameworks within the broader literature. A key finding of the review was that a conceptual modelling framework should include, as a minimum, stages for (i) understanding the problem and objective setting, and (ii) choosing model options, determining model scope and level of detail, and identifying structural assumptions and model type. The benefits of a conceptual modelling framework include aiding the development of modelling objectives, providing tools for communication with stakeholders, guiding model development, experimentation and reuse, and improving model validation and verification. Other key findings were that the framework should not be overly prescriptive about specific methods and it should allow for the variation in requirements of different Public Health economic modelling and the needs of the decision makers. Finally, the review suggested that theory-based evaluation of the framework might be appropriate to explain why it is expected to be effective, as well as qualitatively obtaining stakeholders'/ modellers' views.

Chapter 5

Chapter 5 provided an overview of the qualitative data collection and analysis of data which described modellers' experiences with developing the structure of Public Health economic models and their views about the benefits and barriers of using a conceptual modelling framework. Key findings were that for a conceptual modelling framework to be useful it should be clear about what it can and cannot do, not be overly prescriptive or restrictive, be simple to use in practice and culturally acceptable and consider any diagrams developed by other parts of the team on the project. The research also suggested that a conceptual modelling framework for Public Health economic evaluation should provide a general outline of the model development process in Public Health economic modelling, consider the trade-off between developing an appropriate structure for the problem versus ability to meet deadlines, help modellers determine appropriate and inappropriate simplifications of the problem, incorporate the iterative nature of model development between model conceptualisation and data collection, highlight the difference between causation and correlation and point towards econometric techniques, and facilitate a clear description of the methods for the report to stakeholders. The qualitative research also highlighted key issues which it might be useful for Public Health economic modellers to consider.

Chapter 6

Chapter 6 provides a critical reflection of the use of the draft conceptual modelling framework within a case study assessing the cost-effectiveness of interventions for screening and prevention of type 2 diabetes. Key findings were that the introduction of the conceptual modelling framework should clearly and concisely describe why it is beneficial and there should be a first step describing the necessity to align the framework with the decision making process and develop a project plan. When making judgements about the model structure, a flow diagram or box is more accessible than lots of text for highlighting the key considerations. In addition, there is a need for the project team to question each other's assumptions throughout the conceptual modelling process. A possible information retrieval approach for developing the understanding of the problem and model structure was developed.

Chapter 7

Chapter 7 described the conceptual modelling framework and the justification for key methods and processes. The main contribution of the conceptual modelling framework developed is that it provides a systematic approach to developing a Public Health model structure, and in particular, systematic consideration of: (i) the social determinants of health; (ii) the dynamic complexity (feedback loops, unintended consequences); (iii) the understanding of the problem; (iv) moving from an understanding of the problem to the model structure; (v) stakeholder involvement. Each of these is considered in turn in terms of the contribution of the framework in the context of other research.

Systematic consideration of the social determinants of health

There is currently no systematic approach for identifying relevant factors which might impact upon model outcomes. In addition, modellers do not generally have an understanding of Public Health as a discipline. Thus, it would be unsurprising if modellers failed to identify relevant factors, and current studies show that the social determinants of health are often not included within the model.[45] By drawing upon the Public Health literature and highlighting specific broader determinants of health for consideration at relevant points within the framework, it should help modellers identify relevant factors which can subsequently be included or intentionally and transparently excluded from the model. The framework also highlights that these determinants of health might be used to help choose relevant interventions and subgroups. It should be noted that there is limited effectiveness evidence around the impact of the interventions upon the social determinants of health and further primary research would be beneficial in this area.[73] Similarly to transferring methods for economic modelling from clinical interventions to Public Health interventions, a paradigm shift may be required in order to collect appropriate effectiveness evidence in this area.

Currently, no guidance links the use of Psychology and Sociology models to health economic models, yet there is huge potential to combine them. The framework makes an initial contribution by suggesting that modellers draw upon these behavioural models where relevant. However, very few economic evaluations have previously incorporated these and further research would be useful around how these behavioural models might be employed within Public Health economic evaluation.

Systematic consideration of dynamic complexity

Within health economic modelling, current approaches tend to assume simple cause and effect for developing the model structure. Feedback loops and unintended consequences are often not considered. However, within Public Health where interventions often operate within dynamically complex systems and the scope is generally broader and less well defined, modellers accustomed to developing models for clinical interventions may exclude important relationships because their habitual way of thinking is insufficient. The framework draws upon systems thinking to present an approach which aims to help modellers consider these issues so that all relevant relationships and consequences of the interventions are identified.

Approach for describing the understanding of the problem

Whilst this research was being undertaken, some of the Health Economics community began to recognise the need for describing the understanding of the problem prior to developing the mathematical model.[14;18] The ISPOR guidelines do not propose methods for developing this understanding.[18] The study by Kaltenthaler *et al.* proposes some key issues and considerations for modellers developing a conceptual model of the problem;[14] however there are many issues which are specific to Public Health which are not incorporated within their report since it was developed to aid the development of HTA models. Within this conceptual modelling framework, a new method is proposed which draws upon cognitive mapping, causal diagrams and soft systems methodology. The suggested method aims to strike a balance between exploring the problem sufficiently so as not to exclude any important impacts of the potential interventions and providing an efficient, focused approach. It provides a mechanism for the modeller, along with the stakeholders and project team, to think through all of the potential causal links between the relevant factors associated with the problem. It is centred on the key problem and builds from this in a causal way in relation to the types of interventions of interest to the stakeholders. This approach should prevent an unwieldy conceptual model of the problem which is so big that it is not helpful within the constraints of the decision making process. For example, arguably a diagram like the Foresight obesity map[41] (see Figure 1.3 within Chapter 1) provides too much detail around factors which either cannot or will not be changed by intervention.

The converse is the development of an oversimplified understanding of the problem. There is a step between the modeller considering the evidence identified (both written and through expert advice) and documenting this within the diagram, which occurs within the mind of the modeller. This step involves the modeller deciding whether to include the information that they have identified within the conceptual model of the problem. The method described within the framework provides a tool for doing this, but there remains an element of judgement. Because the diagram is being developed by modellers, it may be that subconsciously modellers exclude factors if they are not likely to be included within the model, which may lead to disposing of some issues too quickly. This could lead to a situation where the understanding of the problem looks very similar to the design-oriented conceptual model. The method attempts to encourage modellers to incorporate relevant factors which may be affected by an intervention, even if they are unlikely to be included within the model because of limited data or expected minimal impacts, in order to enhance model validity and credibility.

To my knowledge, this is the first explicit contribution around how a modeller might consider the breadth of the understanding of the problem in Public Health economic evaluation, and it is hoped that future use of the framework and further research around this issue may build upon the proposed method.

Moving from an understanding of the problem to the model structure

Whilst the conceptual modelling framework by Kaltenthaler *et al.* describes key considerations for the problem-oriented and design-oriented conceptual models, it does not provide a method for moving between the two.[14] Similarly, the existing ISPOR conceptual modelling guidance explains what should be done but does not describe how to do it.[18] Within the conceptual modelling framework developed here, there are three key new methods described for moving from an understanding of the problem to a description of the model structure. The first is a flow diagram which aims to help modellers determine whether the factors identified within the understanding of the problem should be included or excluded from the model boundary. The second is a series of questions for modellers to consider when defining the level of detail based upon the understanding of the problem and the model boundary. The third is a flow diagram which aims to help modellers choose the most appropriate model type given the characteristics of the problem and the constraints of the decision making process. There are also suggestions about how the model structure may be developed following the documentation of the understanding of the problem which have not been combined into one document previously.

Stakeholder involvement

NICE has an approach for choosing and involving stakeholders within the decision making process; however there is no existing guidance for modellers around choosing and involving stakeholders independently of this process. Drawing upon Soft Systems Methodology, the conceptual modelling framework provides an approach for identifying relevant types of stakeholders. It also makes suggestions about what processes might be followed to obtain a sufficiently broad range of stakeholder expertise throughout model development. For example, a key recommendation is the use of stakeholder workshops if time and resource constraints allow and suggestions for how these might be run are proposed.

Chapter 8

Chapter 8 provided an initial evaluation of the conceptual modelling framework developed, with the intention to undertake more substantial evaluation via its use within case studies for future research. The difficulty of evaluating a conceptual modelling framework was highlighted. A verification process suggested that the framework considers all of the key recommendations from previous chapters, although a couple of areas for further development are identified. A key finding was that whilst the theoretical evaluation and modellers taking part within the qualitative research suggested that the content of the framework could potentially improve the quality of Public Health economic models, the format of the framework requires revision in order for it to be useful to modellers. A number of key areas of further research were recommended (see Section 9.4).

9.3 Strengths and limitations of this research

There are a number of strengths and limitations of the methods used to develop the framework which have previously been considered within Section 8.3.1, so these will not be repeated here. This section outlines additional strengths and limitations of the research.

Breadth of decision-making contexts considered

The review of key challenges within Public Health and the review of conceptual modelling frameworks were not limited by country or decision making context, meaning that these findings have international relevance. Whilst no non-UK participants were involved within the qualitative research, some of the participants have experience with international decision making contexts. Although many of the participants involved within the qualitative research and I have substantial experience in developing health economic models for NICE, we also have experience with other decision-making contexts which prevents the research only being relevant within the context of NICE. The case study within diabetes prevention and screening was commissioned by the NIHR under the School for Public Health Research and thus presents another decision making context. It would, however, be useful within future research to test the use of the conceptual modelling framework within different national and international contexts.

Interdisciplinary perspective

The research draws upon literature from the fields of Public Health, Health Economics, Operational Research/ systems thinking, and Sociology and Psychology. This interdisciplinary approach prevented an insular perspective and thus encouraged innovation and is sensitive to the broader requirements of economic modelling within Public Health. For example, the search strategy for the review of conceptual modelling frameworks was not constrained by discipline and this breadth meant that methods development was not limited by what is currently done within the field of Health Economics. The interdisciplinary approach also highlighted the crossovers between disciplines, for example, the idea of the whole not being equivalent to the sum of the parts was present within all of the above disciplines (except Psychology), albeit presented in different forms.

Timeliness

As highlighted previously, when this research began no conceptual modelling framework existed within health economic modelling; however during the time period of this work two such frameworks were developed for assessing the cost-effectiveness of clinical interventions. This suggests that this sort of framework is timely, and participants of HESG expressed this in the context of Public Health. In addition, 14 out of the 17 papers included within the review about the key challenges within Public Health economic modelling (see Chapter 2) were published within the last six years, which highlights the increasing interest in economic modelling in Public Health. Moreover, increasing numbers of Public Health economic models are being commissioned and developed.[47] Thus, this conceptual modelling framework has been developed at a key time for the development of Public Health economic models.

Generalisability

Whilst the breadth of decision-making contexts considered within methods development is considered to be a strength of the research, the application of the conceptual modelling framework developed is currently limited, thus its generalisability has not been tested. As suggested previously, further research should test the use of the conceptual modelling framework within different national and international contexts.

The development of economic approaches within Public Health economic evaluation

Public Health economic evaluation is a relatively new field and as such there are many areas where further research is required, which could feed into the conceptual modelling framework developed, but is beyond the scope of the current work. For example, the approaches for incorporating equity and broader outcomes (such as the compensation test described within Chapter 2 and the use of cost-benefit analysis) within the economic evaluation are important areas for further research. The conceptual modelling framework is designed to be flexible within a range of decision making contexts and as such the fundamental principles and methods would remain. Any such methodological advances could be incorporated within the framework as further research and recommendations are made within the health economics literature.

9.4 Recommendations for further development and research

Modification of the format of the conceptual modelling framework

The current framework needs to be made more accessible to modellers in order for it to be used. This could be done by reducing the length, increasing signposting and moving the example to an Appendix. More case study examples could also be provided. In addition, it may be useful to include supplementary material which tables all of the key features associated with Public Health economic modelling based upon the review in Chapter 2 of the thesis and how they are dealt with in the framework. The conceptual modelling framework could also be developed into an online tool, where an overview would be provided and the modeller would click on links for further detail for each part of the framework, to be used as a reference and educational tool.

Further evaluation of the conceptual modelling framework

This research focussed upon appropriate development of the conceptual modelling framework. Further research should involve extensive evaluation of the framework. Other modellers could employ the framework within a range of case studies. In-depth interviews could be undertaken with these modellers and key stakeholders to investigate whether the conceptual modelling framework might improve model quality and whether there are any additional benefits and issues from using the framework for Public Health economic modelling. In addition, it would be useful to assess how the conceptual modelling is used for model verification and validation in practice.

Encouraging use of the conceptual modelling framework

After revisions to the format of the conceptual modelling framework have been made in the light of the comments from the evaluation focus group, I plan to encourage its use by attending national and international conferences and through peer-reviewed publication. In addition, the development and publication of more case study examples will help to encourage its use.

The development and use of modelling methods to incorporate the social determinants of health such as agent-based simulation and social network analysis

Modelling approaches should be developed to provide the ability to incorporate social network impacts associated with Public Health behaviours such as diet, exercise, smoking, binge drinking and sexual activity,[177;182;183] as well as the community effects associated with upstream interventions such as improving housing. For example, agent-based simulation is likely to be identified as an appropriate model type for many projects based upon the characteristics of the problem. The use of agent-based simulation and social network analysis within health economic evaluation is essentially non-existent and there is a lack of expertise in this area. In addition, data availability within some topic areas may limit application of this type of modelling. There is limited effectiveness evidence around the social determinants of health and further primary research would be beneficial in this area. However, lack of primary evidence should not prevent methods development in this area. Further research around the use of methods such as agent-based simulation and social network analysis is crucial for progressing Public Health economic evaluation, and would facilitate the assessment of the impact of interventions upon health inequities. One approach would be to undertake qualitative research in order to inform the 'rules' of the agents, including facilitating understanding of how and why interventions work. Outside of health economic modelling, this approach has been proposed and applied by several authors.[184]

Drawing upon other disciplines

Whilst the research undertaken here has drawn upon the disciplines of Public Health, Psychology and Sociology, there is enormous scope for advancing modelling methods within Public Health economic evaluation through collaboration with these disciplines to combine the existing knowledge of the social determinants of health and individual and population behaviour with existing modelling and health economic expertise. Further methodological developments within Public Health around the interaction between Epidemiology, behaviour and social structure could help to improve Public Health economic models and this could be incorporated into the conceptual modelling framework. Similarly, within the field of Public Health, research is ongoing around what causes health inequities and how to prevent them, and methodological research within this area could feed into the conceptual modelling framework.

Research to understand how modellers make judgements about level of detail

The questions presented for developing an appropriate level of detail help the modeller to think about relevant tradeoffs. It may be that a better approach could be developed if the process of making these judgements about the level of detail could be better understood across a broad range of projects. It would be useful to investigate this within further research.

9.5 Conclusions regarding the role and value of the conceptual modelling framework

The aim of this research was to develop a conceptual modelling framework which has the potential to improve the quality of Public Health economic model structures. Such a framework has been developed and the theoretical and practical reasons why a conceptual modelling framework could improve the quality of Public Health economic models have been derived. The key benefits of a conceptual modelling framework that have been identified within this thesis are that a framework could aid the development of modelling objectives, provide tools for communication, guide model development, experimentation and reuse, improve model validation and verification, and help characterise structural uncertainties and identify primary research needs.

At the start of this research, there was an absence of any conceptual modelling framework within health economic modelling and substantial variability in practice.[17] The main contribution of this research is that it draws upon several disciplines to provide a systematic approach for developing Public Health model structures, and in particular, systematic consideration of:

- The social determinants of health;
- The dynamic complexity (feedback loops, unintended consequences);
- The understanding of the problem;
- Moving from an understanding of the problem to the model structure;
- Stakeholder involvement.

This systematic approach should help to improve the quality of Public Health economic models which could lead to a more efficient allocation of scarce resources within the decision making process, which would improve overall morbidity and mortality.

Initial evaluation of the conceptual modelling framework suggested that the format of the framework should be made more accessible to modellers for dissemination purposes. This could be done with the addition of more examples and by developing an online tool. This would make the framework accessible to all modellers with different experience and backgrounds, and allow it to be used differently according to existing experience with the conceptual modelling framework. It is anticipated that the conceptual modelling framework could be used as a good practice document, and that the online tool could be used for reference and as an educational tool. Within the framework there is a phase for aligning it with the decision making process, with the intention, supported by the modellers who critically evaluated the framework, that it will be useful within a variety of contexts.

The use of the conceptual modelling framework developed requires a paradigm shift in the way some modellers who are used to developing models of clinical interventions approach decision problems. This may lead to slow adoption of the framework; however this shift is essential if model development in Public Health economic evaluation is to be improved. Training may also be required for some modellers to expand their skills beyond developing decision trees and Markov models. It will be important that the framework is disseminated in a user-friendly manner in order to encourage its use.

The focus throughout this research upon the engagement of stakeholders during the model development process may encourage decision makers to change the way in which they organise the decision making process. This could lead to a fundamental shift in the decision making process, not only to accommodate stakeholder input throughout model development, but also so that modelling takes a more central role throughout the decision making process. For example, it could help stakeholders to identify key issues associated with the problem and to understand the possible long term effectiveness of the interventions.

As described within Chapter 1, Forrester states that 'any worthwhile venture emerges first as an art, and as such the outcomes are special cases and are poorly transferable, but that this can then be transformed into a science by understanding the foundations of the art, making it more useful to new situations'.[50] The research presented here aims to improve and make transparent the current understanding of conceptual modelling in Public Health economic evaluation in order to advance the art towards a science. It provides modellers within Public Health economic evaluation with a conceptual modelling process that they are able to critique, which has not existed prior to this research. It is intended that it will continually be improved following its use within different Public Health economic modelling projects and according to developments within other related research areas such as modelling human behaviour and quantifying relevant outcomes. It also contributes to fulfilling existing research recommendations from other researchers by presenting a domain-specific framework.[1;52] Given the early stage of research in this area, another key contribution of this work is the identification of further research requirements (see Section 9.4).

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Appendices

Appendix A: Review of key challenges within Public Health economic modelling

Appendix A1: Search strategies

Stage 1:

MEDLINE

1. "public health".mp
2. challenge$.mp
3. issue$.mp
4. problem$.mp
5. method$.mp
6. "cost-effective$".ti
7. "economic evaluation$".ti
8. 2 or 3 or 4 or 5
9. 6 or 7
10. 1 and 8 and 9

MEDLINE

1. Kelly.m.au
2. "cost-effective$".ti
3. "economic evaluation$".ti
4. 2 or 3
5. 1 and 4

Stage 2:

International Journal of Public Health, Journal of Public Health, European Journal of Public Health, American Journal of Public Health

1. "cost-effective$".mp
2. "economic evaluation$".mp
3. 1 or 2

Stage 3:

Author searching in MEDLINE:

1. Author name
2. "cost-effective$".ti
3. "economic evaluation$".ti
4. 2 or 3
5. 1 and 4

Appendix A2: Summary of papers included within review of key challenges within Public Health economic modelling

Inclusion of non-healthcare costs and outcomes			
Author (year)	**Title (type of article)**	**Key issues raised**	**Recommended approach**
Kelly *et al.* (2005)	Economic appraisal of public health interventions. (Briefing paper)	-QALY outcome may not be a sufficient measure; -Greater need to develop methods for including equity considerations; -It is important for a model to address what aspects of an intervention are successful/ unsuccessful.	-Cost consequence analysis from perspective of each sector as additional analysis; Discrete choice experiments may be used for valuation. -None provided; -None provided.
Weatherly *et al.* (2009)	Methods for assessing the cost-effectiveness of public health interventions: Key challenges and recommendations. (Full journal article)	Four key methodological challenges: -Quantifying the effectiveness of interventions; -Measuring and valuing outcomes; -Inclusion of intersectoral costs and consequences; -Inclusion of equity.	-More use could be made of techniques for analysing non-experimental data (eg. econometric analysis); -Compensation test approach (Claxton *et al.*) -Cost consequence analysis from perspective of each sector as additional analysis; -None provided.
Claxton *et al.* (2007)	Mark versus Luke? Appropriate methods for the Evaluation of Public Health interventions. (Working paper)	Costs and benefits across sectors should be incorporated.	Compensation test approach.
Mooney (2007)	Economic evaluation of prevention: we need to do better but first we need to sort out what the good is. (Opinion piece)	Relevant costs and benefits may be difficult to agree upon.	None provided.
Shiell (2007)	In search of social value. (Opinion piece)	Insufficient to qualitatively include non-health impacts.	None provided.
Smith and Petticrew (2010)	Public health evaluation in the twenty-first century: time to see the wood as well as the trees. (Full journal article)	-Public Health economic modelling should focus upon broader outcomes such as 'happiness'; -There is a need to focus on the direct and indirect effects of the interventions upon communities and populations, as well as on individual effects.	-None provided; -None provided.

Inclusion of equity			
Author (year)	**Title (type of article)**	**Key issues raised**	**Recommended approach**
Weatherly *et al.* (2009)	Methods for assessing the cost-effectiveness of public health interventions: Key challenges and recommendations. (Full journal article)	Four key methodological challenges: -Quantifying the effectiveness of interventions; -Measuring and valuing outcomes; -Inclusion of intersectoral costs and consequences; -Inclusion of equity.	-More use could be made of techniques for analysing non-experimental data (eg. econometric analysis); -Compensation test approach (Claxton *et al.*) -Cost consequence analysis from perspective of each sector as additional analysis; -None provided.
Cookson *et al.* (2009a)	Explicit incorporation of equity considerations into economic evaluation of public health interventions. (Full journal article)	-There is a need for explicit incorporation of equity; -Policy makers would not fund cost-effective interventions if they infringe individual liberties or discriminate against the individual; -Society would be willing to pay more per QALY gained for certain groups such as children, the severely ill and the socioeconomically disadvantaged.	4 proposed methods: (1) Qualitative discussion around relevant equity issues; (2) Quantitative evidence around the impact of the intervention upon health inequalities; (3) Estimating the opportunity cost of equity considerations in terms of health outcomes willing to forego; (4) Equity weighting of health outcomes.
Richardson (2009)	Is the incorporation of equity considerations into economic evaluation really so simple? A comment on Cookson, Drummond and Weatherly. (Response article).	Potential value of the methods for including equity within economic evaluations proposed by Cookson *et al.*	None provided.
Shiell (2009)	Still waiting for the great leap forward. (Response article)	Political issues associated with the inclusion of equity in economic evaluations.	None provided.
Cookson *et al.* (2009b)	Explicit incorporation of equity considerations into economic evaluation of public health interventions – Reply to Richardson & Shiell (Response article)	Response to above issues.	Four proposed methods above.

Complex systems and multi-component interventions			
Author (year)	**Title (type of article)**	**Key issues raised**	**Recommended approach**
Shiell *et al.* (2008)	Complex interventions or complex systems? Implications for health economic evaluation. (Full journal article)	-Public Health systems are complex, and as such they present new methodological challenges. -The fact that Public Health interventions are often multi-component does not present new methodological challenges.	None provided.
Kelly *et al.* (2005)	Economic appraisal of public health interventions. (Briefing paper)	-QALY outcome may not be a sufficient measure; -Greater need to develop methods for including equity considerations; -It is important for a model to address what aspects of an intervention are successful/ unsuccessful.	-Cost consequence analysis from perspective of each sector as additional analysis; Discrete choice experiments may be used for valuation. -None provided; -None provided.
Weatherly *et al.* (2009)	Methods for assessing the cost-effectiveness of public health interventions: Key challenges and recommendations. (Full journal article)	Four key methodological challenges: -Quantifying the effectiveness of interventions; -Measuring and valuing outcomes; -Inclusion of intersectoral costs and consequences; -Inclusion of equity.	-More use could be made of techniques for analysing non-experimental data (eg. econometric analysis); -Compensation test approach (Claxton *et al*.) -Cost consequence analysis from perspective of each sector as additional analysis; -None provided.
Plsek and Greenhalgh (2001)	Complexity Science: The challenge of complexity in health care. (Full journal article)	There is a challenge to address complexity within healthcare.	Point to the science of complex adaptive systems, but no specific approach described.
Shiell and Hawe (1996)	Health promotion community development and the tyranny of individualism. (Full journal article)	Community impacts of interventions should be incorporated, which is more than the sum of the individual impacts.	None provided.
Smith and Petticrew (2010)	Public health evaluation in the twenty-first century: time to see the wood as well as the trees. (Full journal article)	-Public Health economic modelling should focus upon broader outcomes such as 'happiness'; -There is a need to focus on the direct and indirect effects of the interventions upon communities and populations, as well as on individual effects.	-None provided; -None provided.

Complex systems and multi-component interventions (cont)			
Author (year)	**Title (type of article)**	**Key issues raised**	**Recommended approach**
Whitehead (2010)	The right wood, but barking up the wrong tree. (Commentary - response to Smith and Petticrew)	-There are Public Health interventions which have been undertaken using a macro-level analysis, contrary to what was discussed by Smith and Petticrew. -It is the funders of Public Health economic modelling which encourage a micro-level approach rather than the analysts.	None provided.
Rickles *et al*.(2009)[71]	A simple guide to chaos and complexity. (Journal article 'glossary')	There are limitations associated with understanding causality, which is more complex in Public Health due to the risk factors (the determinants of health) often being social.	None provided.

Technical modelling issues			
Author (year)	**Title (type of article)**	**Key issues raised**	**Recommended approach**
Anderson (2010)	Modelling and evidence synthesis: challenges, value and issues for discussion. (Workshop presentation)	-The differences between HTA and Public Health economic modelling; -Decision trees and Markov models may not be adequate due to the non-discrete behavioural changes, the complex long causal chains and the requirement to simulate many health and non-health outcomes.	-Modelling should be more exploratory, with results presented as a sensitivity analysis rather than a 'base case'; -May need to consider alternative methods which can deal with the complexity of Public Health systems.
Rappange (2009)	Lifestyle intervention: from cost savings to value for money. (Full journal article)	The cost-effectiveness of Public Health interventions may be overestimated because the costs associated with future illnesses are not included within the analysis.	Costs associated with future illness should be included within the analysis.

Appendix B: Review of conceptual modelling frameworks

Appendix B1: Search strategy

Stage 2:

MEDLINE

1. “conceptual model$”.ti
2. “conceptual framework$”.ti
3. “problem formulation$”.ti
4. “economic model$”.mp
5. “economic evaluation$”.mp
6. “mathematical model$”.mp
7. “decision-analytic model$”.mp
8. “quantitative model$”.mp
9. simulation$.mp
10. “markov model$”.mp
11. “decision tree$”.mp
12. “system dynamics”.mp
13. “agent-based model$”.mp
14. “how to”.mp
15. generat$.mp
16. develop$.mp
17. process$.mp
18. stage$.mp
19. or/1-3
20. or/4-13
21. or/14-18
22. 19 and 20 and 21

Scopus and Web of Knowledge:

1. “conceptual model*”.ti
2. “conceptual framework*”.ti
3. “problem formulation*”.ti
4. “economic model*”.mp
5. “economic evaluation*”.mp
6. “mathematical model*”.mp
7. “decision-analytic model*”.mp
8. “quantitative model*”.mp
9. simulation*.mp
10. “markov model*”.mp
11. “decision tree*”.mp
12. “system dynamics”.mp
13. “agent-based model*”.mp
14. “how to”.mp
15. generat*.mp
16. develop*.mp

17. process*.mp
18. stage*.mp
19. or/1-3
20. or/4-13
21. or/14-18
22. 19 and 20 and 21

Appendix B2: Data extraction form for conceptual modelling frameworks

Author, year

Aim of paper

Definition of conceptual modelling

Steps in conceptual modelling process

Proposed approach

Evaluation of approach

Strengths

Weaknesses

Potential generalisability to public health economic models

Theoretical underpinnings of the framework

Areas identified for further research

Appendix B3: Excluded studies and reason for exclusion

Author, year	Reason for exclusion
Amblard et al., 2001[1]	Does not aim to develop a quantitative model.
Andersen and Richardson, 1997[2]	Does not describe a set of principles and methods/ methodologies which facilitate the development of a model structure.
Arbez and Birta, 2011[3]	??
Ares and Pazos, 1998[4]	Does not aim to develop a quantitative model.
Baldwin et al., 2004[5]	Does not describe a set of principles and methods/ methodologies which facilitate the development of a model structure.
Bérard, 2010[6]	Describes current status of group model building, but does not describe a set of principles and methods which facilitate the development of a model structure.
Chwif et al., 2013[7]	No stakeholder involvement is considered.
Cook and Ferris, 2007[8]	Does not aim to develop a quantitative model.
Curtis et al., 2006[9]	Does not aim to develop a quantitative model.
Derrick and Balci, 1992[10]	Describes only the diagrammatic representation of a conceptual model without describing methods for choosing what is included or excluded within the representation.
Derrick et al., 1989[11]	Reviews frameworks describing the steps involved within a conceptual modelling framework without describing methods for development.
Fernández et al., 2010[12]	Solely a contribution of theory.
Franco and Montibeller, 2010[13]	Solely a contribution of theory.
Franco, 2006[14]	Solely a contribution of theory.
Heavey and Ryan, 2006[15], 2011[3]	Describes only the diagrammatic representation of a conceptual model without describing methods for choosing what is included or excluded within the representation.
Jun et al., 2011[16]	Does not describe a set of principles and methods which facilitate the development of a model structure.
Juristo and Moreno, 2000[17]	Does not describe a set of principles and methods which facilitate the development of a model structure.
Kotiadis and Robinson, 2008[18]	A case study of using Soft Systems Methodology.
Kotiadis, 2011[3]	Not the fullest description of this conceptual modelling framework.
Lacy et al., 2001[19]	Provides a review of existing work on conceptual modelling, but does not describe a set of principles and methods which facilitate the development of a model structure.
Lane and Oliva, 1998[20]	Not the most recent article describing this conceptual modelling approach.
Montevechi et al., 2008[21]	Describes only the diagrammatic representation of a conceptual model without describing methods for choosing what is included or excluded within the representation.
Montevechi et al., 2010[22]	Describes only the diagrammatic representation of a conceptual model without describing methods for choosing what is included or excluded within the representation.
Nance, 1994[23]	Describes the steps involved within a conceptual modelling framework without describing methods for development.
Norese, 1995[24]	Does not aim to develop a quantitative model.
Onggo, 2009[25], 2011[3]	Describes only the diagrammatic representation of a conceptual model without describing methods for choosing what is included or excluded within the representation.
Pace, 2011[3]	No stakeholder involvement is considered.
Robinson*, 2011[3]	Not the fullest description of this conceptual modelling framework.
Rouwette et al., 2009[26]	Does not describe a set of principles and methods which facilitate the development of a model structure.
Siau and Tan, 2005[27]	Does not aim to develop a quantitative model.
Sokolowski et al., 2008[28]	No stakeholder involvement is considered.

Author, year	Reason for exclusion
Sotoodeh and Kruchten, 2008[29]	Does not describe a set of principles and methods/ methodologies which facilitate the development of a model structure.
Van der Lei, 2011[30]	Does not aim to develop a quantitative model.
Van der Zee et al., 2010[31]	Does not describe a set of principles and methods/ methodologies which facilitate the development of a model structure.
Van der Zee, 2007[31], 2011[3]	No stakeholder involvement is considered.
Vennix, 1999[32]	Solely a contribution of theory.
Wang and Brooks, 2007[33], 2011[3]	Does not describe a set of principles and methods/ methodologies which facilitate the development of a model structure.

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Appendix C: Qualitative research

Appendix C1: Ethical approval letter

The University Of Sheffield.

Cheryl Oliver
Ethics Committee Administrator

Regent Court
30 Regent Street
Sheffield S1 4DA
Telephone: +44 (0) 114 2220871
Fax: +44 (0) 114 272 4095 (non confidential)
Email: c.a.oliver@sheffield.ac.uk

Our ref: 0515/CAO

16 May 2011

Hazel Squires
ScHARR

Dear Hazel

A methodological framework for developing the structure of public health economic models

Thank you for submitting the above research project for approval by the ScHARR Research Ethics Committee. On behalf of the University Chair of Ethics who reviewed your project, I am pleased to inform you that on 16 November 2011 the project was approved on ethics grounds, on the basis that you will adhere to the documents that you submitted for ethics review.

The research must be conducted within the requirements of the hosting/employing organisation or the organisation where the research is being undertaken.

If during the course of the project you need to deviate significantly from the documents you submitted for review, please inform me since written approval will be required. Please also inform me should you decide to terminate the project prematurely.

Yours sincerely

Cheryl Oliver
Ethics Committee Administrator

Appendix C2: Participant consent form

The University Of Sheffield.

School Of Health And Related Research.

Hazel Squires
ScHARR
Regent Court
30 Regent Street
Sheffield
S1 4DA
Tel: 0114 2220765
Email: h.squires@sheffield.ac.uk

Participant Consent Form

Title of Research Project: A methodological framework for developing the structure of public health economic models

Please initial box

1. I confirm that I have read and understand the information sheet dated *[insert date]* explaining the above research project and I have had the opportunity to ask questions about the project. ☐
2. I understand that I will be being observed during PDG meetings and taking part in interviews before and after the PDG meetings, all of which will be audio recorded. ☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. ☐
4. I understand that my responses will be kept strictly confidential. I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials; however it may be possible for other experts to identify me from the content of the material reported from the research. ☐
5. I agree for the data collected from me to be used in future research. ☐
6. I agree to take part in the above research project and to be audio recorded. ☐

________________________	________________	____________________
Name of Participant	Date	Signature
________________________	________________	____________________
Name of Researcher	Date	Signature

Appendix C3: Information sheet for modellers

The University Of Sheffield.

School Of Health And Related Research.

Hazel Squires
ScHARR
Regent Court
30 Regent Street
Sheffield
S1 4DA

Tel: 0114 2220765
Email: h.squires@sheffield.ac.uk

Information sheet for modellers

You are being invited to take part in a research project titled 'A methodological framework for developing the structure of Public Health economic models'. This information sheet explains what the research involves and why it is being done so that you can decide whether to participate. Please take time to read the following information carefully and ask me if there is anything that is not clear or if you would like more information. My contact details are as follows:

Hazel Squires; h.squires@sheffield.ac.uk; Tel: 0114 2220765. Thank you for reading this.

Background

I have been awarded a 3-year NIHR Doctoral Training Fellowship which began in November 2010 to produce a conceptual modelling framework for developing the structure of Public Health economic models. Conceptual modelling involves understanding the problem and deciding how the problem will be modelled, in a way that allows clear communication with stakeholders and experts. Currently there are no formal methods for doing this within Public Health economic modelling. Three supervisors from the School of Health and Related Research (ScHARR) at the University of Sheffield are involved in this work including Professor Ron Akehurst, Jim Chilcott and Dr Jennifer Burr. During the first year of the research I undertook a literature review around the key challenges within Public Health economic modelling and a multidisciplinary review of existing conceptual modelling frameworks.

Qualitative data collection and analysis

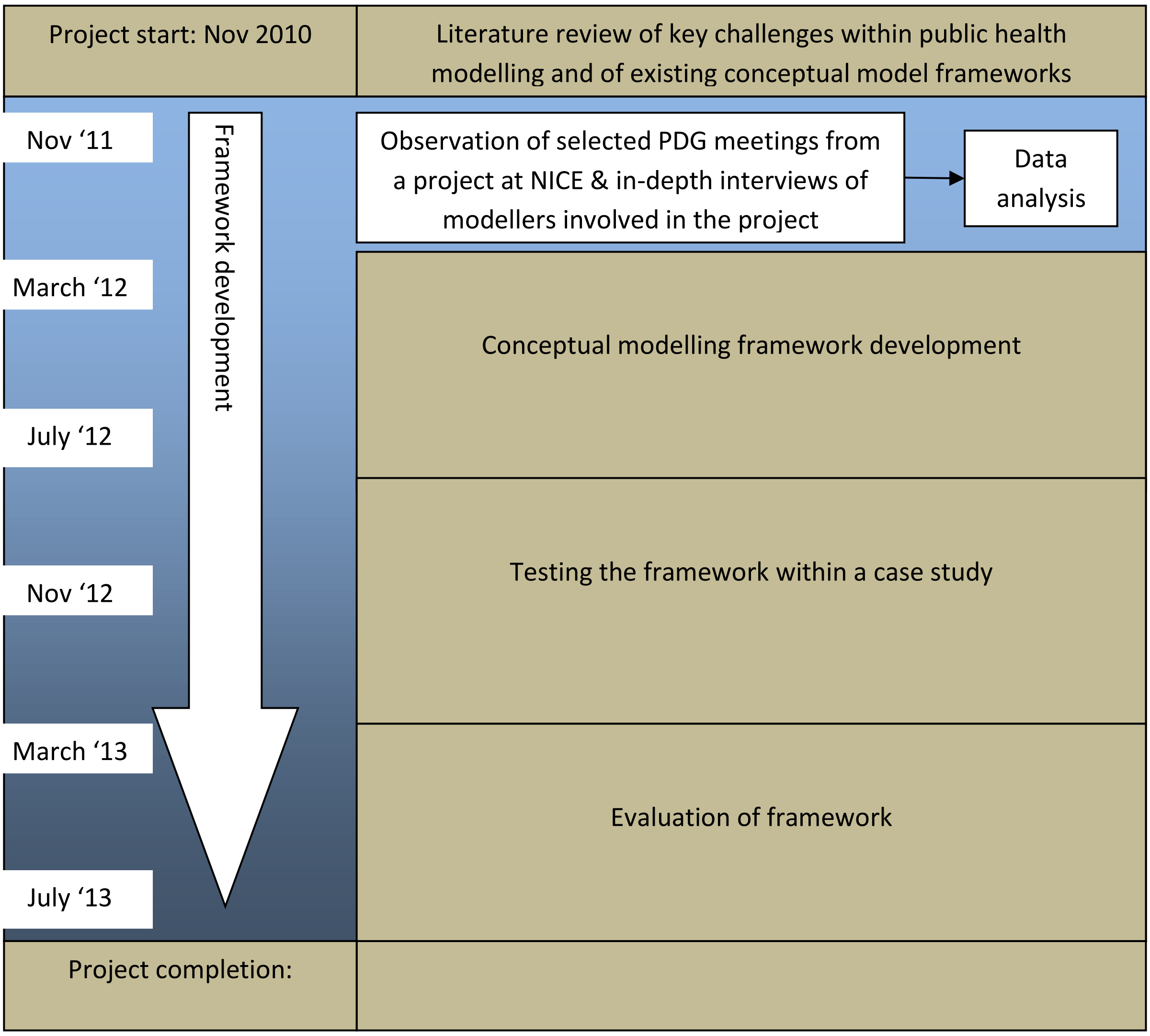
Within the second year of the research, as part of the methodological development of the conceptual modelling framework, I am planning on undertaking some qualitative data collection and analysis to:

1) Understand the model development process in practice for Public Health economic modelling;
2) Understand how and why modellers make decisions about model scope and structure;

3) Establish some of the key issues during model conceptualisation and what has worked well or poorly within Public Health economic modelling;
4) Understand the potential feasibility and barriers to the use of a conceptual modelling framework;
5) Understand some of the requirements and constraints of decision makers.

This will be achieved by observing several Programme Development Group meetings at NICE and interviewing the modellers involved within these. I would like to invite you to participate by allowing me to observe the model development process within key modelling PDG meetings of the Walking and Cycling Project (which I would like to audio record) and by interviewing you prior to and following the meetings to confirm what has been done to date, how decisions have been made and what your next steps will be and why.

An outline of the qualitative data collection & analysis within the wider project is shown below.



Key details:

What would participation involve and what would be expected of me if I take part?

There are usually 2-3 PDG meetings which focus upon the modelling at NICE which I would attend. Within the PDG meetings you would be expected to act as you would normally. I would take notes during the meetings in order for analysis to be undertaken following the meeting. You would be required to take part in an interview the week before each of the 2-3 PDG meeting and to take part in an interview immediately after each, each of which would not last longer than 40 minutes. These will be audio recorded and subsequently analysed to identify key themes. In order to take part, you will need to sign a consent form for the research (see attached) either prior to or at the beginning of the first interview.

Will my taking part in this project be kept confidential?

The name of participants will be anonymised within the study; however it should be noted that experts in the area may be able to recognise you based upon what you have said or the case study being evaluated. Audio recordings will be copied onto my personal computer which is password protected for the data analysis and they will be deleted from the audio recorder after they have been copied over, as soon as possible after the PDG meetings and interviews. The audio recorder and meeting notes will be kept securely during travel. The audio recordings and meeting notes will be used only for analysis and for illustration within research outputs including publications and conference presentations. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.

What will happen to the results of the research project?

The results of the research will be reported within a PhD thesis upon completion of the work. The qualitative data collection and analysis may also be reported within peer-reviewed publications and conference presentations. A copy of any outputs of the research will be circulated to you as soon as possible, and you will be anonymously acknowledged within them.

Do I have to take part?

Taking part in the research is entirely voluntary. If you do decide to take part you will be given this information sheet to keep and you will also be asked to sign a consent form prior to your involvement. You can withdraw at any time without it affecting any benefits that you are entitled to in any way, and you do not need to give a reason.

Additional questions you may have:

Why have I been chosen?

You have been chosen due to the timing of the project at NICE within my research.

What are the possible benefits of taking part?

It is anticipated that by taking part in this research you may facilitate methodological progression in this underdeveloped area.

Who has ethically reviewed the project?

This project has been ethically approved via ScHARR's ethics review procedure. The University's Research Ethics Committee monitors the application and delivery of the University's Ethics Review Procedure across the University.

What happens if the research study stops earlier than expected?

If the research study was stopped earlier than expected for any reason, the reasons for this would be explained to you.

What if I am not happy with the research?

If you have any queries or concerns, you can contact me at any time throughout the project. If you have any complaints about the research you should contact Dr Jennifer Burr (j.a.burr@sheffield.ac.uk). If you feel that any complaints are not handled adequately, you should contact the Registrar and Secretary at the University of Sheffield (registrar@sheffield.ac.uk).

Please contact me if you have any additional questions about the research.

<u>Appendix C4: Topic guide for the qualitative interview before the PDG meeting</u>

Aim: To understand

1) what has been done prior to the first meeting with stakeholders;

2) how modellers make decisions about model scope and structure and the reasons why;

3) key issues during model conceptualisation.

Participant's background:

-Tell me about your background in health economic modelling.

-What public health modelling have you been involved in?

-*What did you do after that?*

Have you been involved in any other public health modelling?

Details of the experience:

-Tell me about what you have done so far on the Walking and Cycling project.

-Tell me about the key problems you have had so far.

-How did you go about understanding the problem?

-Have you developed a model scope? What does that consist of and how did you develop it?

-How did you go about conceptualising the model structure?

-How did you consider the level of detail to include within the model?

-Have you thought about the type of model you might develop?

<u>*Additional probes*</u>

What did you do after that?

You talked about… Tell me more about… It would be useful to explore x further…

What do you mean by…?

Why did you do it that way? In what way…?

What about the interventions you're assessing?

What evidence is that based upon?

How do you decide what to include and exclude?

Reflections on the experience:

-Are you concerned about any aspects of the work you have done so far?

-What aspects of the proposed approach do you think the PDG will be concerned about?

-Why have you chosen to develop the model to this particular point for the PDG meeting?

-What do you think about your current understanding of the problem?

Can you think of anything else the PDG might question?

What about the model scope?

What about the model structure?

Is there anything else you'd like to say about this?

<u>PDG meeting observation</u>

Aim:

1) To understand how stakeholders are involved and affect decisions of model structuring;

2) To understand some of the requirements and constraints of decision makers.

Appendix C5: Topic guide for the qualitative interview after the PDG meeting

Aim: To understand

1) what has changed and what the modellers next steps are as a result of the meeting with stakeholders;
2) what the modeller thinks went well and not so well in terms of their approach;
3) what the modeller thinks of as a conceptual modelling framework and the potential feasibility and barriers to using a conceptual modelling framework.

Reflecting on the experience:

-What are your next steps following the PDG meeting?

How has the PDG meeting affected your next steps? Would you have done that anyway?

-How has the PDG meeting altered your initial thoughts on the modelling?

Why do you think that?

Will it alter the model scope? Will it alter the model structure?

-What do you think went well within the meeting?

Are there any other things you think went well?

-Are there any aspects which you think didn't go so well?

Are there any other aspects you don't think went so well?

-What do you think of as a conceptual modelling framework?

Does it include understanding the problem/ model scoping/ level of detail/ structural assumptions/ choosing model type?

-Do you think model development within Public Health economic modelling would benefit from a conceptual modelling framework?

Why do you think that? Can you think of any other benefits?

-What do you think would be the barriers to using a conceptual modelling framework within public health economic modelling for a decision making process such as NICE?

Why do you think that?

-What aspects of model development do you think are least well developed in terms of guidance for modellers for public health economic modelling?

Are there any other aspects?

-Do you think systems approaches may be helpful in developing public health economic modelling?

What about the use of formal problem structuring methods? What about the use of causal mapping?

Appendix C6: Topic guide for the focus group meeting

Preliminaries

1) Introduce myself
2) Outline of the research topic, purpose (important for participation), funder
3) Confidentiality, audio recording, what will happen to the data, dissemination.
4) Please could everyone treat what is said as confidential and not repeat it outside of the session without permission from the relevant participant.
5) Indication of expectations – want to have a discussion, participants should not wait to be invited before speaking (although don't talk over each other), everyone's views are of interest, want to hear as many different thoughts as possible, as such if agree or disagree with other participants say so.
6) Ask everyone to introduce themselves – names & brief background focusing upon Public Health modelling, one recent case study that they will focus upon and who the work was for.
7) Could highlight the diversity/ similarity of the group as a whole.

Topic guide

How do you go about **understanding the problem**?

Why do you do it that way?

What is the role of evidence?

How do you decide what the **model scope** will be?

How do you go about **conceptualising the model structure**?

How do you decide what to **include and exclude** within the model**?**

How do you consider the **level of detail** to include within the model?

At what stage do you decide what **type of model** you will develop?

Why?

What is the role of evidence?

What are the **main issues** you have experienced during model conceptualisation?

What has worked well to address these?

What has worked not so well?

How much **stakeholder input** do you obtain during model conceptualisation?

For what, how, why?

Do you develop a **conceptual model**?

Can you describe it?

What does it help with?

What do you think of as a **conceptual modelling framework**?

Does it include understanding the problem/ model scoping/ level of detail/ structural assumptions/ choosing model type?

Do you think model development within Public Health economic modelling would **benefit** from a conceptual modelling framework?

Why do you think that?

Can you think of any other benefits?

What do you think would be the **barriers** to using a conceptual modelling framework within public health economic modelling within a decision making process such as NICE?

Why do you think that?

Do you think **systems approaches** may be helpful for developing Public Health economic models?

What about the use of formal problem structuring methods?

What about the use of causal mapping?

Is there ***anything else*** *you'd like to say around what we've talked about today?*

Generic probes

Why do you think that?

What did you do after that?

You talked about… Tell me more about…

It would be useful to explore x further…

What do you mean by…?

Other notes about running the focus group

Pressure on participants to conform: Ask whether anyone has any different views or ask a person who is likely to have a different view

Dominant person: That's really helpful; does anybody else have a view on this?

Quiet person: What do you think? Or you said xxx previously, what…

Recording non-verbal behaviour: 'Everyone's nodding a lot – why is that?'

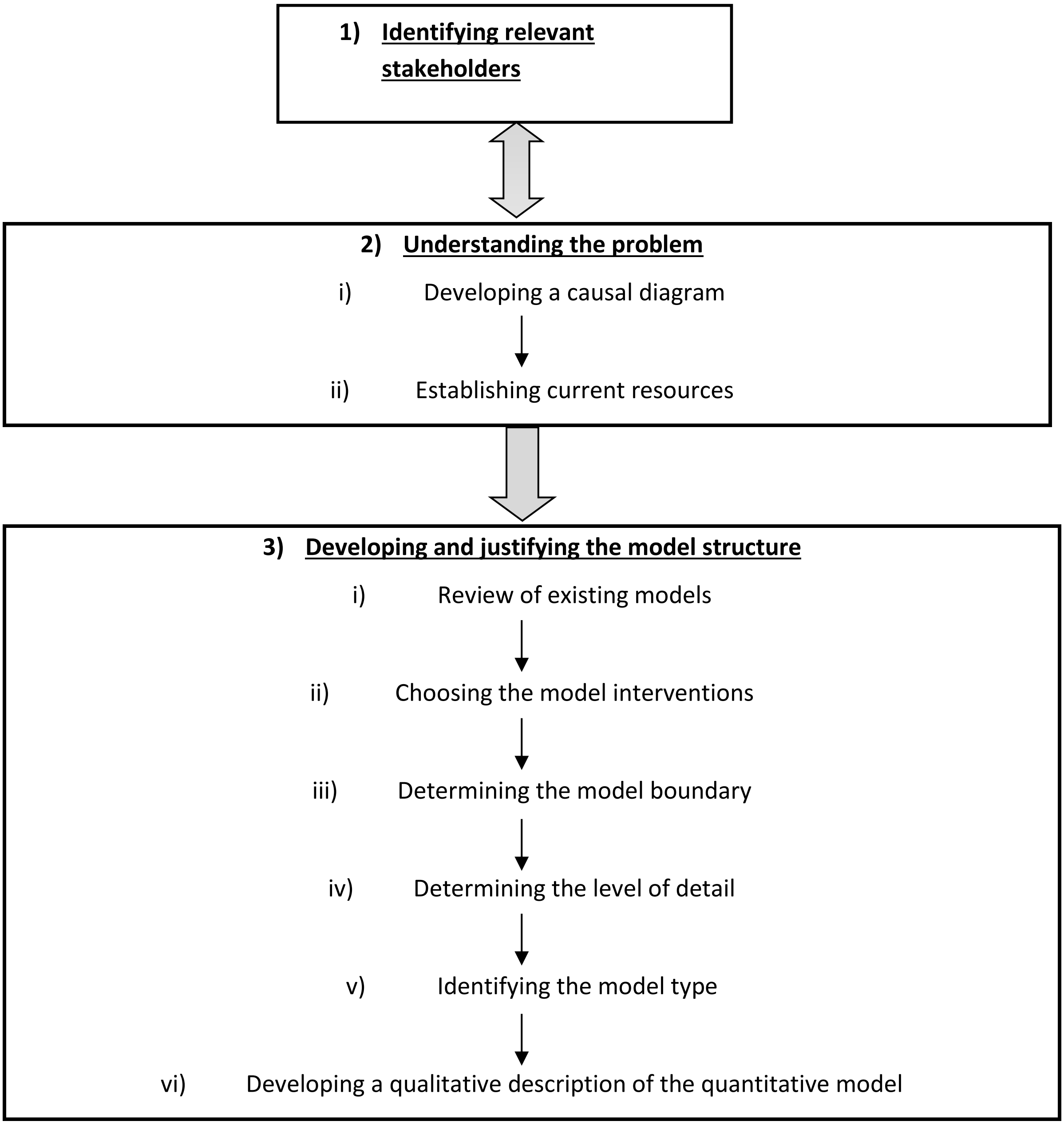
Appendix D: Documents developed within the diabetes project

Appendix D1: Protocol for conceptual modelling phase

Introduction

The conceptual modelling phase of the project will be based upon the Conceptual Modelling Framework for Public Health Economic Modelling[1] and will follow the general stages outlined within Figure 1 below. As shown it will be divided into three key parts; (1) identifying relevant stakeholders; (2) understanding the problem and (3) developing and justifying the model structure.

Figure 1: Outline of process for the conceptual modelling phase



1) **<u>Identifying relevant stakeholders</u>**

A sufficient understanding of the decision problem to be able to identify a relevant group of stakeholders for the project will be developed. We plan to identify the following types of stakeholders to facilitate with model scoping and development as a minimum:

- 3 diabetes epidemiology specialists, identified through discussions with Mike Gillett, Liddy Goyder and Nick Payne, and the external project collaborators. Snowballing will be used if required.
- 1 CVD specialist. This will be Simon Capewell, one of the collaborators;
- 1 clinician with expertise around obesity, identified through discussions with Mike Gillett;
- 1 statistical expert. This will be Peter Diggle, one of the collaborators;
- 2 patient representatives/ lay members, identified through diabetes UK;
- 3 decision makers (preferably 2 local, 1 national), identified through discussions with Mike Gillett, Liddy Goyder and Nick Payne and including contacting Directors of Public Health, the South Yorkshire GP commissioning group specialising in diabetes, NHS Diabetes and the UK Screening Committee.

This is likely to involve contacting a much greater number of stakeholders as it is expected that some of the key diabetes experts and policy makers may not have time to be involved in the project. This will need to be carried out over a number of iterations of waiting for responses and contacting additional potential stakeholders.

We plan to involve the stakeholders in all stages of model development. As part of this, the stakeholders will be invited to attend three workshops throughout the project, as well as being asked to read draft documents produced by the project team. The first two of the workshops relate to the conceptual modelling stages of the project, whilst the final workshop is to present the draft report of the methods and results of the model. Any stakeholders who cannot attend a workshop will be asked to comment on papers produced for the workshop in advance so that their views can be incorporated.

Workshop 1 will be held around October 2012, and the objectives will be (1) to aid in the development of a causal diagram of diabetes natural history and the implications of this upon other diseases; (2) to establish current resource use for diabetes prevention and treatment; and (3) to begin to develop the scope of the model including the model perspective and outcomes and the types of interventions for consideration within the model.

Workshop 2 will be held around the end of February/ beginning of March 2013 (depending upon stakeholder availability) and the objectives will be (1) to consider the review of interventions in order to determine which specific interventions should be considered within the model; (2) to review potential model assumptions.

Briefing papers will be sent to stakeholders prior to each workshop for discussion within the workshop.

2) <u>Understanding the problem</u>

i) Developing the causal diagram

A causal diagram will be developed prior to the first workshop for discussion at this workshop about the decision problem and its causal relationships. The first step for developing the causal diagram is to use the project proposal to describe the problem. The next step is to outline all of the causal links associated with the problem as well as those associated with the types of interventions being considered within the model. The project proposal outlines the scope of the work including the types of interventions being considered within the project, which will be used to facilitate this. The causal diagram will include the disease natural history of diabetes and the causal links with other diseases. A review of the disease natural history of diabetes (discussed in more detail below) will be undertaken in parallel to the development of this causal diagram and will be used to inform it. The role of the causal diagram will be:

- to allow communication with the stakeholders, thus improving our understanding of the problem, as well as helping to raise model credibility;
- to encourage reflection around the decision problem in a structured way and to help the modeller to understand what simplifying assumptions they are making within the model.
- to provide a basis for validation for the model by transparently describing the understanding of the problem which allows what is included and excluded within the model to be justified;
- to help choose the most appropriate analytical model type to develop (eg. discrete event simulation);
- to be included within the methods of the report so that researchers and policy makers who are not involved within the project can see our understanding of the problem and follow what has been done and the reasons for our model choices.

Review of type 2 diabetes disease natural history

A review of the disease natural history of type 2 diabetes will be undertaken with the aim of firstly understanding the key components and issues associated with the disease natural history and secondly facilitating a mathematical description of this disease natural history. A standard Cohrane style of review of the disease natural history of type 2 diabetes would be unmanageable due to the amount of evidence in this area. Thus we will follow an iterative search process, using a number of different search techniques, as described by Paisley (2012).[2] The first stage of the searching is to identify high yield sources of information from which future searches can be developed. Thus, the previous economic models developed at ScHARR and any existing reviews of the disease natural history of type 2 diabetes will be used as a starting point for the search. From these, another iteration of sources will be identified. For example, the ScHARR economic modelling report includes a description of the QDScore, from which a key paper might be searched for as potentially relevant. The definition of relevance will be developed as part of the search process. Each iteration of the search process will be described within the methods of the report.

Data extracted during the first stage of defining relevance will be the population, the approach employed, the conclusion and key points from the discussion. During the later stages of the review, more detail around the methods and results of included studies will be extracted, in order to define appropriate data for the mathematical model. This will include the equation(s) developed as well as the quality of the study. This review will be presented as part of the main report, rather than being a standalone document.

ii) Identifying current resources

This will involve describing the resources required for each factor within the causal diagram. For example, the factor 'clinically diagnosed diabetes' would include the resources associated with treatment of diabetes. These will be identified by any relevant literature identified during the search for the disease natural history of diabetes, as well as additional informal literature searches. A table of current resources will be produced for discussion at Stakeholder Workshop 1.

3) Developing and justifying the model structure

i) Review of existing models

A review of existing diabetes prevention and screening economic models will be undertaken, again following the methods described by Paisely (2012).[2] The review will begin with identifying relevant existing reviews and these will be updated and additional searches undertaken as necessary. The review will be used to facilitate choices about model structuring. The inclusion criteria will be dependent upon the number and types of studies identified by the searches. A modified version of the Drummond checklist will be used for data extraction.[3]

ii) Choosing the model interventions

Following Stakeholder Workshop 1, a review of relevant interventions for screening and prevention of type 2 diabetes will be undertaken. The review will begin with identifying relevant existing reviews of interventions to avoid repeating existing work as it is known that other reviews have previously been carried out. These reviews will then be updated as appropriate. Data extraction will include interventions and comparators (including resource requirements), populations, outcomes, study design, key results and study limitations. The exact interventions for consideration within the model will be discussed within Stakeholder Workshop 2 based upon the findings of this review.

iii) Determining the model boundary

We will discuss with stakeholders the most appropriate model outcomes and perspective. It is likely that a cost per QALY analysis will be presented from an NHS perspective in the base case analysis. It may also be appropriate to present a cost-consequence analysis alongside the cost-effectiveness analysis. This will be discussed within Stakeholder Workshop 1.

Following identification of the relevant interventions (described above), we will consider the appropriate comparators, model population and whether there are any relevant subgroups which should be modelled. These will be discussed within Stakeholder Workshop 2.

For each factor within the causal diagram which does not have many links to the remaining factors, we will assess whether removing it will impact substantially upon the model results; that is, the extent of the expected difference between the intervention(s) and comparator(s). This will be informed where evidence is available by the review of existing economic models in the area. Where factors from the causal diagram are excluded, the reason for exclusion will be documented. An example of a factor which may be included within the understanding of the problem because it will be affected by the interventions but subsequently be excluded from the model is pancreatic cancer, due to the relatively small impact the interventions will have upon pancreatic cancer incidence in comparison to diabetes and CVD.

iv) Determining the level of detail

The level of detail included within the model will be specified according to the interventions and comparators being assessed and the defined model boundary. For each factor identified within the model boundary, the level of detail will be moderated by the availability of data. Data for inclusion for specifying the model structure and for the parameters will be identified at this point. This will be based upon any literature identified during the development of the causal diagram for which specific literature was noted as useful as well as additional specific searches. Decisions about when to stop searching for information may be made based upon the expected impact of that factor upon the model results compared with the information retrieved for representing other factors within the model, given the constraints of the decision making process. Again, sufficient evidence is required to be able to justify why the modelling choices have been made.[2] Elements for which there is a lack of empirical data which are considered to have key differential impacts upon the comparator(s) and the intervention(s) may be informed by expert elicitation. At this stage we will choose the most appropriate approach for estimating the disease natural history parameters, which may be taken from existing studies or calibrated using statistical methods such as the Metropolis Hastings algorithm.[4] Building upon the work by Robinson (2011),[5] for each factor included within the model boundary, a table will be developed outlining the level of detail being included.

i) Identifying the model type

The model type will be determined based upon the taxonomy by Brennan et al. (2006)[6] using the understanding of the problem that has been developed in addition to the requirements of the decision maker including time/ resources available, data availability, the availability and access to the use of existing relevant good quality economic models which could be used as a starting point and the likelihood of the intervention being cost-effective in combination with the requirements of the model for future use. Based upon our current understanding of the problem and data availability it is likely that the model will be a patient-level simulation.

ii) **Developing a qualitative description of the quantitative model**

A qualitative description of the quantitative model will be developed for including within the report. This enables transparent communication of the model between the project team, the stakeholders and researchers and policy experts not involved within the project who would like to understand the model. A different modeller (PW) will take the lead for developing the quantitative model and the diagrams developed will be used within the handover phase.

Project timescales

Model development stage	**Activity**	**When undertaken**	**By whom**
Develop conceptual description our understanding of the decision problem	Targeted background reading & discussion with Mike & Jen about key issues	July	HS
	Formal review of disease natural history	Aug – Nov	LP
	Draft causal diagram	Aug – Sept	HS
	Description of current resources	Sept	LP & HS
	Stakeholder workshop 1: Discuss causal diagram, current resources & model outcomes	Beg Oct	All
Develop description of the model structure	Review of previous diabetes prevention/ screening models (& obesity prevention models?)	Oct – 15th Nov	HS/ PW
	Review of model interventions (systematic reviews)	Dec - Feb	LP
	Choosing the model interventions	15th Nov – end Feb	HS
	Determining the model boundary	15th Nov – end Feb	HS
	Determining the level of detail	15th Nov – end Feb	HS
	Identifying the model type	15th Nov – end Feb	HS
	Stakeholder workshop 2: Agree final model interventions, discuss model boundary & assumptions	End Feb/ March 2013	All
Develop & analyse	Developing & validating the quantitative model	March – Aug 2013	PW

quantitative model	Running model strategies	Sept 2013	PW
	Stakeholder workshop 3: Discuss draft report with results	Oct 2013	All
	Respond to stakeholder comments including re-running analyses if necessary	Oct - Nov 2013	PW
Dissemination	Dissemination of findings	Dec 2013 – April 2014	PW/ All

Project team: Hazel Squires (HS), Louise Preston (LP), Jim Chilcott (JC), Penny Watson (PW), Alan Brennan (AB), Mike Gillet (MG)

Throughout the conceptual modelling phase of the project HS, LP and JC will hold weekly meetings. MG will attend around half of these meetings as appropriate and AB will be invited to attend the meetings on a monthly basis. PW will begin attending meetings in October following the completion of her PhD thesis.

References

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Appendix D2: Example email to potential stakeholders

Dear xxx,

The NIHR School for Public Health Research is funding the development of a common modelling framework for the clinical and economic assessment of population/community public health interventions and targeted identification and screening interventions for prevention of type 2 diabetes. This project is being undertaken as a collaboration between ScHARR at the University of Sheffield, Cambridge Institute of Public Health, Peninsula College of Medicine and Dentistry and LiLac. The aim of the project is to support commissioners of public health services and other stakeholders in their decision making concerning strategies for diabetes prevention in order to provide overall health improvement and support the reduction of health inequalities. We would like to ask for your support in this exercise through contribution to a stakeholder/expert group. This will involve attending (or otherwise contributing to) 3 four-hour stakeholder workshops in Sheffield (1 on 5th October this year & 2 next year) and commenting on up to 3 documents throughout the course of the project.

The objectives of the first workshop will be 1) to aid in the development of a causal diagram of diabetes prevention, natural history and management, 2) develop the scope of the model and 3) consider the types of interventions for detailed consideration within the model. If you can attend the meeting then further details and discussion documents will be provided in advance.

Please let me know if you would like to be involved or if you would like further details.

Best wishes,

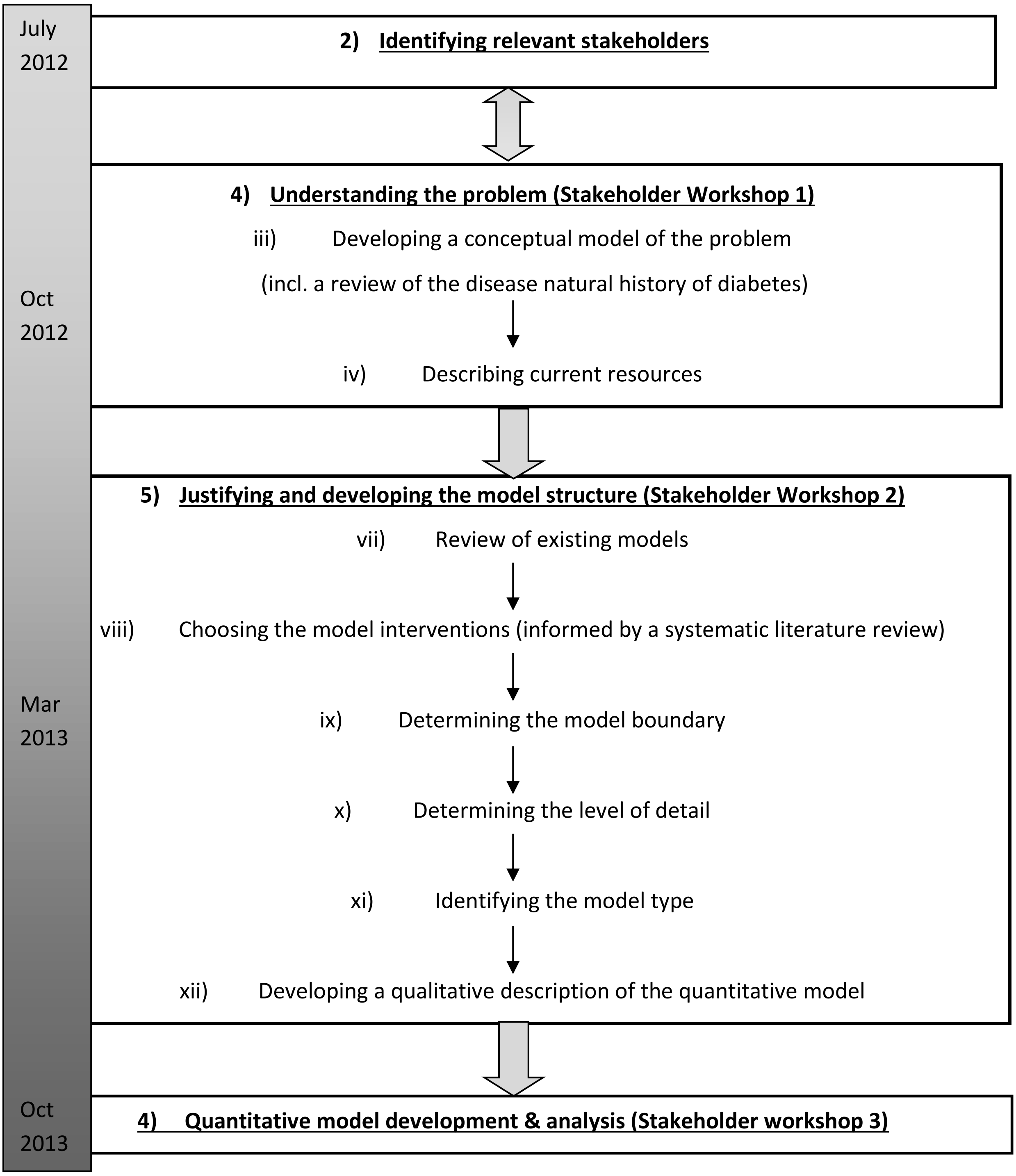
Hazel.

Appendix D3: Discussion document for Stakeholder Workshop 1

Overview of general project process

This project aims to support commissioners of public health services and other stakeholders in their decision making concerning strategies for diabetes prevention in order to provide overall health improvement & support the reduction of health inequalities. The process for developing the structure of the diabetes screening and prevention model is described in Figure A.

Figure A: Outline of conceptual modelling process



The first phase of this process has been undertaken and we have a team of stakeholders involved including decision makers, diabetes/ cardiovascular (CVD) experts and lay members. This first workshop aims to facilitate Phase 2 (understanding the problem). We will also begin to think about the model scope. The second workshop, to be held around March 2013, will facilitate Phase 3 (developing and justifying the model structure). The third workshop, to be held around October 2013, will be to discuss the draft modelling report.

Within this document we are aiming to set out our current understanding of the problem and the sources upon which this is based. This is not necessarily what will be included within the final model; however after incorporating your feedback, it provides a basis for us to be able to make decisions about what can be included within the model and what it is reasonable to exclude.

Specific objectives of Stakeholder Workshop 1:

1) To develop a conceptual model describing the decision problem
2) To identify any key evidence which may be useful for the modelling
3) To agree the types of interventions to be considered within a systematic literature review (eg. lifestyle interventions for subgroups of the general population, pharmacological interventions for people with IGR)
4) To discuss model perspective(s), outcomes, & populations
5) To discuss resource use

Objective 1: To develop a conceptual model describing the problem

A conceptual model which aims to capture potentially causal relationships associated with the problem has been developed for discussion. It includes the disease natural history of diabetes and potentially causal links with other diseases. The role of the conceptual model is:

- to provide a tool for communication, thus improving our understanding of the problem;
- to encourage reflection around the decision problem in a structured way and to help the modellers to be clear about the simplifying assumptions they are making within the model;
- to transparently describe the understanding of the problem which allows what is included and excluded within the model to be justified;
- to help choose the most appropriate analytical model type to develop;
- to be included within the methods of the report so that researchers and policy makers who are not involved within the project can see our understanding of the problem and follow what has been done and the reasons for our model choices.

We would like your input into this problem-oriented conceptual model in order to develop it further. The current version aims to provide a tool for communication about the problem and to generate discussion about aspects you agree/ disagree with, or feel that are missing.

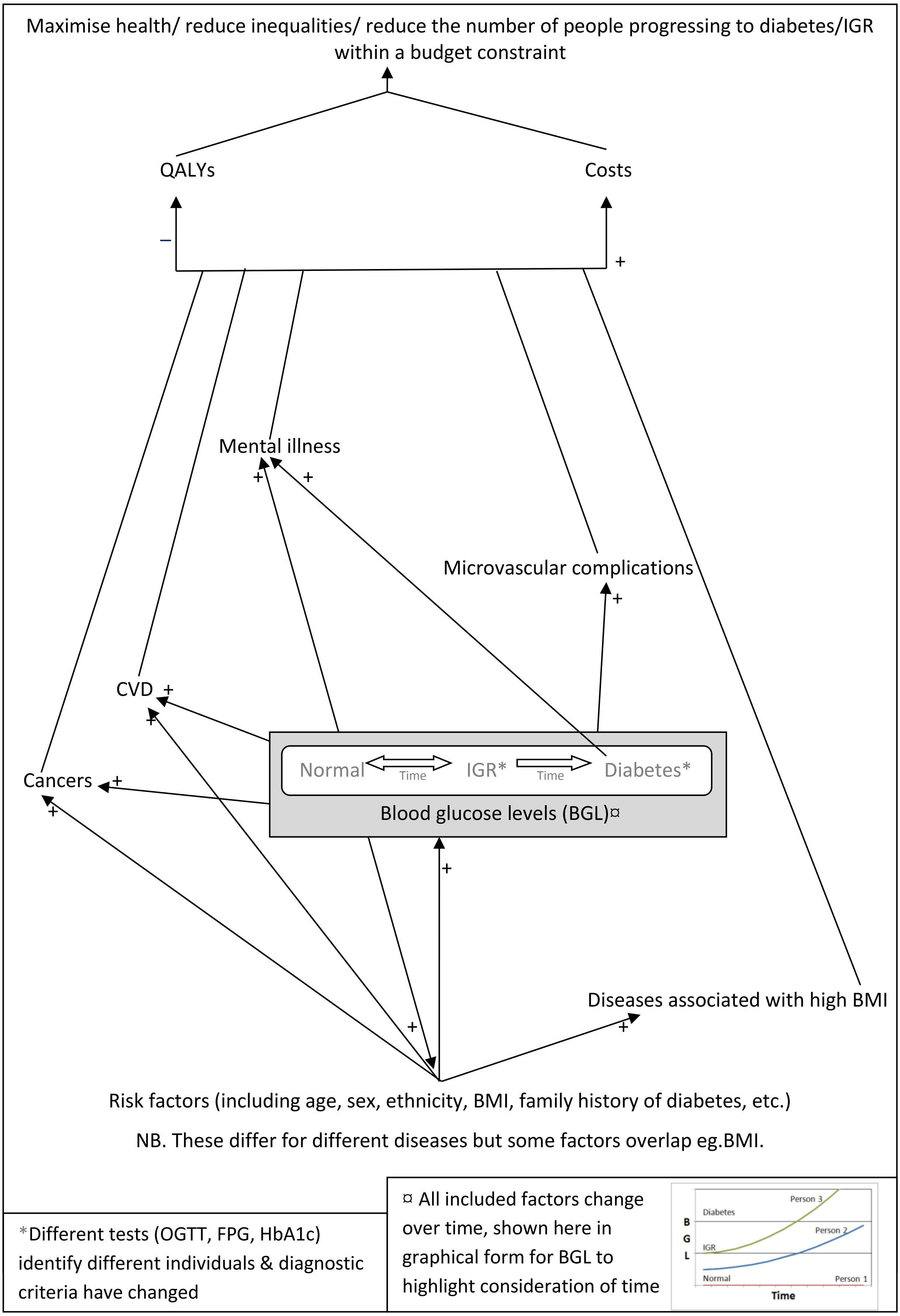
The problem-oriented conceptual model has been developed iteratively using the project proposal, existing ScHARR modelling reports, ScHARR diabetes modelling experts and targeted literature searches. The project proposal was the starting point for the development of the diagram, followed by the existing ScHARR modelling reports and discussions with ScHARR diabetes modelling experts. From these, targeted literature searches have been undertaken to further develop the problem-oriented conceptual model. Potentially relevant papers were identified through citation searching, reference searching and author searching of the initial papers identified. Papers were identified to define each of the relationships within the conceptual model. A review of the disease natural history of diabetes is being undertaken in parallel and has been used to inform the conceptual model.

A simplified version of the conceptual model is shown in Figure B below so that you can see the sort of factors we will be considering. The following pages focus on specific parts of the figure and describe how they have been developed and we will go through each of these in turn within the workshop. Within this figure:

$X \xrightarrow[+]{} Y$ should be interpreted as an increase in X leads to an increase in Y
(thus a decrease in X leads to a decrease in Y)

$X \xrightarrow[-]{} Y$ should be interpreted as an increase in X leads to a decrease in Y
(thus a decrease in X leads to an increase in Y)

Figure B: Problem-oriented conceptual model of diabetes prevention



Part I: The key problem

The starting point for the diagram was to consider the key problem based upon the project proposal. This was identified to be that high blood glucose levels are associated with diabetes and Impaired Glucose Resistance (IGR). There are modifiable and non-modifiable risk factors associated with high blood glucose levels which include (but are not limited to) age, sex, BMI, family history of diabetes, use of antihypertensive therapy and ethnicity, and these affect the probability of having higher blood glucose levels.

Disease natural history based upon blood glucose levels or IGR/ diabetes

The disease natural history of diabetes over time may be described using blood glucose levels over a continuous scale, or by using the discrete classifications of IGR and diabetes. Ideally we would want to describe the disease natural history in terms of blood glucose levels rather than IGR/ diabetes because: (1) the definition of diabetes has changed and existing evidence generally relates to the previous definition; and (2) evidence suggests that there is a continuously increasing risk of diabetes-related complications associated with blood glucose levels (see discussion in Part II). For the latter, it is not unusual to use discrete categories to characterise continuous processes when describing diseases. However, because we have evidence relating blood glucose levels to complications on a continuous scale in addition to the change in definition of diabetes, using discrete categories of IGR and diabetes is less preferable than using blood glucose levels directly if possible.

The literature generally suggests that diabetes is a chronic progressive disease. However, some evidence suggests that type 2 diabetes is reversible following bariatric surgery [163] and Lim *et al.* suggest that a reduction in dietary intake can reverse diabetes in terms of both beta cell function and hepatic insulin sensitivity [164]. Clarification is required around whether when using the health states ‘normal’, ‘IGR’ and ‘diabetes’, regression from diabetes to IGR and from IGR to normal is possible in terms of both the clinical definition and the risk of complications associated with each of these health states (see discussion of complications in Part II).

The need for understanding the relationship between risk factors and blood glucose levels

A review of studies assessing the effectiveness of interventions is planned to be undertaken, building upon existing reviews, and some of these studies are expected to show the trend of blood glucose levels over time for both the interventions and the comparators. If all of the intervention studies reported a measure of blood glucose levels then it would not be necessary to describe the relationship between the risk factors and blood glucose levels; we could directly describe the blood glucose levels over time and the impact of the interventions upon these. However, it is expected, based upon existing systematic reviews of the interventions, that many of the intervention studies will report behaviour changes (eg. measures of physical activity/ diet) or BMI/ weight outcomes rather than blood glucose levels [165;166]. Thus, one way of describing the disease natural history over time in order to be able to understand the impact of the interventions upon this disease natural history is to describe the risk factors over time and then relate those risk factors to blood glucose levels.

Risk scores

We have not identified any studies which describe the relationship between the risk factors and blood glucose levels directly using a statistical model. There are a large number of studies which describe the relationship between the risk factors and the risk of diabetes within a statistical model [167]. Studies identified by targeted literature searches suggest that it is important that studies relating the risk factors to diabetes are developed in the populations they will be used within [167;168]. Thus we have focused upon risk scores which have been developed within the UK population only. Targeted literature searches identified four UK risk scores associated with diabetes. The Cambridge Risk Score predicts those currently at high risk of having diabetes within the UK [169], whilst the Leicester Risk Assessment Score and the Leicester Practice Computer Risk Score predict those currently at high risk of having IGR or diabetes within the UK [170;171]. The QDiabetes predicts the 10-year risk of diabetes [172]. This score includes only clinically detected diabetes by GPs rather than screen-detected diabetes.

The risk factors included within these studies are shown in Appendix A. All four risk scores include age (some studies used a continuous measure, others divided into categories), sex (male/ female), BMI (some studies used a continuous measure, others divided into categories), family history of diabetes in first degree relative (yes/ no, some studies divided ‘yes’ into parent or sibling had diabetes/ parent & sibling had diabetes) and use of antihypertensive therapy (yes/ no) as risk factors. Additional risk factors included in some but not all of the studies are ethnicity (some studies used white European/ other, others divided ‘other’ into more categories), smoker (yes/ no, some studies also included ex-smoker), Townsend Score (a measure of deprivation), diagnosed CVD (yes/ no), use of corticosteroids (yes/ no) and waist circumference (categorised).

Diagnosis criteria for IGR/ diabetes

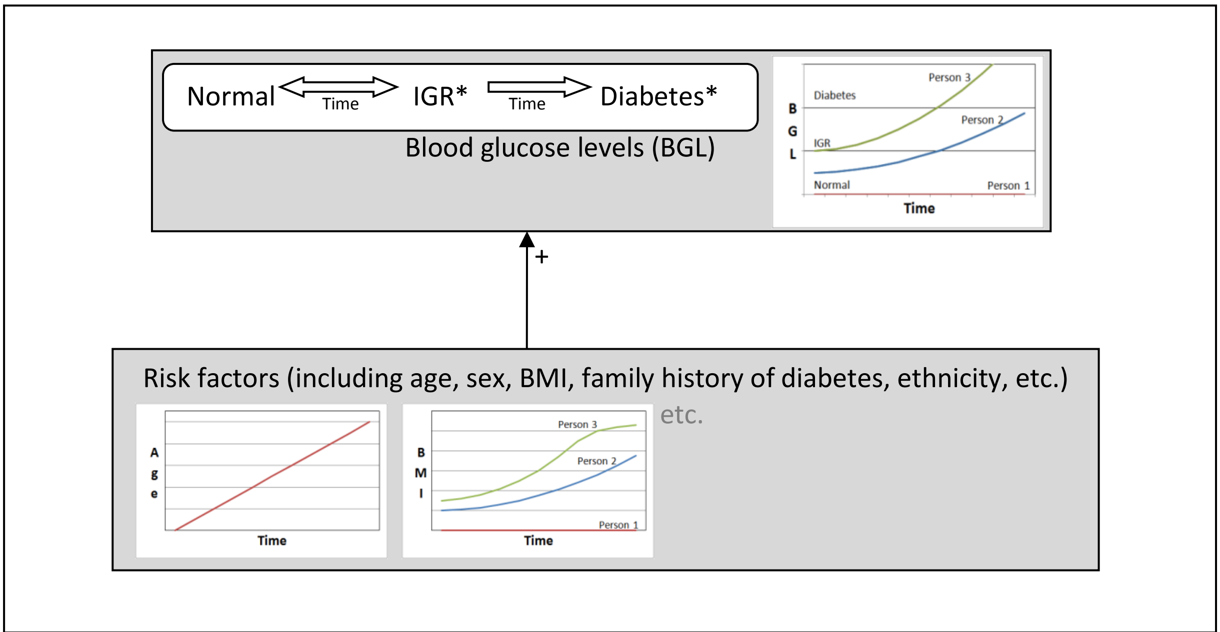
Clinical guidelines from the National Institute for Health and Clinical Excellence (NICE) based upon the World Health Organisation (WHO) criteria suggest that either HbA1c levels or Fasting Plasma Glucose (FPG) levels may currently be used to diagnose diabetes and IGR (see Figure D within the Resource Use section for the criteria). The three tests which have been used in standard practice for assessing blood glucose levels (HbA1c, FPG, OGTT) identify different individuals who may be associated with different outcomes [173]. Only the Leicester Practice Computer Risk Score uses the current World Health Organisation diagnostic criteria [174].

Risk factors and blood glucose levels over time

If we can define the relationship between the risk factors and blood glucose levels (or diabetes risk if this is not possible), then by understanding what happens to these risk factors over time it would be possible to estimate blood glucose levels (diabetes risk) over time. Some of the risk factors cannot be altered (eg. ethnicity), whilst others change over time and are either non-behaviour related (eg. age) or behaviour-related (eg. BMI). Clearly we know the trajectory of age, however the trajectory of BMI, waist circumference, family history of diabetes, use of antihypertensive treatment and corticosteroids, and smoking habits are more difficult to describe. Some intervention studies report these changes over time [165;166]. However, where this information is not available, it should be possible to identify longitudinal evidence for each of these factors. For example, Livshits et al. has analysed data from a longitudinal study over 15 years of a population of UK women aged 45 – 68 years which shows the trajectory of BMI over time [175].

Figure C1 below shows the key causal relationship that an increase in risk factors associated with diabetes leads to an increase in blood glucose levels. It also aims to describe the other issues discussed above.

Figure C1: Conceptual model of the key problem



*Different tests (OGTT, FPG, HbA1c) identify different individuals & diagnostic criteria have changed

Key questions for stakeholders:

1) *Do you agree/ disagree with the discussion around Figure C1?*
2) *Are there any other key issues associated with these relationships which you would like to highlight?*
3) *Do you know of any evidence upon which we could predict blood glucose levels over time based upon risk factors?*
4) *Would it be possible to use any existing datasets to do this?*
5) *Is regression from diabetes to IGR and from IGR to normal possible in terms of both the clinical definition and the risk of complications associated with each of these health states?*
6) *Is BMI a sufficient measure for estimating blood glucose levels for predicting the impact of lifestyle interventions given the different mechanisms of diet and physical activity upon blood glucose levels?*

Part II: Diabetes-related complications

To develop our understanding of the problem further, the next step was to consider the key reasons why the increase in blood glucose levels is considered to be a problem. Existing ScHARR modelling reports were used as a starting point for undertaking targeted searches around the relationship between diabetes and diabetes-related diseases. It was established that the key aim in identifying diabetes and IGR is to identify and provide interventions to those people who are at an increased risk of future complications including retinopathy, nephropathy, neuropathy and cardiovascular disease (CVD). CVD includes hypertension, coronary heart disease (leading to heart attacks and angina), congestive heart failure, peripheral artery disease (including leg claudication and gangrene) and cerebrovascular disease (including stroke and dementia).

The continuous nature of the risk of complications

Models exist which relate diabetes to the risk of the above diabetes-related complications, in particular the analysis of the UKPDS study outcomes [176]. However, evidence suggests that the risk of these complications is continuous and increases prior to the diagnosis of diabetes [177-179]. Thus the probability of having complications is not dependent upon whether or not diabetes is clinically diagnosed, but upon the individual's blood glucose levels. The benefits of any interventions which delay or prevent the diagnosis of diabetes may be overestimated if these complications are assumed to only follow a clinical diagnosis of diabetes. In addition, this will have differential effects on interventions provided at different points in the screening and prevention pathway, making this important for comparisons between interventions. Whilst some studies suggest that the risk of complications below currently recommended diabetes diagnosis levels (HbA1c levels below 6.5%, FPG levels below 7mmol/L) is relatively low [177]; others suggest a substantial increase in the risk of complications associated with HbA1c levels of over around 5.5% [178;179].

Use of evidence to describe the relationship between blood glucose levels and complications

Some studies consider the relationship between HbA1c / blood glucose levels and the complications in diabetic populations [176;180], whilst others consider non-diabetic populations [179;181], and some combine the two populations [177;178]. Considering only the diabetic population (generally based on FPG or OGGTT levels) is insufficient because complications may have onset prior to clinical diagnosis of diabetes, whilst considering only the non-diabetic population does not generally provide information around the relationship between higher blood glucose levels and the complications. Those people who have been diagnosed with diabetes will have screening for retinopathy, neuropathy, nephropathy and risk factors of CVD, and thus these may be picked up at an earlier stage than in the non-clinically diagnosed population. This is likely to lead to differences between the diabetic and non-diabetic populations in the relationship between HbA1c levels and these complications (due to the use of statins, photocoagulation and other treatments). Thus there is a question about the most appropriate evidence to use here.

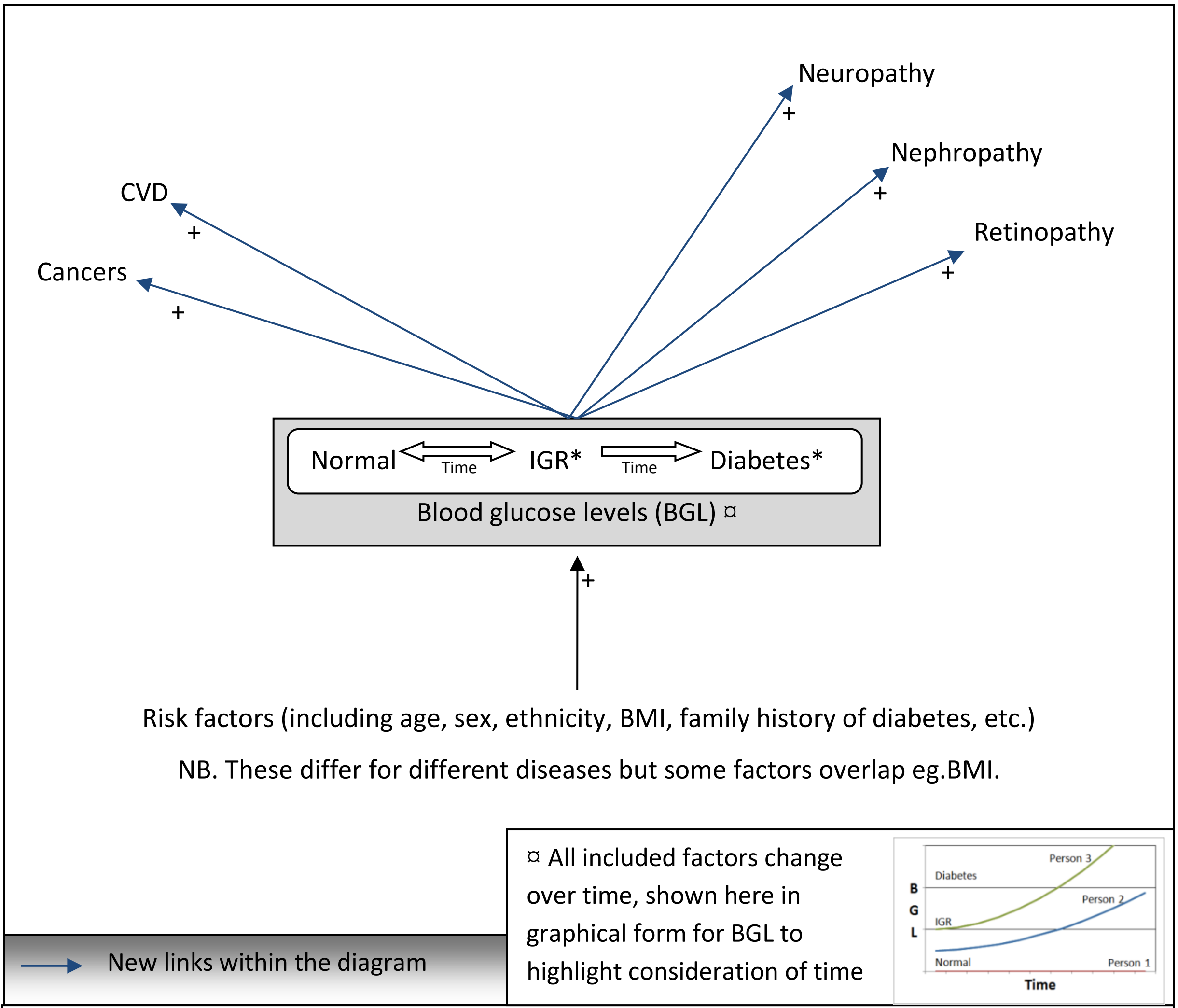
An iterative, targeted literature search suggested that HbA1c levels have been shown to be better predictors of the risk of retinopathy, nephropathy and CVD than FPG or OGTT tests [177;178;182]. Whilst there is generally a similar sort of relationship between HbA1c levels and the complications as between FPG/ OGTT levels and the complications, FPG/ OGTT levels are much more variable (on a daily basis) and each of the tests identifies different groups of people [173]. Most studies suggest that the risk of complications can be represented by a J-shaped curve, whereby beyond HbA1c levels of around 5.5% there is a continuous increase of complications [177;178;181;183]. For CVD, this has been shown to be the case independently for hypertension, coronary heart disease, heart failure and cardiovascular mortality. Evidence has also been identified which suggests that there may be a relationship between HbA1c levels and colorectal cancer and postmenopausal breast cancer [183]. There is a greater association with cancer mortality than cancer incidence which suggests that HbA1c levels may influence cancer progression more than cancer initiation [183]. A study of the risk of cause-specific mortality by the Emerging Risk Factors Collaboration also suggests that diabetes is associated with an increased risk of mortality from liver, pancreas, ovary, colorectal, lung, bladder and breast cancer [184].

Disease natural history of diabetes-related complications over time

There is a disease natural history associated with each of these complications included within Figure 4. The evidence described above highlights when people display symptoms of the complications/ are diagnosed, rather than the onset of the complications which will be at an earlier point in time. The evidence above does not describe the progression of the complications. Clarke et al. have undertaken analysis on the UKPDS dataset to describe the outcomes associated with each of the complications over time following diabetes diagnosis [176]. However, no such analysis has been identified for the outcomes of the complications over time prior to diabetes diagnosis.

These potentially causal relationships are shown in Figure C2 below.

Figure C2: Conceptual model of key diabetes complications



*Different tests (OGTT, FPG, HbA1c) identify different individuals & diagnostic criteria have changed

Key questions for stakeholders:

1) *Do you agree/ disagree with the discussion around Figure C2? Are there any additional complications associated with high blood glucose levels which should be considered?*
2) *Are there any other key issues associated with these relationships which you would like to highlight?*
3) *Will treatment for diabetes substantially affect the relationship between blood glucose levels and diabetes-related complications? What would be the most appropriate evidence for understanding the relationship between blood glucose levels and complications?*
4) *Is there any evidence of the relationship between HbA1c levels/ FPG levels & neuropathy?*
5) *Is there any analysis of the risk of complications over time prior to clinical diagnosis of diabetes?*

Part III: Higher level goals associated with the interventions

The next step considers the ultimate goals associated with what we are trying to achieve to help resolve the decision problem.

Costs and QALYs

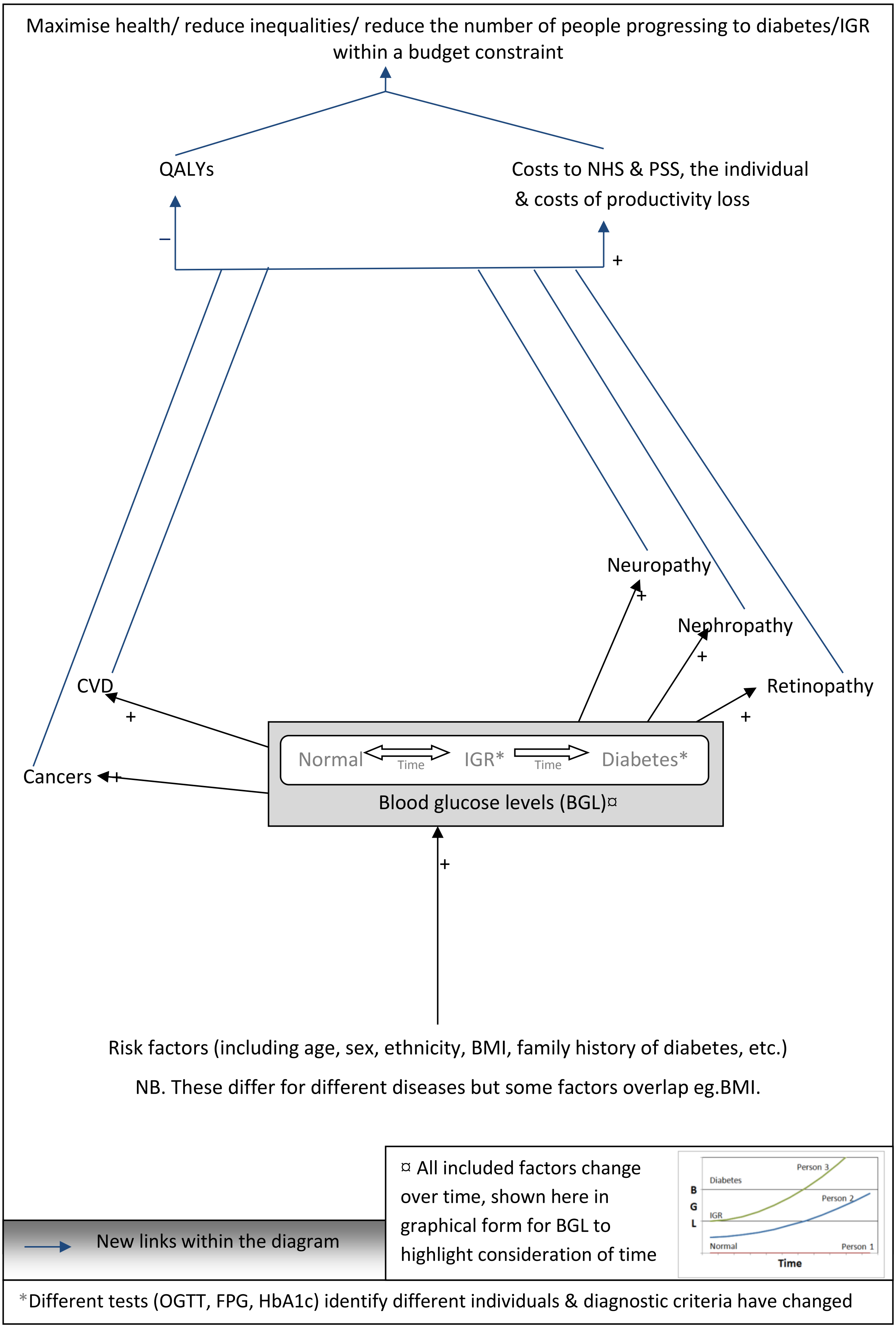
All of the complications associated with type 2 diabetes lead to a reduction in survival and/or quality of life, typically expressed as Quality-Adjusted Life Years (QALYs) within health economics. QALYs are estimated by summing health utility scores over a lifetime, where 1 is equivalent to full health and 0 is equivalent to death. For example, if a person spent 20 years in health state A which is associated with a utility of 0.8, followed by 30 years in health state B which is associated with a utility of 0.5, the total QALYs for that person would be 20 x 0.8 + 30 x 0.5 = 31. All of the complications associated with type 2 diabetes are also associated with costs to the National Health Service and Personal Social Services (NHS and PSS), the individual and lost productivity and leisure time. Which of these costs we want to include within the modelling will need to be discussed.

Equity

A goal may be to increase health within a specific budget constraint; however there may be primary or secondary goals associated with equity. For example, it might be that a goal is to reduce type 2 diabetes and its associated complications in those people from certain ethnic origins such as people of South Asian origin who evidence suggests on average have higher blood glucose levels than people of white ethnic origin [171]. Evidence shows that people with a higher socioeconomic status tend to benefit more from Public Health interventions than people with a lower socioeconomic status; thus an intervention for the general population which improves average health may widen the gap [33].

It is therefore for discussion about what the goals of this analysis should be. These potential higher level goals are shown in Figure C3 below.

Figure C3: Conceptual model of diabetes prevention with higher level goals



Key questions for stakeholders:

1) *Which types of costs would you like the model to consider (eg. Costs to NHS & PSS, Cost to the individual, the cost of productivity loss, any others?)?*
2) *How should interventions be chosen? Do you want to maximise the health of the general population within a budget constraint or reduce inequalities within the general population by maximising the health of specific subgroups of the population within a budget constraint?*

Part IV: Additional potentially causal relationships

The next step considers whether there are any other potentially causal relationships which should be included within the diagram.

Other diseases associated with diabetes risk factors

There are other diseases associated with some of the same risk factors associated with diabetes, in particular BMI and age. If interventions are used to alter the risk profiles of individuals in terms of BMI then this will affect other diseases as well as diabetes. The risk of some types of cancers would be affected, including postmenopausal breast cancer, colorectal cancer, oesophagus cancer, kidney cancer, endometrium cancer, gallbladder cancer and pancreatic cancer [185]. In addition, evidence suggests that there is a direct impact of BMI upon the risk of CVD [186]. It is important not to double count the impact of BMI upon the risk of CVD through this potential duel mechanism. Studies also suggest that dementia is independently associated with BMI [187], and the same issue of double counting the impact of BMI upon the disease applies. Osteoarthritis has also been shown to be associated with BMI [188].

Inter-generational impacts

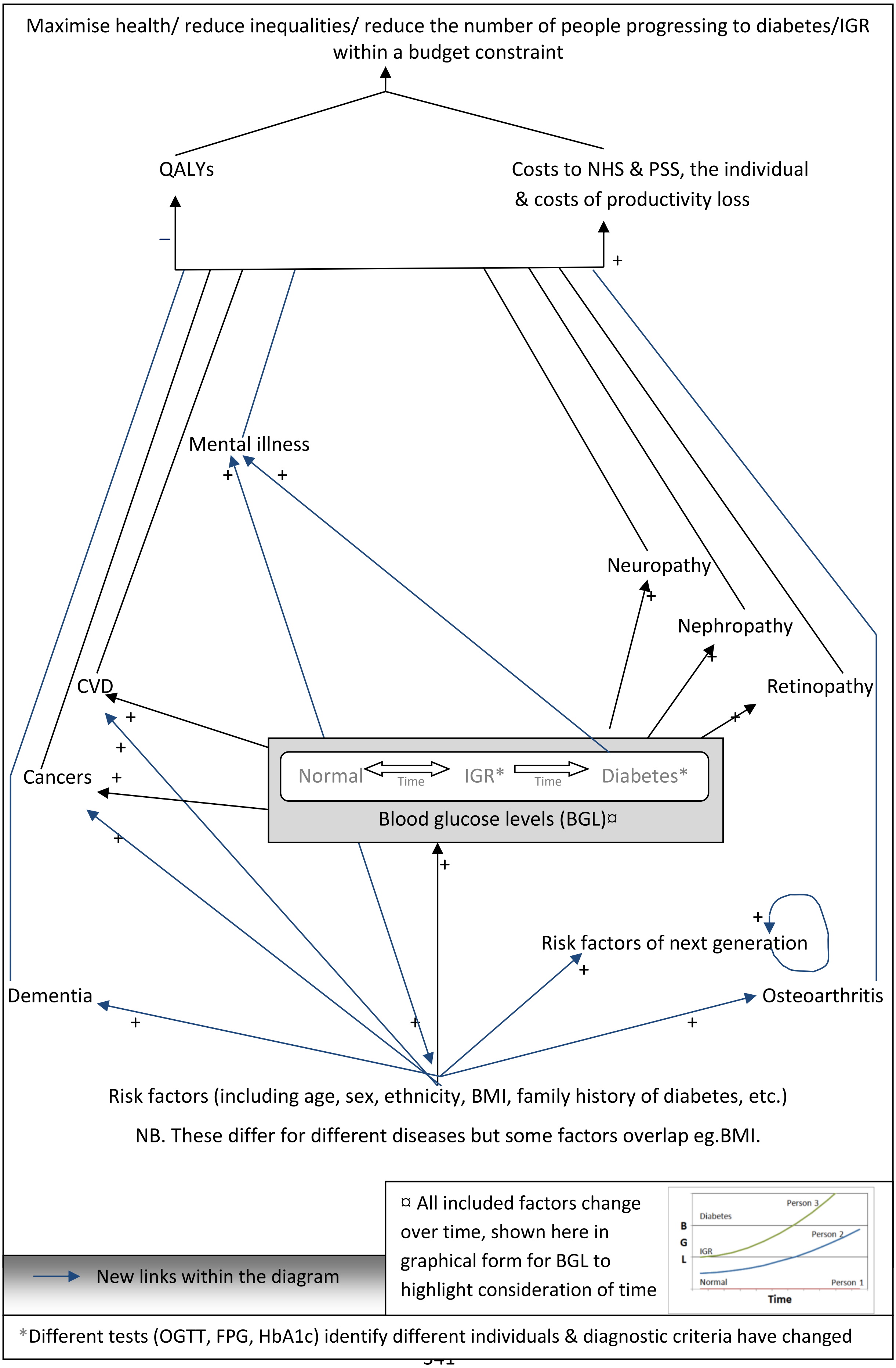
In addition, risk factors within one generation are associated with risk factors for the next generation. The family history of diabetes is a direct link; however there is also evidence that parents' lifestyle behaviours will affect children's lifestyle behaviours [189]. Thus if interventions are effective at changing lifestyle behaviours and preventing diabetes, the next generation will have an increased probability of better outcomes.

Association with mental illnesses

Diabetes has been shown to be associated with an increased risk of depression [190] and mental illnesses more generally [184]. The relationship between depression and diabetes is complex and currently not completely understood. However, it has been suggested that people with clinically diagnosed diabetes have an increased probability of developing depression, which in turn is associated with a reduction in metabolic control, and that some of the risk factors associated with diabetes may also affect the probability of developing depression [190]. Diabetes has also been shown to be associated with self harm [184].

These potentially causal relationships are shown in Figure C4 below.

Figure C4: Problem-oriented conceptual model of diabetes prevention



Key questions for stakeholders:

1) *Do you agree/ disagree with the discussion around Figure C4?*
2) *Are there any other key issues associated with these relationships which you would like to highlight?*
3) *Do you disagree with any of the potentially causal links?*
4) *Are there any other (positive or negative) consequences of each factor? For example, Seshasai et al. (2011) suggest that diabetes is associated with an increased risk of mortality from infectious diseases and injuries; should these be included within the conceptual model and, if so, where?*
5) *Are there any links which may be correlated rather than causal i.e. two factors that appear to be causally related which can be explained by a third.*
6) *Are there any other possible causal links between the factors?*

Objective 2: To identify any key evidence which may be useful

In discussing the problem-oriented conceptual model we will hopefully have identified some useful literature sources/ datasets. The references for the current document are included at the end of the document.

Key questions for stakeholders

1) *Are there any literature sources or datasets which have not already been highlighted which may be useful in describing these relationships?*

Objective 3: To agree the types of interventions to be considered within a systematic literature review

There are several potential types of interventions for consideration within the model and these have been incorporated into the conceptual model within Figure C5. This includes comparing population/ community level interventions & targeted intervention through identification of high risk individuals/ screening. A systematic literature review will be undertaken to identify evidence on the effectiveness of relevant types of interventions in preventing and screening type 2 diabetes and we would like to agree the scope of this review. The review will build upon existing relevant systematic reviews. The potential types of interventions which have currently been identified are:

<u>In the general population/ subgroups of the general population</u>

1) Lifestyle interventions
2) Different combinations of risk assessment/ screening strategies in order to identify IGR/ diabetes

<u>In those with IGR</u>

1) Lifestyle interventions
2) Pharmacological interventions

Pharmacological interventions are associated with an increased risk of hypoglycaemia and other AEs [191]. If people with IGR employ lifestyle interventions, they may reduce the necessity for pharmacological interventions and thus reduce these adverse events.

<u>Outcomes of intervention studies</u>

Based upon existing systematic reviews of some of these types of interventions, a small number of intervention studies report impacts upon HbA1c directly and some report BMI outcomes; however many studies report behavioural outcomes such as increase in fruit and vegetable intake and increase in physical activity. Thus there is another potentially causal link between these behavioural factors and the risk factors, which have not explicitly been incorporated into Figure C5. This relationship could be described using data from the Health Survey for England as was done within the previous ScHARR modelling work for NICE [192].

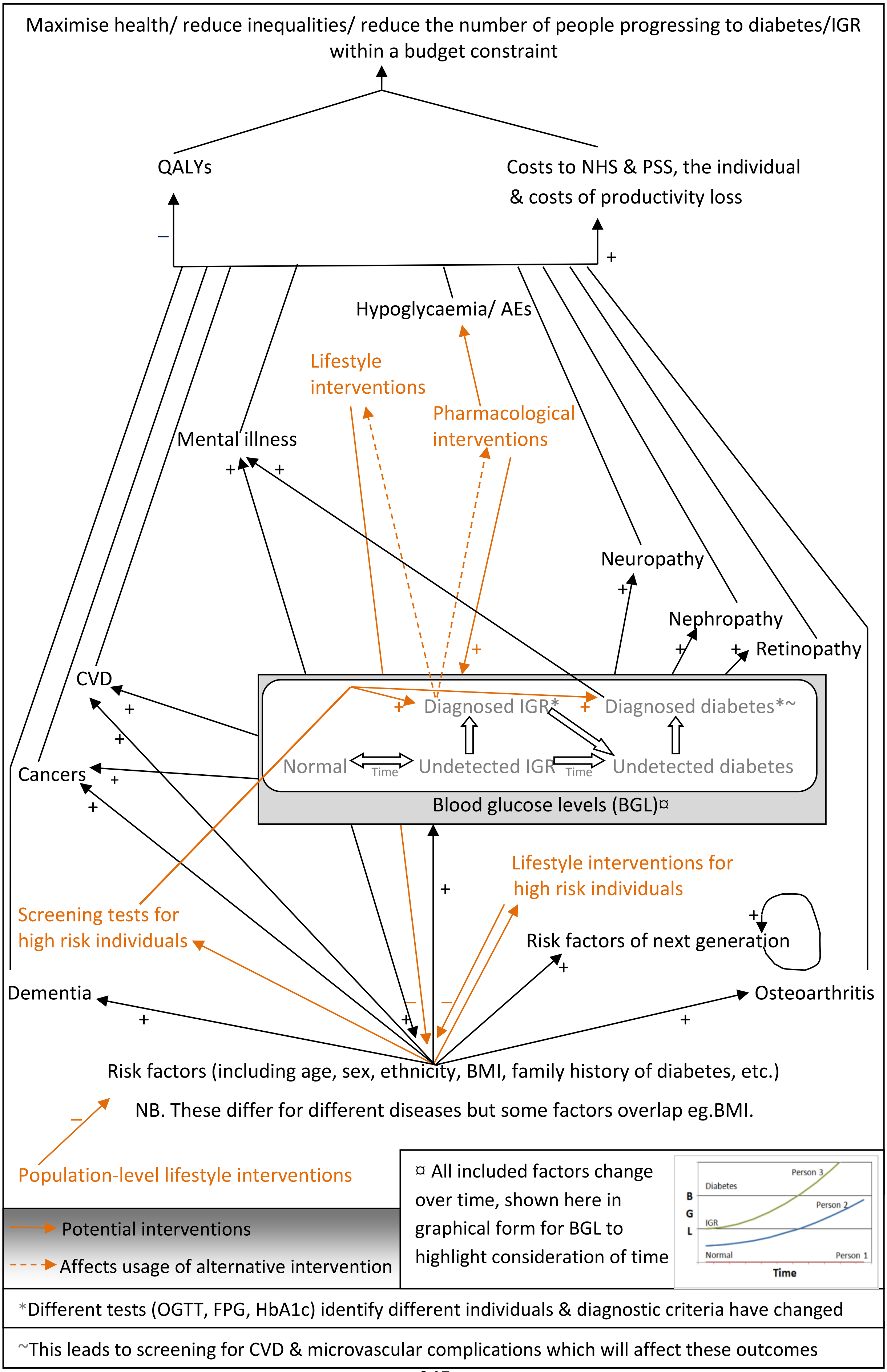
The impact of clinical diagnosis of diabetes upon diabetes-related complications

Screening tests for high risk individuals will increase the number of clinically diagnosed IGR and diabetes cases. Following a diagnosis of diabetes, screening for diabetes-related complications is undertaken, including CVD risk factors and microvascular complications (neuropathy, nephropathy and retinopathy) [191]. Thus earlier clinical diagnosis may improve outcomes associated with diabetes complications, although evidence to date from intervention in screen-detected cohorts has not been entirely compelling [193;194].

Key questions for stakeholders relating to the types of interventions to be considered:

1) *Do we want to assess alternative screening options within the model?*
2) *Do we want to consider pharmacological interventions for IGR or are we interested solely in lifestyle interventions?*
3) *Are we interested in lifestyle and self-management interventions for people with diabetes?*
4) *Should we focus upon any of these intervention types more than others? Are there any additional types of interventions we should consider?*
5) *What would happen in the absence of the interventions versus as a result of the interventions – would behaviour be prevented or delayed? What is the best evidence for this? What would be considered to be a good outcome of an intervention?*
6) *Might some other organisation (for example, a fast food company) act to substantially reduce the impact of interventions?*
7) *What are the important adverse events associated with pharmacological interventions?*
8) *Would the interventions have any other impacts not already considered?*

Figure C5: Conceptual model of diabetes prevention with potential types of intervention



Objective 4: To discuss model perspective(s), outcomes, & populations

It is useful for all of the stakeholders to provide input around what would be the most appropriate modelling perspectives, outcomes and populations in order for the model results to be useful to commissioners of diabetes prevention services. The specific model populations considered within the model will be dependent to some extent on data availability.

Modelling perspective:

The modelling perspective is what types of costs and outcomes should be included within the model. For example, the NICE Public Health methods guide recommends taking a Public Sector Perspective or a NHS and Personal Social Services (PSS) perspective as appropriate, which would mean that a model needs to include all costs and outcomes incurred by all Public Sectors or the NHS and PSS respectively. Another example of a perspective that may be taken includes the societal perspective which includes all costs to society. We have previously considered this issue to some extent when discussing Figure C3. If the question being answered relates to how to spend a budget for healthcare, then a NHS and PSS perspective may be most appropriate.

Key questions for stakeholders

1) *What do you think would be the most appropriate perspective(s) for the modelling?*

Model outcomes:

It is important for us to know at this stage which outcomes would be most useful to commissioners of diabetes prevention services. Typically, depending upon the perspective(s) taken, the outcomes presented would be the Incremental Cost per Quality-Adjusted Life Year (QALY) gained, the Incremental Cost per Life Year Gained (LYG) as well as incremental costs, incremental QALYs and incremental LYs. The QALY measure includes both survival and quality of life impacts. The incremental cost per QALY gained enables comparisons of the cost-effectiveness of the diabetes prevention and screening interventions with interventions for other diseases to be made, as well as enabling comparisons to be made between different diabetes prevention and screening interventions.

It may be that it would be useful to have a type of budget impact model where the people in the model represent the current distributions of age, ethnicity, BMI etc. within the population in order to estimate:

- Number of patients requiring screening per year
- Number of IGR patients identified per year
- Number of diabetes patients identified per year
- Total costs over the next 1, 2, 3, 4, 5,..., n years

These outputs would be dependent upon the geographical area served and hence better estimates would be predicted by local commissioners inputting their own data about the population.

Key questions for stakeholders

1) *What would be the most useful outcomes from the model for you?*

Model population:

The model population will depend to some extent on the studies identified for the effectiveness of the interventions. However, it would be useful to know if there are specific subgroups which you think should be considered. Some possibilities are listed below, although this is not necessarily an exhaustive list.

1) Those without clinically diagnosed diabetes/ IGR:
    a. General population
    b. Specific age groups
    c. Specific ethnic groups
    d. Overweight/ obese group
    e. Smokers
    f. Geographical areas with higher levels of deprivation
    g. Clinically diagnosed CVD
    h. People being treated for hypertension
    i. People using corticosteroids
    j. Pregnant women (with or without gestational diabetes)
2) Those with IGR
3) Those with diabetes

Key questions for stakeholders:

1) *Are there any specific groups which you think should be considered within the model if evidence allows?*

Objective 5: To discuss resource use

Eventually within the model we will need to include detailed costings associated with resource use for each of the factors included within the model. We would like at this stage to develop an understanding of the resource processes associated with some of the key factors within the conceptual model. Figures D and E1-E5 show the processes associated with diagnosis and treatment of type 2 diabetes according to NICE guidelines. Please let us know if this does not represent current practice.

It is likely that the costs associated with each of these will be based upon existing costing or cost-effectiveness studies due to the substantial analysis which has already been undertaken in this area. Thus, this will help us to be able to identify existing studies which incorporate appropriate resource use, and to know if clinical practice has altered substantially since these NICE guidelines were produced.

The resource use associated with the delivery of the interventions will be based upon the studies identified within the effectiveness review.

Key questions for stakeholders:

1) *Do the processes shown within Figures D and E1 – E5 represent current practice?*

Figure D: NICE recommendations for risk assessment and screening of diabetes[195]

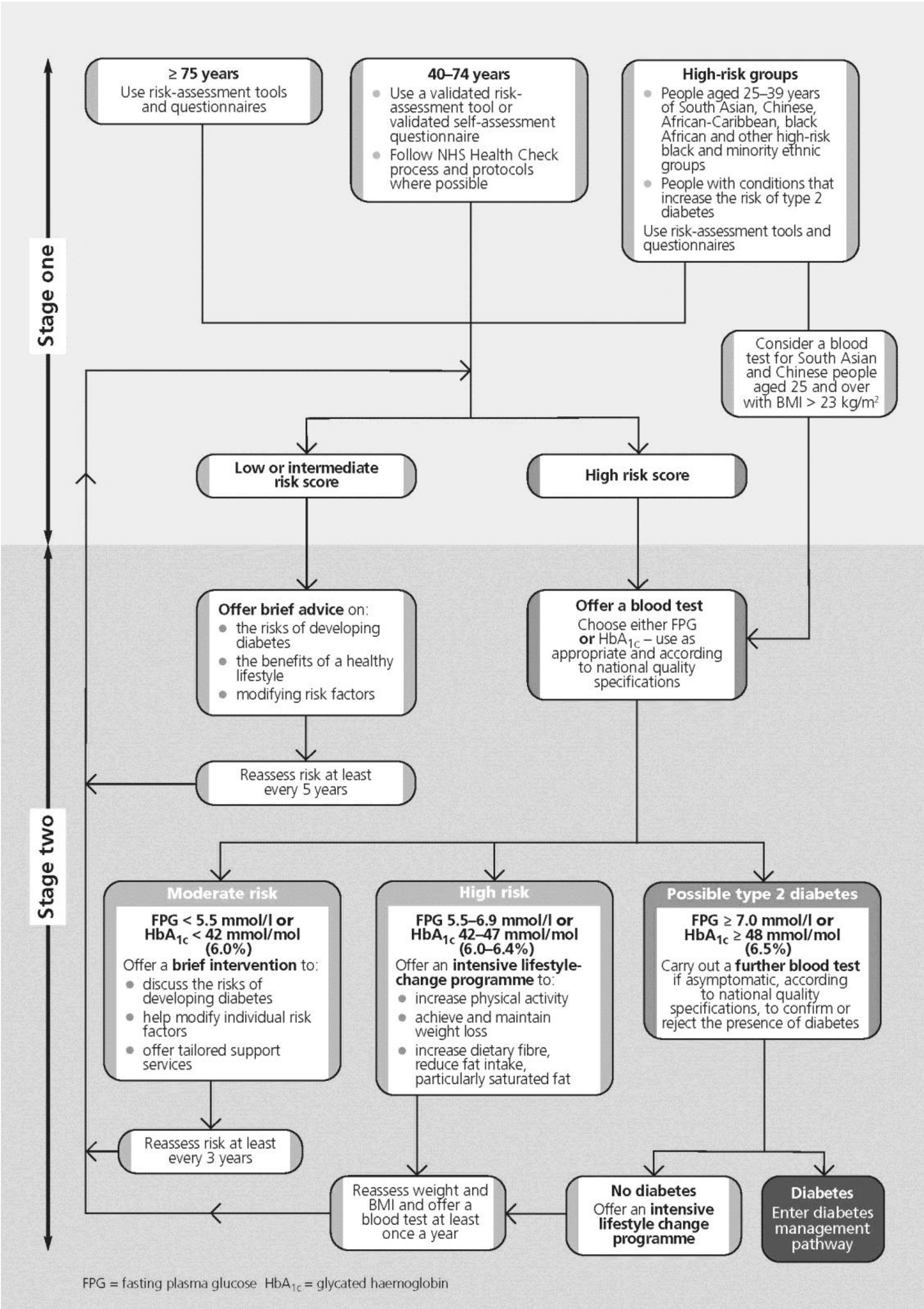
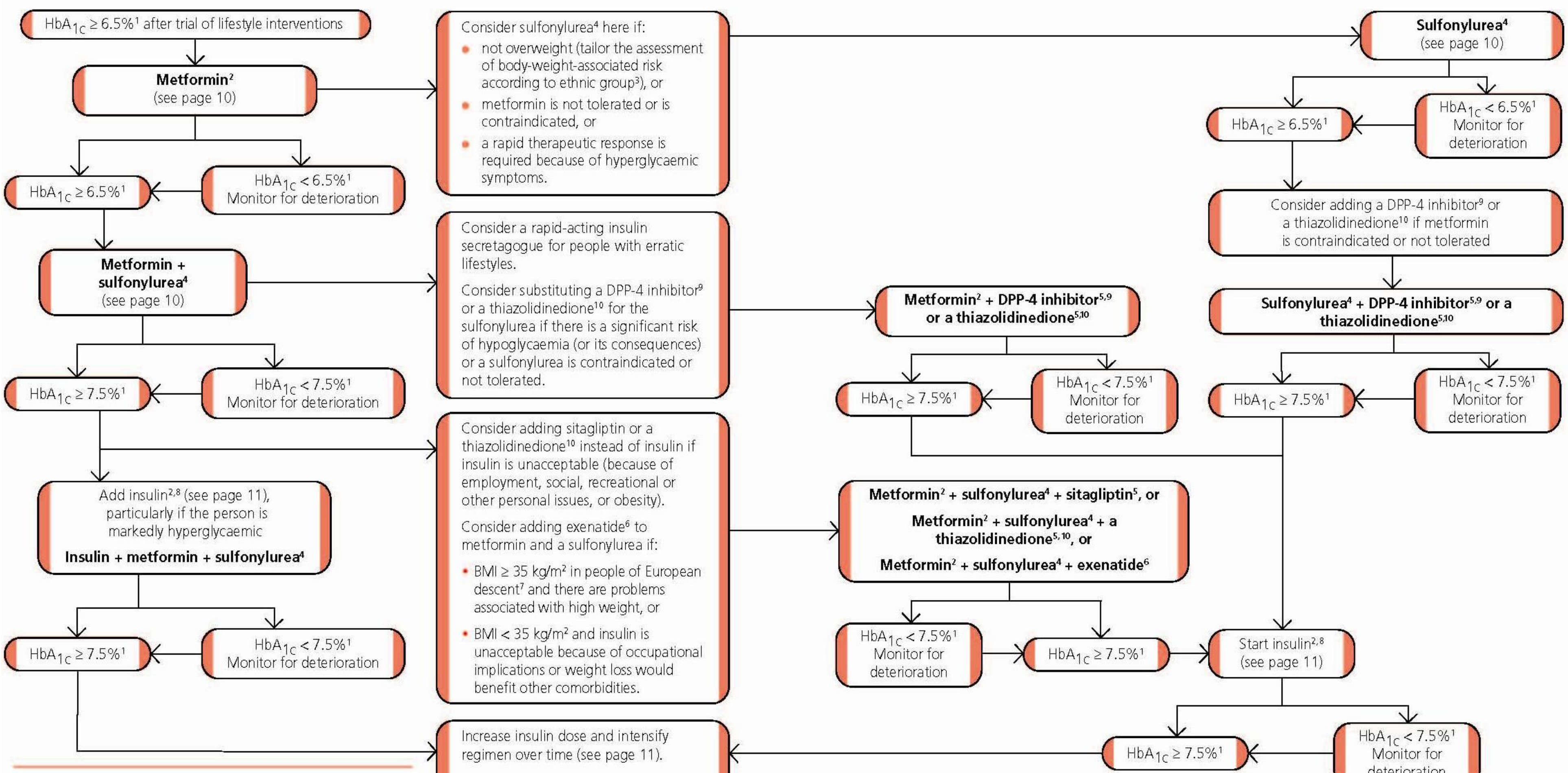


Figure E1: Diabetes management

<table>
<tr><td rowspan="3">Diabetes diagnosis
↓
6 months
↓
1 year (& annually)</td><td rowspan="3">Measure HbA1c levels at 2-6 monthly intervals until stable, then 6 monthly</td><td>Structured group education programme delivered by a trained educator & nutritional advice</td><td rowspan="3">Pharmaco-therapy as necessary (see Figure E2)</td><td>Measure blood pressure if not hypertensive or renal disease (see Figure E3)</td><td>Assess CVD risk & perform full lipid profile</td><td>Enquire for neuropathic symptoms incl. erectile dysfunction (see Figure E4)</td><td>Eye screening; refer to an ophthalmologist if necessary</td><td>Assess urine sample; refer to renal specialist if necessary</td></tr>
<tr><td>Ongoing nutritional advice</td><td colspan="5"></td></tr>
<tr><td>Structured group education programme reinforcement & review</td><td>Measure blood pressure if not hypertensive or renal disease (see Figure E3)</td><td>Assess CVD risk & perform full lipid profile</td><td>Enquire for neuropathic symptoms incl. erectile dysfunction (see Figure E4)</td><td>Eye screening; refer to an ophthalmologist if necessary</td><td>Assess urine sample; refer to renal specialist if necessary</td></tr>
</table>

Figure E2: Pharmacotherapy for type 2 diabetes[196]



[1] Or individually agreed target.
[2] With active dose titration.
[3] See the NICE clinical guideline on obesity (www.nice.org.uk/CG43).
[4] Offer once-daily sulfonylurea if adherence is a problem.
[5] Only continue DPP-4 inhibitor or thiazolidinedione if reduction in HbA_{1c} of at least 0.5 percentage points in 6 months.
[6] Only continue exenatide if reduction in HbA_{1c} of at least 1 percentage point and weight loss of at least 3% of initial body weight at 6 months.
[7] With adjustment for other ethnic groups.
[8] Continue with metformin and sulfonylurea (and acarbose, if used), but only continue other drugs that are licensed for use with insulin. Review the use of sulfonylurea if hypoglycaemia occurs.
[9] DPP-4 inhibitor refers to sitagliptin or vildagliptin.
[10] Thiazolidinedione refers to pioglitazone.

Figure E3: Pharmacotherapy for type 2 diabetes [191]

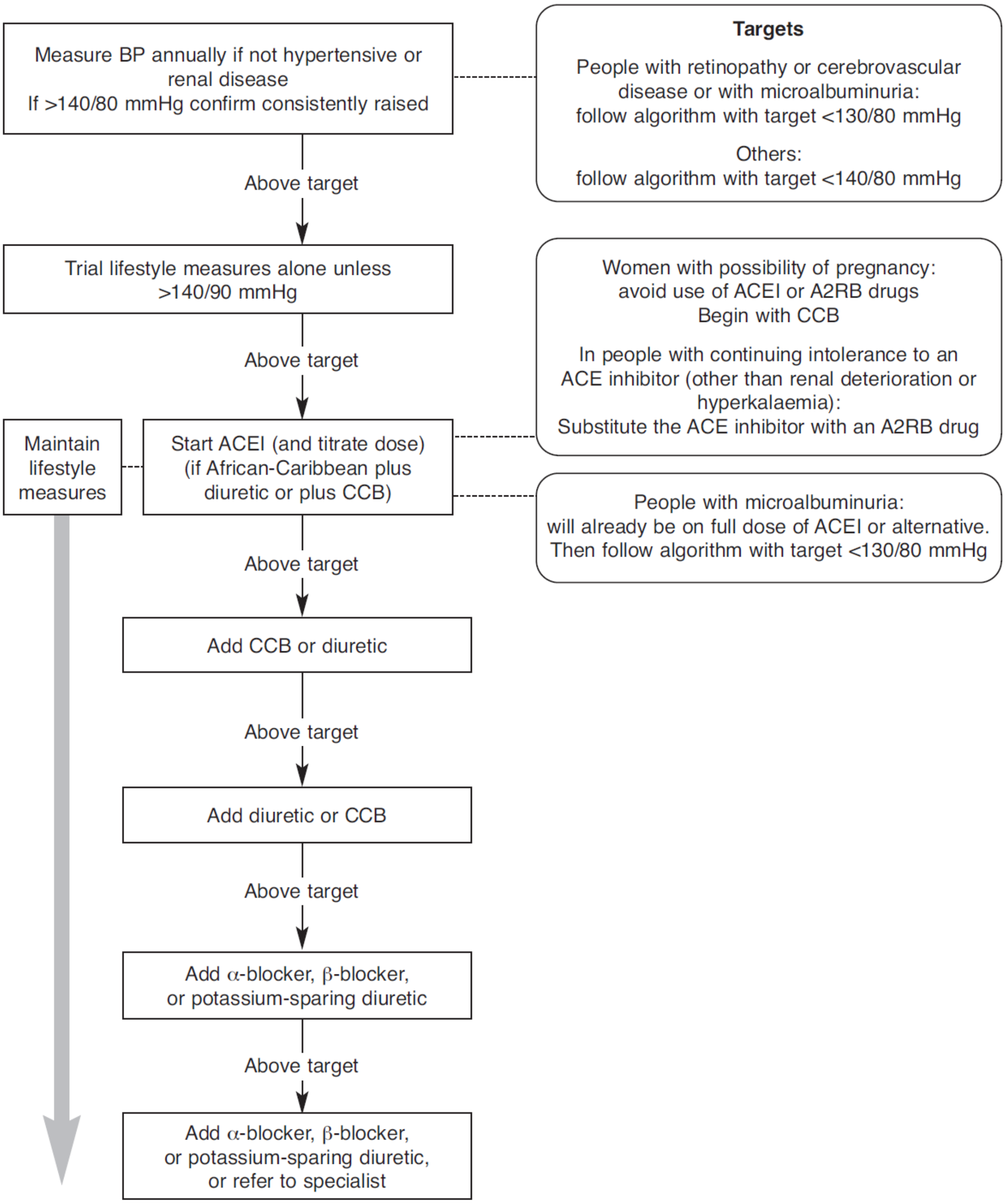


Figure E4: Diabetic symptomatic neuropathy management [191]

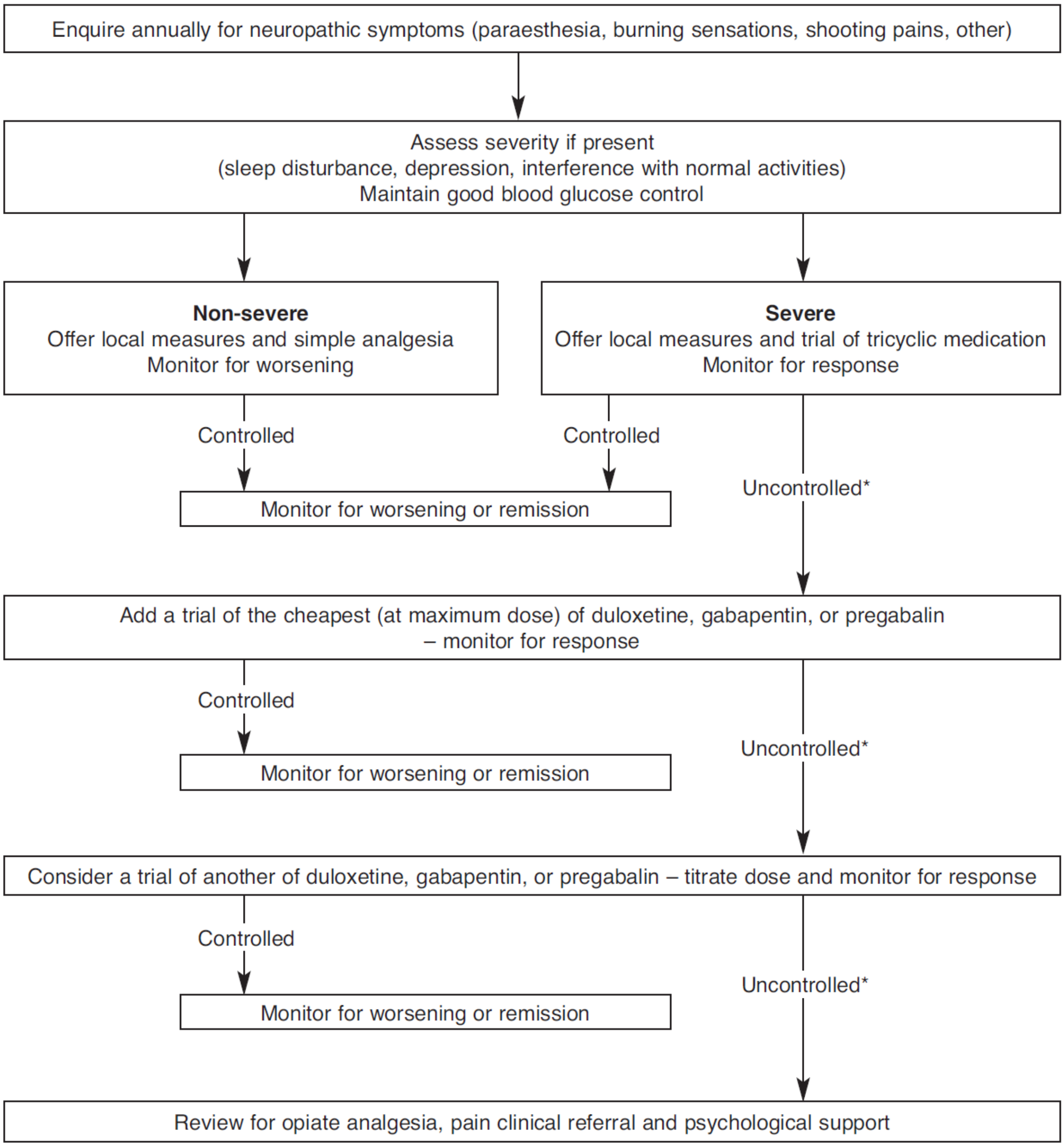
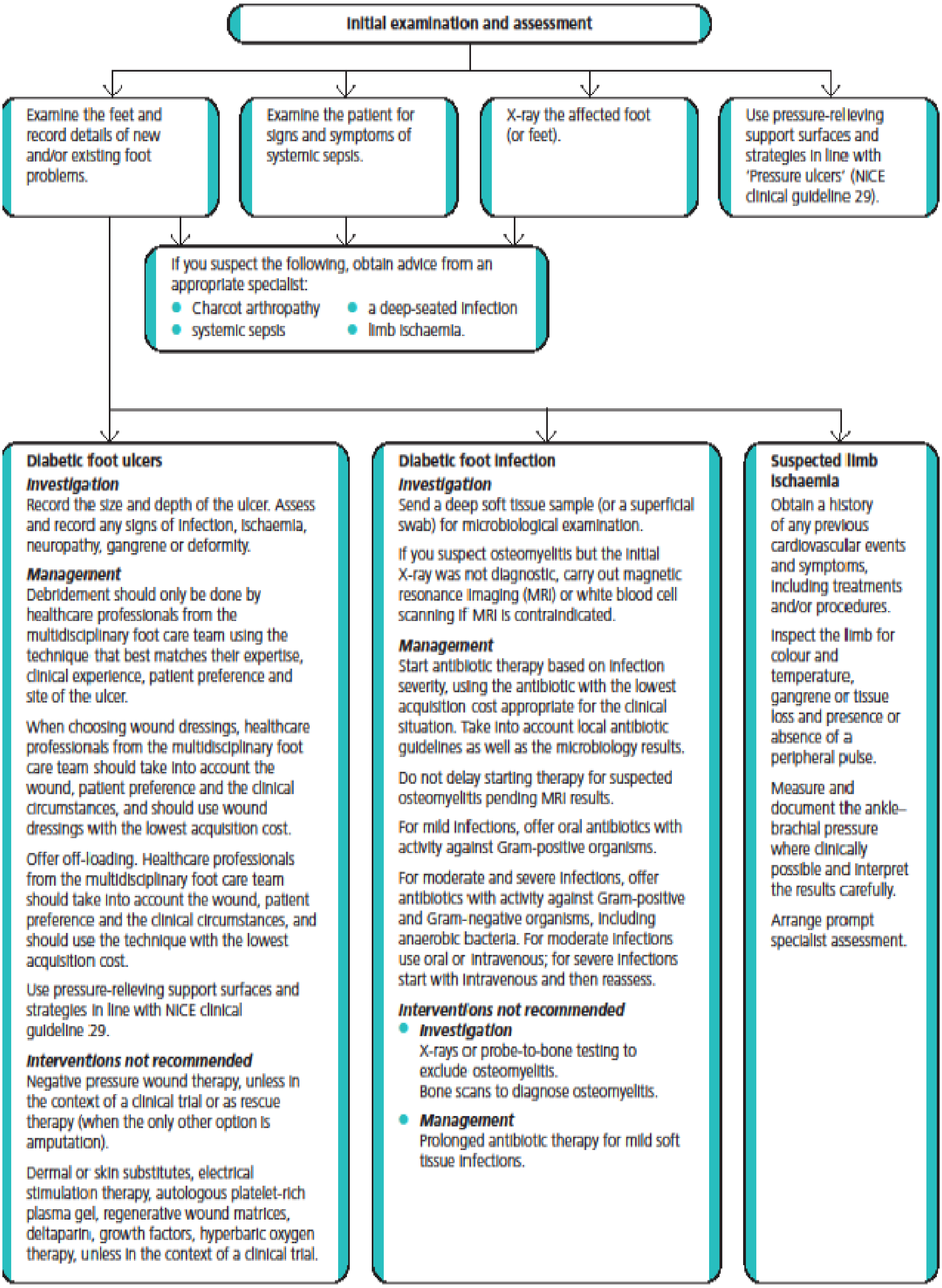


Figure E5: Foot care management [197]



Next steps

We will update this document according to your feedback and re-circulate:

1) The updated problem-oriented conceptual model;
2) The types of interventions we will be considering within the systematic review;
3) The modelling perspective(s) and outcomes.

We will then be working out the best way of translating this understanding of the problem into a model. At the next workshop we will discuss the effectiveness review and exactly which interventions to assess within the model, and the structural assumptions to be included within the model.

Appendix A: Risk factors & derivation of diabetes risk scores

Name of risk score	Age	Sex	Ethnicity	BMI	Smoking	Family history	Townsend score	Use of antihypertensive drugs	CVD	Current use of corticosteroids
Qdiabetes	√	√	√	√	√	√	√	√	√	√
Cambridge risk score	√	√	-	√	√	√	-	√	-	√
Leicester Risk Assessment Score	√	√	√	√	-	√	-	√	-	-
Leicester Practice Computer Risk Score	√	√	√	√	-	√	-	√	-	-

Name of risk score	Derivation	External validation	Test used
Qdiabetes	[172]	[198]	Clinical diagnosis by GP
Cambridge risk score	[169]	[199;200]	OGTT
Leicester Risk Assessment Score	[170]	[170]	OGTT
Leicester Practice Computer Risk Score	[171]	[171]	HbA1c/ OGTT

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Appendix D4: Outcomes of Stakeholder Workshop 1

1. Conceptual model of the problem

The conceptual model was discussed and revised, as shown in Figure 1 below. The green parts of the conceptual model are those which have been added as a result of stakeholder input.

There was a discussion around whether blood glucose levels should be considered as a risk factor for the long term outcomes associated with diabetes alongside the other risk factors for diabetes such as age, sex and ethnicity. This alternative conceptual model is shown in Figure 2.

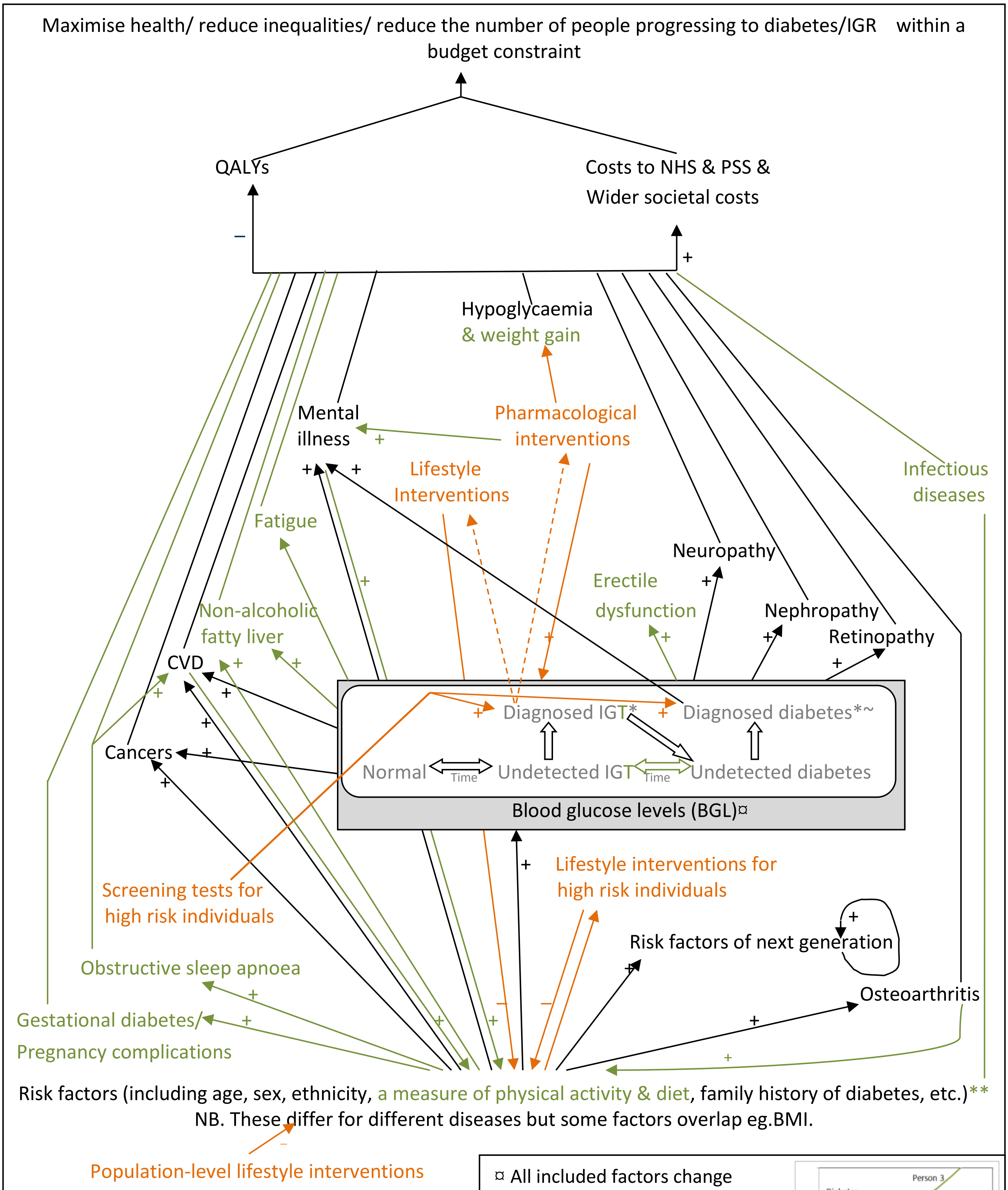
There was a discussion around the use of the term IGR and there was some consensus that the term IGT was more commonly used.

The marked heterogeneity of type 2 diabetes was highlighted.

- Please let me know if you think anything else should be included/ changed within the conceptual model.

- Please comment on whether you think it is appropriate to link the risk factors (including blood glucose levels) directly to retinopathy, neuropathy and nephropathy, as shown in Figure 2.

Figure 1: Conceptual model of diabetes prevention with potential types of intervention

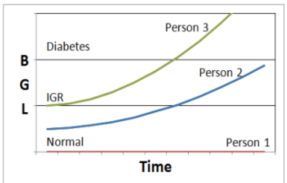


Potential interventions

Affects usage of alternative intervention

*Different tests (OGTT, FPG, HbA1c) identify different individuals & diagnostic criteria have changed

¤ All included factors change over time, shown here in graphical form for BGL to highlight consideration of time

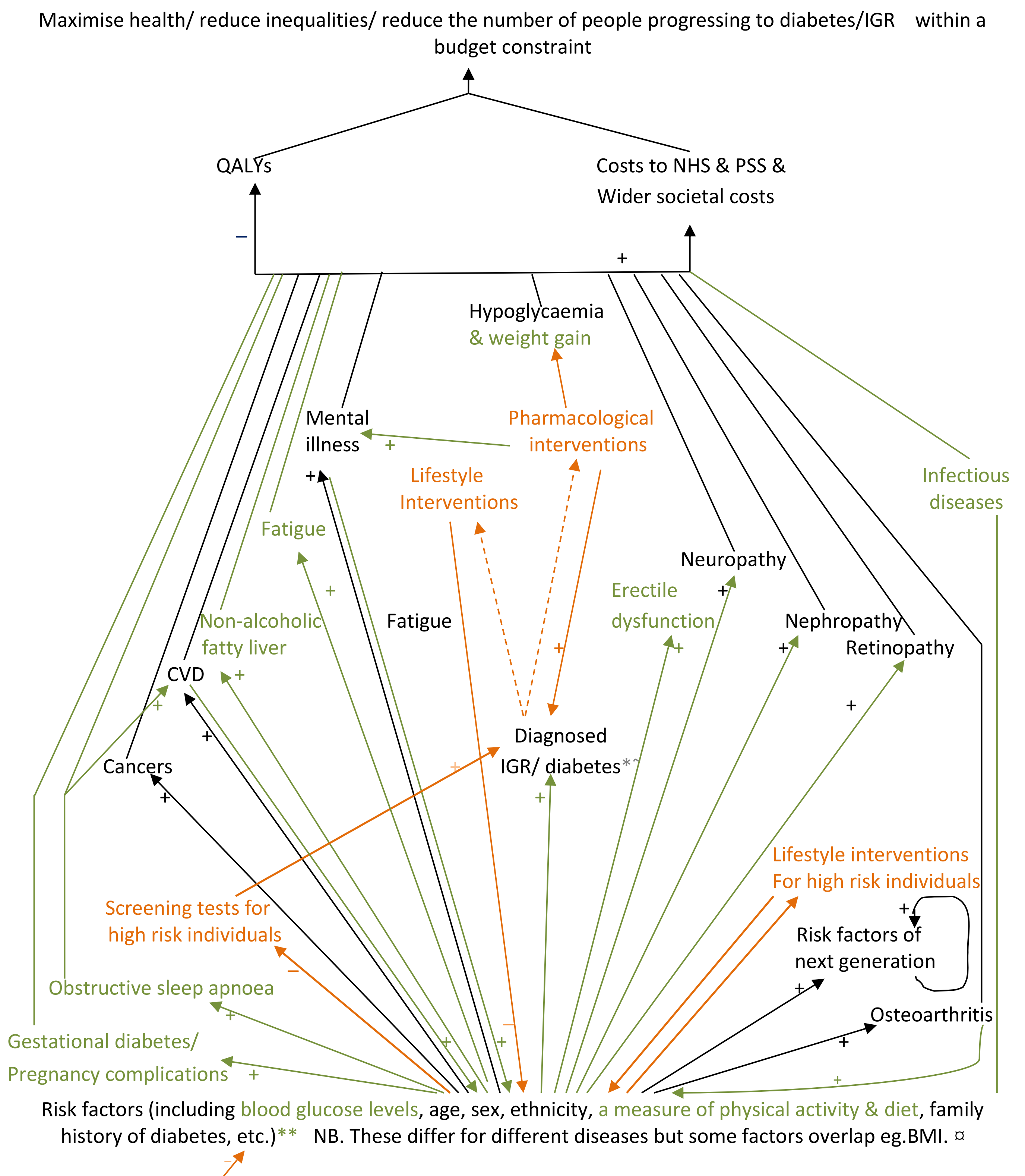


~This leads to screening for CVD & microvascular complications which will affect these outcomes. If BGL are decreased, the risk of complications may decrease even if the individual is still termed 'diabetic'.

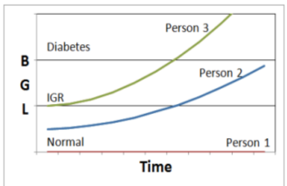
**Risk factors may be worse in the future as lifestyles become more sedate

CVD, retinopathy & hypoglycaemia may affect driving ability

Figure 2: Alternative conceptual model of diabetes prevention with potential types of intervention



¤ All included factors change over time, shown here in graphical form for blood glucose levels to highlight the consideration of time



*Different tests (OGTT, FPG, HbA1c) identify different individuals & diagnostic criteria have changed

~This leads to screening for CVD & microvascular complications which will affect these outcomes. If BGL are decreased, the risk of complications may decrease even if the individual is still termed 'diabetic'.

**Risk factors may be worse in the future as lifestyles become more sedate

CVD, retinopathy & hypoglycaemia may affect driving ability

2. Types of interventions (and populations) for consideration

Stakeholders listed which interventions they thought were important to consider within the model, shown in Table 1 below.

- If you think there are any additional interventions which are not listed within this table which would be important to consider, or you would like to reword any which you have written, please let me know.

It was highlighted that some interventions are statutory, such as the Health Checks and Children measurement programme, so these should be included as a baseline. The issue about opportunity costs and whether it will be important to consider what we should do less of was raised. The discussion suggested that it would be useful to do this. There was also discussion of basic Health Check versus Health Check plus including diabetes and/or CKD.

It was suggested that the sustainability of programmes is very important. Often programmes are short term or cancelled which can leave patients without ongoing support. A package of interventions should be considered to avoid rebound after the intervention has finished.

Similarly, there was a discussion around there not being one intervention that works for everyone, but that it is important to have a package of options for achieving weight loss.

It was highlighted that commissioners are not making decisions about pharmacological interventions.

Table 1: Interventions identified by stakeholders

Intervention	Target population	Who would pay	Who would deliver	Any unintended effects
Screening interventions				
NHS Health Checks	Adults	PH/LA	Private Provider	
General CVD and associated risk assessment screening	Targeted by age, sex and ethnicity	NHS	Primary Care	
Self-assessment risk analysis online advertised by GPs, Diabetes UK etc	Everyone	Patient		
Sugar, HbA1c measurement	Those deemed at risk by the GP, CVD screening, high blood pressure, patient request	GP	GP	
Sugar, HbA1c measurement	Racial populations known to be at raised risk e.g. south Asian	GP	PH Primary Care	Decliners
Specific ethnic group checking data e.g. HbA1c	Ethnic groups	Special Government fund	Pharmacy/nurses	Alienate ethnic population
Community based screening e.g. church	All adults over 25 or selected high risk groups as per NICE	NHS CCG LA H&WB groups	Primary Care Pharmacies Community groups as per NICE	Anxiety (not much)
National Child Measurement Programme (NCHP)	Reception and Year 6	PH/LA	School Nurse Service	

		Pharmacological Interventions		
Metformin	Those unable to achieve adequate response to lifestyle interventions to prevent diabetes	CCG	Prescriptions	GI side effects (flatulence!)
		Diet and Exercise Interventions		
Group based exercise interventions	Physically inactive in potentially at risk groups	LA	LA	
Facilities for exercise	Physically inactive in potentially at risk groups	NHS	NHS	
Leisure Facilities/referral to Activity Sheffield Health Champions	People who self assess as needing. Targeted at inactive	GP CCG Sheffield City Council	CCG SCC	Health problems like arthritic knees
YMCA exercise class	Those who already have a healthy diet	Exercise on referral (CCG)	YMCA qualified instructor	Possible additional stress from needing to attend extra class
Exercise on referral schemes	Moderate to high risk of T2D	CCG's LA's Private Health Insurers	Commercial Providers	
Commercial Physical Activity one to one interventions e.g. Fitness First	Moderate to high risk of T2D	CCG's LA's Private Health Insurers	Commercial Providers	
Weight Watchers Style Programme	Overweight	Local/NHS/Council	Specialised External body	Yo Yo effect of weight loss
To have direct access to dieticians when newly diabetics are diagnosed by GPs for the system to work closely with all services	Newly diagnosed diabetics	CCGs	GPs and NHS together	

Weight Management e.g. Weigh Ahead Dietetics	Those with BMI over 35	GP City Council	PH set up Community dieticians	DNA's
Group based lifestyle intervention based around diet and exercise (similar to DESMOND)	Those identified at high risk of diabetes	GP CCG	Nurse or dietician or exercise physiologist	Possible additional stress from needing to attend extra class
Private sector weight loss classes e.g. slimming world	Those needing to loose large amount of weight	Initially GP or CCG then patient	Weightwatchers	Possible additional stress from needing to attend extra class
Dietician led education course	Those for whom significant increase in physical activity is problematic	CCG	Specialist diabetes dieticians	Stress to patient
Group based weight loss interventions e.g. -WeightWatchers, other commercial programmes -Primary Care Led e.g. CounterWeight, Waste the Waist	Moderate to high risk of T2D (as per NICE)	CCG's LA's (H and WB) Private Health Insurers	Commercial Providers Primary Care Staff	
Commercial Diabetes Prevention Programmes in Development e.g DESMOND-DP, NDPS, X-POD	Moderate to high risk of T2D (as per NICE)	CCG's LA's (H and WB) Private Health Insurers	Commercial Providers Primary Care Staff	
Individual behaviour change interventions (one to one, unlikely to be cost effective)	Moderate to high risk of T2D (as per NICE)	CCG's LA's (H and WB) Private Health Insurers	Commercial Providers Primary Care Staff	
Mixed model weight loss interventions	Moderate to high risk of T2D (as per NICE)	CCG's LA's (H and WB) Private Health Insurers	Commercial Providers Primary Care Staff	
Community interventions e.g. cooking demonstrations, work with restaurants to make healthier options available	All	CCGs Las	LA's and associated providers	
Training of health professionals to deliver brief interventions for lifestyle change	Health Professionals	NHS	NHS	Increase in inequalities
Health trainers and health champions to support individuals in lifestyle change	Local communities	?	?	?

Brief Intervention Training	All	PH/LA	Providers	
Tier 1,2,3 obesity services	Adult	PH/LA	Local dietetic and MDT	
Childhood obesity interventions	Children and families	PH/LA	Leeds Met	
Weight Management (WW)	Adults/families	PH/LA	GP's	
Population-level interventions				
Change in transport policy Transport Plans	General Population	Government		
Affordable access to healthier foods	Universal and targeted at groups at greater risk e.g. deprived/BME	LA's	LA's and third sector	Increased inequalities as better off more able to take advantage of the interventions
Taxation/Prohibition/Advertising bans in respect of e.g. sugary soft drinks i.e. empty calories	Esp. young people	Food industry	Central Government Local Government Legislation	
Walking and cycling (transport and leisure) initiatives	Universal and targeted at groups at greater risk e.g. deprived/BME	LA's	LA's and third sector	Increased inequalities as better off more able to take advantage of the interventions
Change in agricultural policy	General Population	Government		
We need to work with supermarkets in promoting healthy food and farmers in affordable production	Everyone	Sainsburys etc. Would need financial incentives	Supermarkets PH champions	Patients Budget concerns

Organisational level – something about overall responsibility at LA level and their responsibility for mix of interventions				
People with other issues other than diabetes which bring the onset of diabetes such as CVD	People not yet diagnosed with diabetes	CCG	GPs and NHS together	
Diabetes UK roadshows and publicity (they have their own risk calculator)	Everyone	Diabetes UK Charity		
Healthy Schools/School Meals				
Olympics Health Moneys	Everyone	The money allocated to Sheffield ?£60m?	Private consortia	
Green Space (Environment)	All	LA	PH and LA	
Vegan Lifestyle (suggested this week to the UN)	All	?	Government Intervention	Food Industry rejections

3. Model perspectives and outcomes

The discussion of model perspectives and outcomes suggested that the perspective should be broader than a NHS and Personal Social Services (PSS) perspective and that a societal perspective would be of interest to stakeholders, with a breakdown of costs and outcomes presented. A number of relevant groups of interest were discussed:

1) The Private Health Insurer will have an interest to raise profits, and avoid long term costs. They may have an incentive to introduce programmes to improve their PR and advertising.
2) Social services and local government will want to lower costs to the public sector and meet other objectives within departments, such as education. There is a problem in that the payers of the interventions are not necessarily in the department that will benefit further down the line. Public sector responsibilities can affect several different departments.
3) There are also parties outside of the public sector that are affected. For example the Academies in education can be considered outside of the local government.
4) The involvement of Housing Associations should also be considered if modifications to the home are needed and patients are not the home owner.
5) The Well@Work programme involves employers and this perspective might want to be considered.
6) Most interventions are funded by government in some form, but the delivery can be very different. The costs should also consider the time and human resource costs and who eventually performs the intervention.
7) The cost to the population at risk should be considered, for example, testing costs (linked to driving). A patient perspective should consider the costs of lifestyle changes, expensive diet or weight watchers. Pharmacological interventions are free for diabetics, so they may be cheaper for the individual patients. Other patients in related risk groups, such as high blood pressure are not eligible for free prescriptions. This may have cost implications for screening programmes.
8) Pharmaceutical companies have an interest in screening programmes to raise sales as more diabetes patients are identified.
9) The Charity and voluntary sector were also briefly mentioned.
10) Societal costs will be important, such as work absence and caregiver costs.

Discussion around commissioning and who funds which interventions

There was a discussion around the changes to the PCTs and the new plans for how the responsibilities will be divided. It was highlighted that who will commission interventions will be different around the country.

The Health and Well-being board will commission services specifically for the prevention and screening of diabetes. The CCG will have a seat on that board, but it will not take responsibility for the programmes. The budgets between the two groups will not be transferable in the short term. The CCG does not have a direct role in screening and prevention of diabetes, but has an interest in it because they commission the secondary care treatment. The Health and Wellbeing board cannot say they want to cut the budget of the CCG (in terms of secondary care) and increase their budget for prevention of diabetes from the saved money, but the CCG could fund prevention which may be in their interests.

Weight management programmes will be the responsibility of Public Health. Health Checks will be funded by the Local Authority. Part of education programmes will be funded by CCGs, whilst part will be funded by the Local Authority. Pharmaceutical interventions sit between several funding streams.

- Please let me know if this summary of the discussion of model perspectives and outcomes does not capture any issues raised.

- Please let me know if you think that anything that was discussed at the workshop is not reflected within this document.

Appendix D5: Discussion document for Stakeholder Workshop 2

This document aims to outline our draft scope and key assumptions for the economic model so that we can:

a) discuss which specific interventions should be considered within the model;
b) agree on the boundary of the model;
c) discuss the appropriateness of alternative key model assumptions;
d) agree upon the perspectives & outcomes of the model;
e) discuss the appropriateness of alternative assumptions to describe the cost and quality of life inputs.

This document includes:

(1) A summary of a review of intervention effectiveness evidence;
(2) A summary of a review of similar cost-effectiveness models and the implications for this model;
(3) A description of the type of model being developed;
(4) A draft model boundary;
(5) Specification of key model assumptions;
(6) The perspectives & outcomes of the model;
(7) Costs & utility assumptions associated with the relevant diseases.

We present key questions that we have within each section.

1. Summary of intervention effectiveness evidence for type 2 diabetes screening and prevention

We have divided the potential interventions into the following population groups:

A) For the general population to reduce risk factors for diabetes;
B) For people with non-diabetic hyperglycaemia;
C) For people within the general population who are at high risk of developing non-diabetic hyperglycaemia and type 2 diabetes, including identification and risk assessment (eg. overweight or obese, low socioeconomic status, South Asian, those with CVD, those picked up by health checks).

Systematic reviews produced for NICE projects already exist for (B) and (C) above.[1;2] We have undertaken a literature review for population-level interventions (A above). This was limited to a review of systematic reviews due to the large number of studies in this area. We used the interventions you identified within the first stakeholder workshop to help develop the searches. The search strategy is described in Appendix 1. We did not identify any evidence on walking and cycling/

transport policy interventions within our review of systematic reviews; however an existing NICE report describes a recent review of this area.[3]

All of the above reviews are made up of heterogeneous studies in terms of population, intervention, comparator, outcomes and country. Thus, meta-analysis of many of the studies is not appropriate. Therefore, the effectiveness and cost of each intervention assessed will generally be based upon one specific study. From the reviews, Table 1 shows the interventions we have identified for possible comparison within the model, along with the studies we could use to model the effectiveness of these interventions. Table 1 also lists the studies which we have identified but that were not considered to be relevant or of sufficient quality, based upon the criteria below:

<u>Intervention grouping level</u>

1) Intervention is not generalisable to the UK in any of the studies due to substantial differences in current practice (e.g. transport infrastructure in the Netherlands) or populations (e.g. intervention provided to only a Hispanic population);

   OR

2) Intervention is not effective in any of the studies within the systematic reviews;

   OR

3) Intervention already exists as standard practice within the UK.

<u>Individual study level</u>

4) No outcomes reported related to diet, exercise or blood glucose levels (e.g. only impact upon traffic congestion reported) or only subjective outcomes reported (e.g. only increased knowledge about diet or intention to exercise reported)

   OR

5) Only poor evidence exists around intervention effectiveness due to:
    a. short term follow up
    b. poor study design
    c. poor reporting of the study (e.g. the intervention, comparator, population, outcomes or study design are unclear).

Table 2 shows key details of the studies which we are proposing could be used within the model.

No effectiveness evidence has been identified within our search for systematic reviews around the following interventions which were suggested within the first stakeholder workshop:

1) Affordable access to healthier foods ;
2) Change in agricultural policy;
3) Work with supermarkets in promoting healthy food;
4) Increase green space;
5) Vegan lifestyle.

Screening

Based upon an email discussion with stakeholders, there is variation in diabetes screening practice and GPs may use FPG, RPG or HbA1c. OGTT is rarely used in practice, apart from for small specific groups of patients such as pregnant women. More HbA1c tests can be undertaken per day and the cost is likely to be reduced as these tests are used more often. Questions which you may want us to consider within the model are:

1) What should the frequency of repeat screening tests be for people with non-diabetic hyperglycemia?
2) Currently IGR and/or IGT may be classed as high risk groups. Which groups of people should be most appropriately classified as high risk groups in terms of their risk of complications?

Table 1: Interventions and related effectiveness evidence

Population	Intervention	Effectiveness evidence which could be used within model	Effectiveness evidence identified but not planned to be used (reason)
General Population	Taxation of snacks	Oaks, USA, Kim & Kawachi, USA (*in Thow et al. 2010*[4])	Asfaw, Egypt (population) (*in Thow et al. 2010*[4])
	Taxation of soft drinks	Fletcher et al., USA (*in Thow et al. 2010*[4])	Tefft, USA (incompatible outcome measure); Bahl, Ireland (as above) (*in Thow et al. 2010*[4])
	Community-based health education plus counselling & environmental change	Jenum et al., Norway (*in Sheill et al. 2008*[5])	-
	Community-based health promotion	Howard et al., USA Women's Healthy Lifestyle Project, USA (Kuller et al. and Simkin-Silverman et al.) *(in Mernagh et al. 2010*[6]*)*	-
	University-based health education	Hivert et al., Canada *(in Mernagh et al. 2010*[6]*)*	-
	Workplace-based environmental change (high intensity)	Emmons, USA Sorensen, USA *(in Mhurchu et al. 2010*[7]*)*	Cook, NZ (smaller sample size); Linenger, USA (weaker study design) *(in Anderson et al. 2009*[8]*)*; Saarni, Finland (weaker study design, no comparator); Hope et al. Ireland (as above); Lassen et al. Denmark (as above); Kwak et al. Netherlands (weaker study design, non-randomised) *(in Maes et al. 2011*[9]*)*; Sorensen (2007), US (smaller sample size) *(in Mhurchu et al. 2010*[7]*)*
	Workplace-based environmental change (low intensity)	Holdsworth, UK (2004) *(in Mhurchu et al. 2010*[7]*)*	Holdsworth, UK (1999) (2004 study was a better design) *(in Mhurchu et al. 2010*[7]*)*; Tanaka et al. Japan (population) (*in Sheill et al. 2008*[5]*)*; Oshaug et al. Norway (weak quality) *(in Maes et al. 2011*[9]*)*
	Workplace-based health checks (high intensity)	Gomel, Australia *(in Anderson et al. 2009*[8]*)*	Elliot, USA (limited follow up), Gill et al. Sweden (weak quality – case study); Murza et al. Germany (weaker study design – no comparator) *(in Maes et al. 2011*[9]*)*
	Workplace-based health checks (low intensity)	Hanlon et al., Scotland *(in Maes et al. 2011*[9]*)* Connell, USA *(in Verweij et al. 2011*[10]*)*	Shimizu, Japan (population); Erfurt, USA (population) *(in Anderson et al. 2009*[8]*)*; Racette, USA (smaller sample size) *(in Verweij et al. 2011*[10]*)*; Campbell, USA (smaller sample size, population); Braekman, Holland (shorter follow-up) *(in Mhurchu et al. 2010*[7]*)*
	Workplace-based health education/promotion (high intensity)	Aldana, USA *(in Anderson et al. 2009*[8]*)*	Anderson, US (older); Crouch, US (smaller sample size); DeLucia, US (as above); Muto, Japan (population); Proper, Netherlands (shorter follow-up); Robison, US (as above); Weir, US (dated, no comparison); WHO, Europe (dated) *(in Anderson et al. 2009*[8]*)*
	Workplace-based health	Talvi, Finland	Bruno, US (dated, shorter follow-up); Brownell, US (smaller sample size); Cockcroft,

	education/promotion (low intensity)	*(in Maes et al. 2011[9])* Elberson, USA *(in Anderson et al. 2009[8])*	UK (shorter follow-up); Forster, US (as above); Fukahori, Japan (population); Furuki, Japan (population); Gerdle, Sweden (smaller sample size); Briley, USA (smaller sample size); Gomel, Australia (weaker study design); Hedberg, Sweden (smaller sample size); Pohjonen, Finland (as above) *(in Anderson et al. 2009[8])*; Von Thiele Schwarz, Sweden (population narrow – female dentists) *(in Verweij et al. 2011[10])*; Pratt, 17 countries (General Electric employees) (weaker study design, no comparator) *(in Mhurchu et al. 2010[7])*; Nisbeth, Denmark (smaller sample size); Siggaard, Denmark (as above); Papadaki, Scotland (as above and weaker study quality) *(in Maes et al. 2011[9])*
	Sustainable Travel Towns	Sloman et al., UK[11]	-
	Pedometer interventions	Baker et al., UK [12]	-
Non-diabetic hyper-glycaemia	Diet and exercise if screening identifies non-diabetic hyper-glyceaemia	DPS, Finland (*in Jones et al.*)	DPP, USA (less relevant than Finnish DPP); Indian DPP (setting); Da Qing, China (population); Japanese DPP (population); FHS, UK (small sample); Malmo, Sweden (not randomly assigned); Malmohus, Sweden (dated); ODES, Norway (follow up shorter, sample size smaller than US & Finnish trials); Asti DPP, Italy (as previous); VIP, Sweden (as previous). (*in Jones et al.*)
High-risk of non-diabetic hyper-glycaemia / diabetes (low SES)	Education to promote increased fruit &veg intake	Ashfield-Watt et al. (2007)[13] Bremner et al. (2006)[14]	-
	Behavioural counselling	-	Steptoe et al. (2004)[15] (The NICE PDG agreed unsuitable)
	Workplace counselling	-	Proper et al. (2003)[16] (as above)
	Exercise consultation	-	Lowther et al. (2002)[17] (Had negative impact on physical activity)
	Access to internet portal	-	Lindsay et al. (2008)[18] (as above)
	Broad dietary education/ cooking skills	McKellar et al. (2007)[20] Wrieden et al. (2007)[19]	-
	Opening of a new food retail outlet	Cummins et al. (2008)[21]	-
	Small scale multi-component	Gray et al (2009)[22]	-
	Large-scale, region-wide multi-component	Schuit et al. (2006) [23]	-

Table 2: Key details of studies

Author (year)	Intervention (incl. length of time provided & maintenance)	Population/ setting	Follow up period	Sample size	Study type	Outcomes	Effectiveness
Oaks (2005) in *Thow et al (2010)*[4]	State tax of 5.5% of soft drinks and snacks.	USA	15 years	Not stated in SR	Ecological	Obesity prevalence	No relationship.
Kim & Kawachi (2006) in *Thow et al (2010)*[4]	Change in state taxes on soft drinks or snack foods.	USA	Not stated in systematic review (SR)	Not stated in SR	Ecological	Obesity prevalence	No association with obesity point prevalence. With no tax more than 4 times as likely to experience a high relative increase in obesity prevalence; those that repealed a tax were more than 13 times as likely.
Fletcher et al. (2011)[24]	State soft drinks tax, average 3%.	USA	16 years	Not stated in SR	Ecological	BMI	1% tax decreased BMI by 0.003 points.
Jenum et al. (2003, 2006) in *Sheill et al (2008)*[5]	Community-based health education plus environmental change plus counselling. Intervention duration was 3 years.	Norway, community setting (2 multi-ethnic districts of Oslo)	Not stated in SR	Not stated in SR	Interven-tion	Physical activity (measured by self-report); BMI	Increase in PA in I (+9.5%, $p<0.01$) compared to minor changes in C (exact change not reported in original study). Smaller increase in BMI in I compared to C (exact difference not stated in SR).
Howard et al. (2006) in *Mernagh et al (2010)*[6]	Community based health promotion to promote a decrease in fat intake and increases in vegetable, fruit, and grain consumption. 18 group sessions in year 1, then 4 per year for the duration of the trial.	USA, community-based from 4 clinical centres, 50-79 years old	Mean follow-up 7.5 years, change at 1 year also reported in SR	48, 835 women	RCT	Change in body weight; BMI; waist circumference	Change at 1 year Weight I: -2.2kg ($p<0.001$) C: No change At the end of follow-up differences were observed between I & C in weight (0.5kg, $p=0.01$), BMI (0.3kg/m^2, $p<0.001$) and waist circumference (0.3cm, $p=0.04$).
Kuller et al. (2001) & Simkin-Silverman et al. (2003) in *Mernagh et al (2010)*	Community based health promotion. Cognitive-behavioural programme with duration of 5 years.	USA, community-based, 44-50 years old	6, 18, 30, 42 and 54 months after randomis-ation	Up to 535 women	RCT	Weight; BMI; Body fat (%); waist circumference	Change at 54 months (from baseline) Weight I: 0.08 C: 2.36 ($p<0.01$) BMI I: 0.05±2.0 C: 0.96±1.8 ($p<0.001$) Body fat I: -0.5±4.1 C: 1.1±3.9 ($p<0.01$) Waist circumference I: -2.90 C: -0.46 ($p<0.01$)

Author (year)	Intervention (incl. length of time provided & maintenance)	Population/ setting	Follow up period	Sample size	Study type	Outcomes	Effectiveness
Hivert et al. (2007)[25]	Small-group interactive seminars to educate students and modify diet/ exercise behaviour. Fortnightly for the first 2 months of the semester, monthly for the rest of the 2 years (total = 23 seminars)	Canada, university students	1 year & 2 years	I: 58 C:57	RCT	Weight (kg); BMI	Change at 2 years Weight I: -0.6±0.5 C: +0.7±0.6 ($p<0.05$) BMI I: -0.3±0.2 C: +0.2±0.2 ($p<0.05$)
Holdsworth (2004)[26]	Environmental (low intensity) - changes to cafeteria menus. Duration of intervention was 6 months	UK, workplace-based, 4 intervention workplaces and 2 control	1 year	577 employees at 6 worksites I: 453 C: 124	Quasi-experimental study	Dietary habits measured using a food frequency questionnaire	Vegetable consumption I: 27% made +ve changes C: 19% made +ve changes Fruit consumption I: 37% made +ve changes C: 25% made +ve changes
Emmons (1999) in *Mhurchu et al (2010)*[7]	Workplace based environmental change – risk factor education programmes and changes to nutrition policy and practice.	USA, workplace-based intervention	130 weeks	397 employees at 22 worksites	Cluster RCT	Total fat, fibre and fruit and vegetable intake (FFQ)	Total fat I: -2.2% C: -1.8% Fruit & vegetable servings/day I: +0.2 C: -0.2
Sorensen (2003) in *Mhurchu et al (2010)*[7]	Workplace based environmental change – worker participation in programme planning, worksite environmental changes & individual behaviour change programmes	USA, workplace-based intervention	104 weeks	5156 employees at 15 manufac-turing worksites	Cluster RCT	Dietary intake (fruit and vegetable screening questionnaire)	Fruit and vegetable servings/day I: -0.1 (7 sites) C: +0.05 (8 sites)
Connell (1995) *(in Verweij et al. (2011)*[10]	Workplace based health checks – 3 intervention groups and control. Ia: Health promotion + Health risk appraisal (HRA) booklet, Ib: Health promotion, Ic: HRA booklet, C: HRA.	USA, workplace-based intervention with office workers, nurses & instructional staff	1 year	801 employees Ia: 142 Ib: 248 Ic: 253 C: 158	Cluster RCT	BMI	Significant decrease in Ia, Ib, Ic vs. C: ß: −0.05 ($p < 0.01$), ß: −0.05 ($p < 0.01$), ß: −0.04 ($p < 0.05$) vs. ß: 0

Author (year)	Intervention (incl. length of time provided & maintenance)	Population/ setting	Follow up period	Sample size	Study type	Outcomes	Effectiveness
Hanlon et al. (1995, 1998) *(in Maes et al. 2011[9])*	Workplace based health checks. Health checks followed by a health education package that included an interview backed up by written information and feedback on risks. Intervention duration 12 months.	Scotland	5 months & 1 year	1,632	RCT	BMI; Diet; Physical activity	No significant effect on BMI or physical activity. Effect on diet.
Aldana (2005) *(in Anderson et al. 2009[8])*	Workplace based health education/promotion – lectures, pedometers, books, shop tours, cooking demonstrations, health knowledge test, compared to no contact. Intervention duration 1.5 months, maintenance not reported.	USA, workplace based intervention targeted to care provider employees.	6 months	145	RCT	Weight(kg)	Significant decrease in I compared with C. I: -4.4 C:-1.0 ($p<0.0001$)
Talvi (1999) *(in Maes et al. 2011[9])*	Workplace based health checks and education/promotion - employees were offered special counselling according to their individual needs in 9 target areas. Intervention duration different for each health promotion action.	Finland, oil refinery workers, one rig with intervention compared to one rig with minimal intervention	3 years	I: 412 C: 473	Non-RCT	BMI, Diet, Physical activity habits	No effect on BMI or diet. Effect in the targeted direction on physical activity.
Elberson (2001) *(in Anderson et al. 2009[8])*	Workplace based health checks and education/promotion – Ia (structured): planned exercise classes, Ib (unstructured): access to gym, no classes, Ic: all of the above. Intervention duration 12 months, maintenance not reported.	USA, workplace based intervention.	1 year	374	Retro-spective cohort	BMI	Structured: Baseline BMI 25.01, change at 12 months -0.57 (within group $p=0.185$) Unstructured: Baseline BMI 27.97, change at 12 months +0.30 (within group $p=0.001$)
Gomel (1993) *(in Anderson et*	Workplace-based health checks & education/promotion - risk assessment & feedback on risk	Australia, workplace based	1 year	431	Cluster RCT	BMI	No difference between intervention groups and control.

Author (year)	Intervention (incl. length of time provided & maintenance)	Population/ setting	Follow up period	Sample size	Study type	Outcomes	Effectiveness
al. 2009[8])	factor profile; up to 6 life-style counselling sessions over a 10-week period; incentives incl. lottery tickets & money for achieving goals. Intervention 6 months.	intervention with ambulance employees					
Sloman et al 2010[11]	Sustainable travel towns which implemented intensive town wide Smarter Choice Programmes to encourage use of non-car options; bus use, cycling and walking, and less single occupancy cars	United Kingdom	30 Months	12,000	Ecological/ Cluster RCT	Cycle trips per head, walking trips per head	Cycle trips per head grew by 26-30%. Comparison towns cycle trips decreased. Walking trips per head grew substantially by 10-13% compared to a national decline in similar towns.
Baker et al. (2008) [12]	Walking programme with goals set in steps using an open pedometer for feedback	United Kingdom	52 Weeks	63	RCT	Step counts	Intervention (77%) vs.Control (54%) achieved week 4 goals (X2= 4.752, p=0.03) Significant decrease in count week 16-52.
DPS, Finland *(in Jones et al.)*	Control group: lifestyle advice was given as 'standard care counselling' at baseline. Intensive intervention group: given individualised, detailed dietary counselling, with 7 sessions during the first year & every 3 months thereafter.	Finland, with IGT. All were middle-aged (40–64 years) & BMI>25 kg/m2 at baseline.	3 years	522 (172 men and 350 women)	RCT	Multiple outcomes including BMI, weight, waist circumference and incidence of diabetes.	During the first three years of the study, 22 subjects (9%) in the intervention group and 51 (20%) in the control group developed diabetes (p= 0.0001, 2 test).
Ashfield-Watt et al. (2007)[13]	Initiatives that involved building community networks to increase fruit and vegetable intakes in five deprived communities by improving awareness, attitudes & access to fresh fruits & vegetables. Intervention duration 12 months.	Residents in 5 UK deprived areas	1 year	1554	Non-RCT	Fruit & vegetable intake, measured using a short dietary/ attitude questionnaire	Median total fruit and vegetable intakes decreased significantly over one year in the control group (-0.4 portions per day, *p*<0.01), but there was no significant change in total fruit and vegetable intakes in the intervention group.
Bremner et al. (2006)[14]	'5-a-day' community intervention to increase fruit & vegetable intake, including home delivery & transport links, voucher schemes, media campaigns, growing & cookery skills & encouraging	Residents in 66 (former) UK health authorities with the highest levels	Baseline (pre-test) was in 2003 and follow-up (post-test) was in	98,640	Non-RCT	Fruit & vegetable intake and knowledge	Fruit consumption (unadjusted): Experimental and control group respondents were more likely to consume fruit as a between meal snack at follow-up (significance not reported).

Author (year)	Intervention (incl. length of time provided & maintenance)	Population/ setting	Follow up period	Sample size	Study type	Outcomes	Effectiveness
	networking in groups involved in promoting healthy eating. Duration not specified but at least 1 year.	of deprivation and poorest health status.	2005.				Vegetable consumption (unadjusted): Experimental and control group respondents were more likely to consume vegetables as portions with main meals at follow-up (significance not reported).
Wrieden et al. (2007)[19]	Informal food skills and food education sessions, following a 'CookWell' manual. Intervention duration 7 months.	Adults in rural & urban communities in Scotland aged 30-55 in lower SES groups who do not exercise often.	2 & 6 months	93	Non-RCT	Fruit & vegetable intake; other eating habits (e.g. tuna and total fish intake)	At T2, a mean change equivalent to one portion a week was seen in the intervention group for fruit (P= 0.047), but no other significant changes were seen. This change was not sustained and there was no significant difference between the intervention and comparison groups (T1–T3).
McKellar et al. (2007)[20]	Mediterranean-type diet intervention involving a cookery course, weekly 2-hour sessions. Intervention duration 6 weeks.	Females with rheumatoid arthritis living in urban areas of deprivation in Glasgow.	3 & 6 month	130	Non-RCT	Fruit & vegetable intake; weight control; consumption of high fat foods; physiological measurements	Evaluation of cardiovascular risk factors showed a significant drop in systolic blood pressure by an average of 4 mm Hg in the intervention group (p=0.016), while the control group showed no change. Consumption of fruit, vegetables & legumes was below the recommended minimum of 5 portions a day, in both groups at baseline. By 3 months this had improved significantly in the intervention group who were attending cooking classes. This group also had a significant improvement in ratio of monounsaturated :saturated fats consumed.
Cummins et al. (2008)[21]	Provision of a new food hypermarket within the intervention area (natural public health intervention). Intervention duration 1 year.	Residents of households in two deprived areas of Glasgow.	1 year	603	Pros-pective cohort study	Fruit and vegetable consumption, self reported & psychological health, & socio-	Weak evidence for an effect of the intervention on mean fruit consumption (-0.03, 95% CI -0.25 to 0.30), mean vegetable consumption (-0.11, 95% CI -0.44 to 0.22), and fruit and vegetables combined (-0.10, 95% CI -0.59 to 0.40).

Author (year)	Intervention (incl. length of time provided & maintenance)	Population/ setting	Follow up period	Sample size	Study type	Outcomes	Effectiveness
						demographic variables.	Odds ratios & 95% confidence intervals of reporting fair to poor self-reported health and poor psychological health for the intervention compared with comparison community.
Gray et al (2009)[22]	Camelon weight management group programme, tailored to men, incorporating advice on physical activity, diet and alcohol consumption. Intervention duration 12 weeks.	Male residents of a deprived community in Scotland.	Pre-programme, short-term (12-week, immediately post-programme, long-term (1 to 49 months after programme)	110	Case series	Weight loss, waist circumference reduction, BMI reduction.	Short-term (end of 12 weeks programme) weight loss for completers was a mean weight loss of 4.98 kg. 44.3% achieved a weight loss of 5% to 10%. Long-term weight loss maintained an average 3.7% weight loss (range = 32.6 weight loss to 25.6% weight gain) compared with their baseline weight (no further information on what this actually meant). Compared with pre-programme weight, 14 weighed less, 2 were stable (±0.5 kg) 4 weighed more; no further detail reported.
Schuit et al. (2006) [23]	Over 5 years 790 interventions were implemented in the local population and targeted groups.	Netherlands	5 years	3895	Cohort study	Body mass index, waist circumference, blood pressure, serum glucose & serum total & high-density lipoprotein (HDL) cholesterol	Difference in mean change in risk factors between intervention & reference group for BMI: −0.36kg/m2 in men & −0.25 kg/m2 in women; waist circumference −2.9cm in men & −2.1cm in women; systolic blood pressure: −7.8mmHg in men and −5.5mmHg in women; cholesterol 0.11 mmol/L in women & serum glucose −0.23 mmol/L in women. ($p<0.05$)

Key questions for stakeholders:

1) Do you think we should compare all of the interventions listed in Table 1/ which of these should we prioritise?
2) Are you happy with the effectiveness evidence we have identified to use to model these interventions shown in Table 1?
3) Do you think we should do additional specific searches for effectiveness evidence of the five interventions described above Table 1 which were not included within the systematic reviews?
4) Should we assume that the screening strategy as set out in the NICE guidance is current practice? Do you think it would be useful to investigate the two questions relating to screening above Table 1 or any others relating to screening?
5) Limited evidence has been identified for the effectiveness of targeted interventions within the South Asian ethnic group. Should we be considering assessing the cost-effectiveness of a hypothetical targeted intervention for this subgroup?
6) Are there any other groups of people who you might want to aim interventions at in practice?
7) How would socioeconomic status be usefully described?
8) Which combinations of interventions should we consider which would be most important for potential implementation?

2. Results of cost-effectiveness model review for type 2 diabetes screening and prevention interventions

The purpose of this literature review was to facilitate development of the model boundary and assumptions by considering:

i) What structural assumptions have been made in previous economic evaluations and the strengths and weaknesses of these approaches? With particular focus on:
   a. Patient transition from high risk states to diabetes
   b. Patient progression to further complications

ii) What data have been used to estimate progression to diabetes?

iii) Which model parameters have the greatest impact on the cost-effectiveness outcomes?

A brief summary is presented here, although more detailed information about the methods and findings can be found within Appendix 2 for the interested reader. Findings from this literature review are included within subsequent sections of this document where relevant.

The literature review identified 42 articles describing 34 simulation models for interventions to prevent progression to Type 2 diabetes.

- We identified a broad range of public health interventions
  - Seventeen studies reported a targeted lifestyle intervention
  - Seven studies reported targeted lifestyle interventions and pharmacological interventions
  - Eight studies reported pharmacological interventions
  - One study reported policy changes
  - Two studies reported policy changes and targeted lifestyle interventions
  - Six studies reported screening and lifestyle intervention programmes
  - One study reported surgery
- The studies were grouped into five model structure categories
  - Population multistate life-tables (n=9)
  - Pre-diabetes based structure (n=16)
  - BMI only based structure (n=9)
  - Other and multiple risk factor structure (n=6)
  - Archimedes Model (n=1)
- Multistate model studies report results from three models
  - The ACE-prevention model used 5 year follow-up Australian cohort data to estimate baseline risk of diabetes

    - The RIVM chronic disease model used Dutch cohort data to estimate baseline risk of diabetes
    - A single study reported a model for Australian using survey data from Australia
- Pre-diabetes intervention models used different methods to estimate baseline risk of diabetes
    - Ten studies used individual trials
        - Six studies used the Diabetes Prevention Programme
        - Three studies used the Finnish Diabetes Prevention Study
        - One study used an older lifestyle intervention trial
        - One study used a drug trial
    - One study used a meta-analysis of trials
    - Five studies used observational data
- BMI interventions models used more observational cohort data to estimate baseline risk of diabetes
    - Two studies used data from trial
    - Seven studies used observational data
- Obesity models tend to stratify risk by BMI
    - Two studies assume a single obese state
    - Ten studies assume risk is variable with BMI
    - Three studies also stratify risk by age
- The overall conclusions of the review were that:
    - The model should simulate risk factors for diabetes and cardiovascular risk as continuous variables
    - The trajectory of blood glucose, and risk of CVD should be estimated as a function of multiple risks, (e.g. diet, physical activity, obesity)
    - Correlation between the multiple risk factors should be described in the simulation
    - The model should simulate the general population to allow multiple sub-groups to be identified

3. The type of model being developed

The aim of a health economic model is to capture all of the differences between the costs and effects associated with two or more different interventions. For chronic diseases such as diabetes, this involves calculating costs and effects over the lifetime of individuals. Models are simplifications of reality. There is always a trade off between developing a model which more closely represents reality and the time taken to develop the model. Models also require assumptions to be made when bridging the gap between available evidence and the need to incorporate key facets of the problem. Model assumptions can be tested within sensitivity analyses which involves assessing the impact of alternative plausible assumptions upon the model results.

The studies identified in the economic evaluation review suggested that a broad range of simulation methods have been used to describe progression to Type 2 Diabetes.

- Six studies reported a decision tree model
- Nineteen studies reported a Markov model
- Nine studies reported a Multi-state life table
- Nine studies reported a patient level simulation

We plan to develop a patient-level simulation which means that individuals will be followed over their lifetime and it will be possible to model the heterogeneity between individuals. It will also allow timing of events to be modelled more flexibly. These are important given the impact of different risk factors upon disease progression and the competing risks of developing different diseases.

The type of model being developed is based upon the algorithm shown in Appendix 3 for the interested reader.

4. Draft model boundary

From the conceptual model of the problem developed within Stakeholder Workshop 1, decisions about whether to include or exclude factors within the model need to be made. We are limited by time and resources so cannot include everything within the model.

The review of economic evaluation studies identified that most studies only included cardiovascular disease as a long term complication.

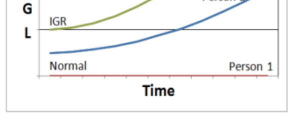
- Nine models did not include long term complications of Type 2 Diabetes.
- Twenty-five models assume a risk of cardiovascular disease.
- Nine assume a risk of retinopathy.
- Ten assume a risk of nephropathy.
- Seven assume a risk of neuropathy.
- Three assume a risk of osteoarthritis.
- Six assume a risk of cancer.
- None assumed a risk of mental illness, fatigue, pregnancy complications, or the risk for future generations.

Overall, very little sensitivity analysis was undertaken within these existing studies around the impact of each of the diseases to assess whether they are likely to impact upon the model results substantially. The conceptual model from Stakeholder Workshop 1 is shown in Figure 1 below and Table 3 below suggests which factors might be included within the model and which might be excluded from the model. This potential model boundary based upon Table 3 is then shown within Figure 2. The algorithm used to help choose which factors to include and exclude are shown in Appendix 3 for the interested reader.

Potential interventions
Affects usage of alternative intervention

*Different tests (OGTT, FPG, HbA1c) identify different individuals & diagnostic criteria have changed

graphical form for BGL to highlight consideration of time

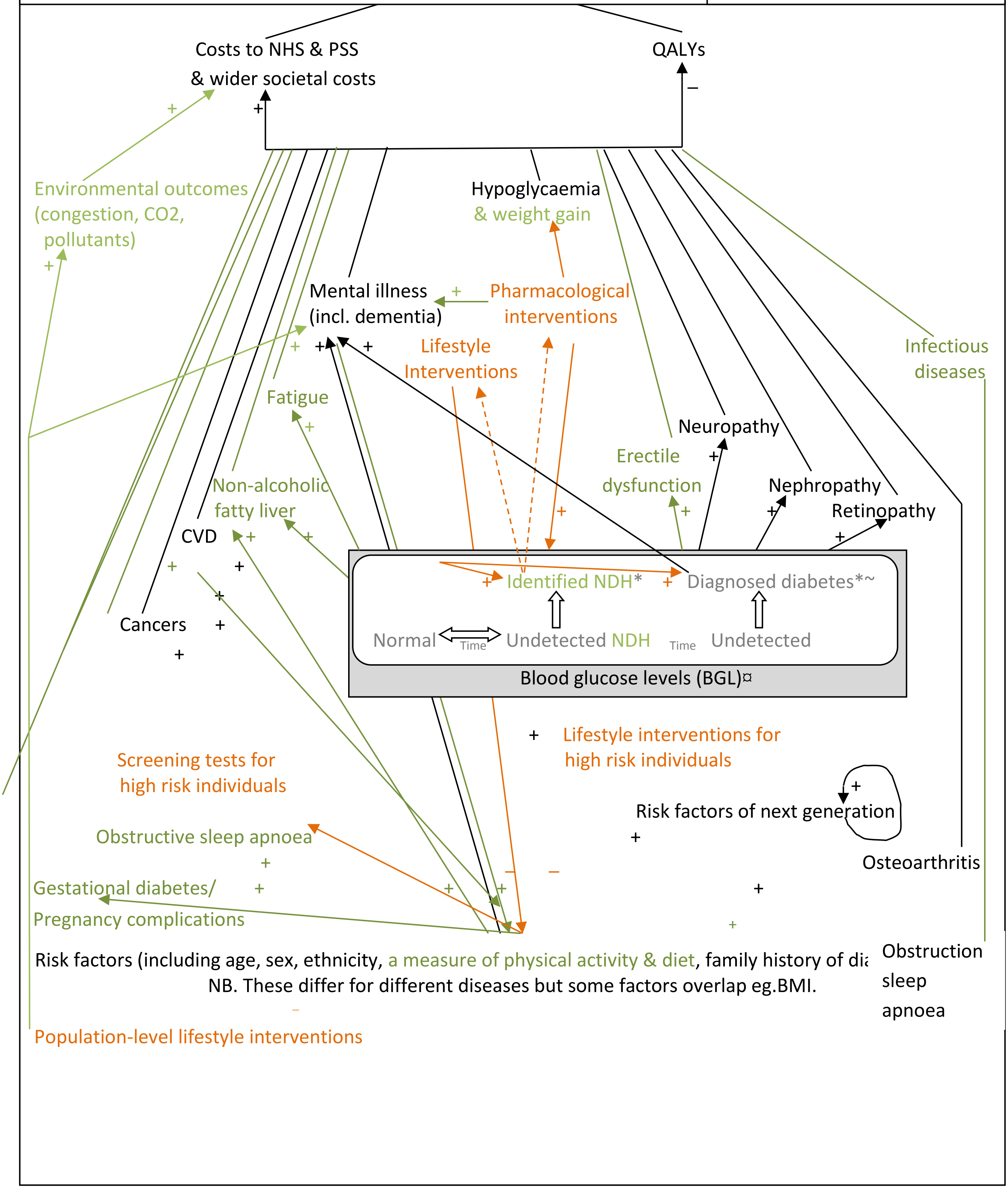


~This leads to screening for CVD & microvascular complications which will affect these outcomes. If BGL are decreased, the risk of complications may decrease even if the individual is still termed 'diabetic'.

**Risk factors may be worse in the future as lifestyles become more sedate

CVD, retinopathy & hypoglycaemia may affect driving ability

NDH: Non-diabetic hyperglycemia



CVD, retinopathy & hypoglycaemia may affect driving ability

Table 3: Diabetes model boundary table

Factor	Include/ exclude	Reason for inclusion/ exclusion
Risk factors	Include	Key component of causal diagram
Gestational diabetes/ pregnancy complications	Exclude	This is a small subgroup and is not considered to be a focus of this project.
Osteoarthritis	Include	From a random sample of 3664 members of the Dutch population aged >25 years, Tukker reports that 'for each unit increase in BMI respondents were 8% more likely to report OA or chronic pain' and the Foresight report highlights the high prevalence of osteoarthritis within the UK population. In addition, the report by Gillett et al. suggests that the cost of osteoarthritis is comparable to the cost of diabetes.
Risk factors of next generation	Exclude	Within the high risk group, only a minority of people will parent a young child due to the age of the people affected, thus there would be limited impact upon the next generation. Within the general population, Whitaker et al. suggest that parental obesity more than doubles the risk of adult obesity among their children. This could bear substantial future costs and effects; however because these costs and outcomes would occur so far in the future, by applying a discount rate to both costs and effects (a method recommended by NICE, where more weight is placed on current costs and effects than those in the future), there would be minimal impact upon the model results. Thus time would be better spent on other factors within the model. See Section 5a for a brief discussion of social network effects.
Blood glucose levels/ Non-diabetic hyperglycaemia/ Diabetes	Include	Key component of causal diagram.
Hypoglycaemia & weight gain associated with pharmacological interventions	Include (but not as a separate factor)	The quality of life implications of hypoglycaemia and weight gain are likely to be captured within the quality of life of people with diabetes. There are likely to be minimal additional costs associated with hypoglycaemia and weight gain above those associated with treating the disease.
Non-alcoholic fatty liver	Include (but not as a separate factor)	This is likely to be included within the costs and quality of life estimates associated with diabetes and obesity.
Fatigue	Include (but not as a separate factor)	The quality of life implications of fatigue are likely to be captured within the quality of life of people with disease. There are likely to be minimal additional costs associated with fatigue above those associated with treating disease.
Neuropathy	Include	Key outcome associated with diabetes.
Erectile dysfunction	Include (but not as a separate factor)	This is likely to be included within the costs and quality of life impacts of neuropathy.

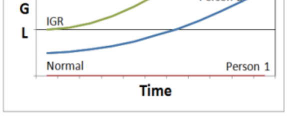
Factor	Include/ exclude	Reason for inclusion/ exclusion
Nephropathy	Include	Key outcome associated with diabetes.
Retinopathy	Include	Key outcome associated with diabetes
Cancers (post-menopausal breast cancer, colorectal cancer)	Include	The report by the World Cancer Research Fund (WCRF) Panel on Food, Nutrition, Physical Activity and the Prevention of Cancer suggests that BMI has a significant impact upon the incidence and mortality of post-menopausal breast cancer, colorectal cancer, oesophagus cancer, kidney cancer, endometrial cancer, gall bladder cancer and pancreatic cancer. It also suggests that physical activity is associated with colorectal cancer, postmenopausal breast cancer and endometrial cancer. In addition, a study by Joshu suggests a relationship between HbA1c levels and cancer incidence (particularly post-menopausal breast cancer and colorectal cancer). Prevalence of colorectal cancer and post-menopausal breast cancer within the UK population is high and they are associated with substantial impacts upon costs and quality of life. The EPIC trial also supports this.
CVD including hypertension, coronary heart disease (leading to heart attacks & angina), congestive heart failure, peripheral artery disease (incl. leg claudication & gangrene) and cerebrovascular disease (incl. stroke & dementia)	Include	Has a substantial impact upon both costs and effects.
Mental illness (incl. dementia)	Partly include (but not as a separate factor)	The relationship between mental illness and diabetes is complex and currently not completely understood. Part of the relationship is associated with the incidence of cerebrovascular disease and the impact of mental illness will be captured within these costs and outcomes. The remaining associations, such as the direct increase in mental illness as a result of being diagnosed and living with diabetes, are difficult to untangle and are expected to have a small impact upon the model outcomes relative to other model factors.
Obstructive sleep apnoea	Include (but not as a separate factor)	The relationship between risk factors and CVD is expected to capture those events resulting from obstructive sleep apnoea. The quality of life associated with people who are overweight is likely to include poorer quality of life resulting from obstructive sleep apnoea. In the instances where sleep apnoea is treated, the cost is minimal.
Infectious diseases	Exclude	Relative to other model factors, this is likely to have a smaller impact upon the model outcomes.
Environmental outcomes (congestion, CO2, pollutants)	Not currently clear	This depends upon the choice of interventions within the model (see Section 1).

Potential interventions

Affects usage of alternative intervention

*Different tests (OGTT, FPG, HbA1c) identify different individuals & diagnostic criteria have changed

graphical form for BGL to highlight consideration of time

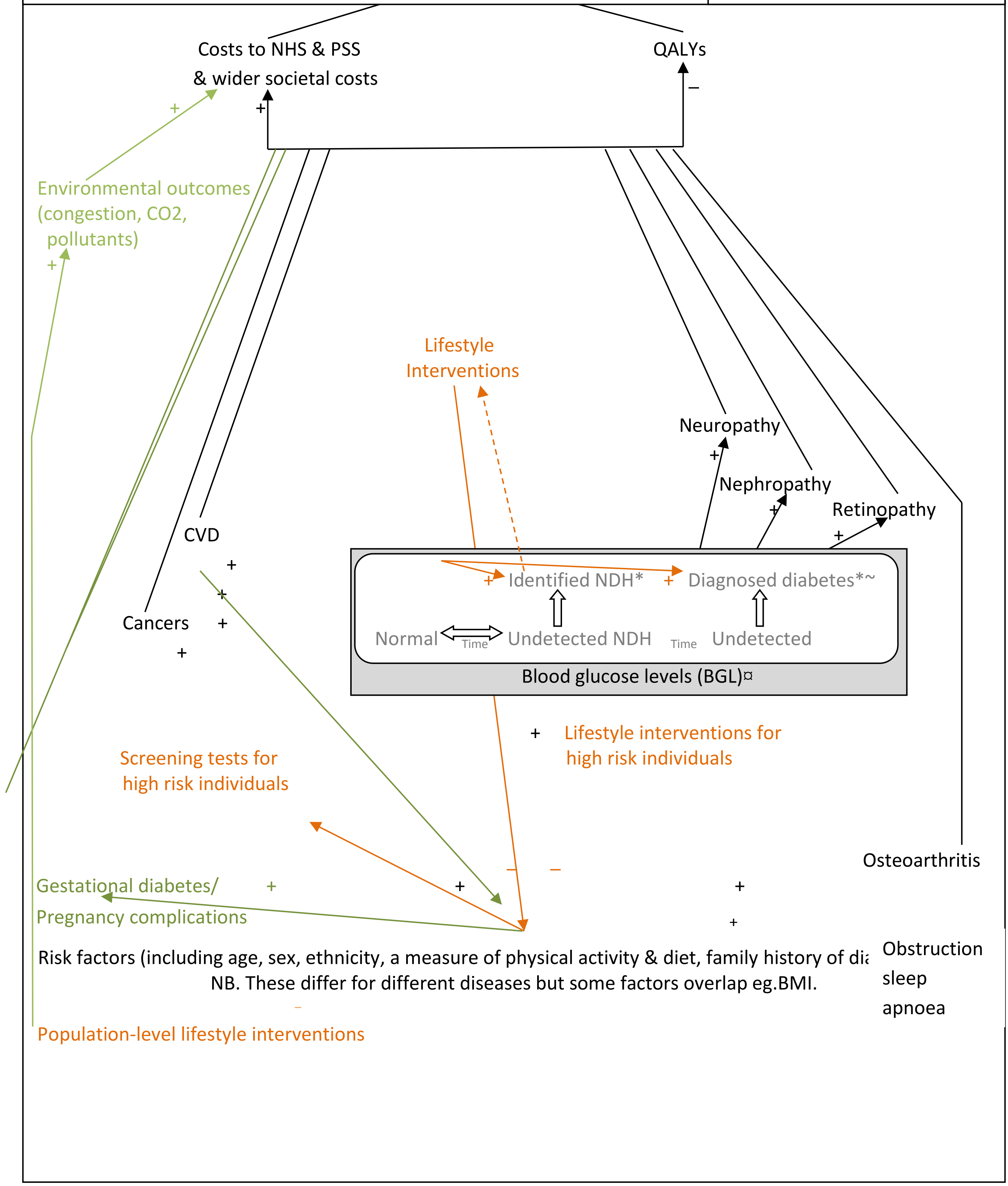


~This leads to screening for CVD & microvascular complications which will affect these outcomes. If BGL are decreased, the risk of complications may decrease even if the individual is still termed 'diabetic'.

**Risk factors may be worse in the future as lifestyles become more sedate

CVD, retinopathy may affect driving ability

NDH: Non-diabetic hyperglycemia



CVD, retinopathy & hypoglycaemia may affect driving ability

Key questions for stakeholders:

1) Are there any excluded factors which you strongly think should be included within the model?

5. Specification of key model assumptions/ simplifications

There are four types of key model assumptions/ simplifications which we need to make:

a) Extrapolation of study outcomes;
b) How interventions will be implemented (including maintenance);
c) The relationship between the factors included within Figure 2 above;
d) The costs and utilities of the factors included within Figure 2 above.

Decisions about these assumptions were facilitated by some key questions shown in Appendix 3 for the interested reader.

a) Extrapolation of study outcomes

Where long term evidence is available for the intervention (for example, the Finnish DDP) we can use that trend to extrapolate over the long term. We are currently assessing whether there is a differential impact upon outcomes between interventions from the studies we have identified with longer term follow up so that we can make assumptions about the long term effectiveness of interventions which are reported within studies with shorter term follow up.

It is possible that social networks will impact upon the effectiveness of the interventions because (a) an intervention given to an individual may also impact upon the individual's family and friends indirectly[27] and (b) an intervention given to lots of individuals that know each other, may have a greater impact than if the individuals receiving the intervention do not know each other. If the study assessing the effectiveness of interventions is carried out within the same population as the population would be in practice, then the effect of the latter would be captured within the mean estimate and the effect of the former would be largely captured. However, when extrapolating beyond the study follow up, it may be that these impacts would lead to a step change in population behaviour. We do not currently have sufficient evidence or sufficient resources within this project to be able to model these social networks over time; however we are looking into the potential of a future research project around this.

b) How interventions will be implemented

We plan to generally assume that the interventions within Table 2 will be implemented as described by the studies outlined within Table 2; however we may try to extrapolate to other subpopulations.

c) The relationship between the included factors

Baseline population

A population representing the characteristics of the overall population of England can be simulated using data from the Health Survey for England based upon the model by Gillett et al.[28] The survey includes information from a representative sample of over 15,000 adults in England around blood pressure, height, weight, BMI, waist circumference, smoking, alcohol, fruit & veg, general health, CVD, diabetes and physical activity. The 2008 survey includes additional information about diet and exercise. Within the model by Gillett et al., missing values were imputed by randomly sampling characteristics based upon all those individuals of the same age and gender. In addition, the Social Economic Grouping collected within the Health Survey for England was used as a proxy for Townsend Score.[28] We plan to follow this same approach. The prevalence of each of the diseases will be sourced from the Health Survey for England if included within this dataset; otherwise alternative sources such as the Office for National Statistics will be used to describe disease prevalence.

The relationship between the risk factors and CVD outcomes

We plan to use the QRisk2 score to estimate each individual's first CVD outcome since this risk equation was developed within a UK population and includes diabetes as a risk factor.[29] The QRisk2 score estimates an individual's 10-year risk of a CVD event based upon age, sex, ethnicity, Townsend score, smoking status, treated diabetes, family history of CVD, cholesterol, blood pressure, BMI, kidney disease, rheumatoid arthritis and atrial fibrillation. We prefer the QRisk2 score to the UKPDS risk equations because our focus within the model is those who are non-diabetic and the UKPDS risk equations were developed within a diabetic population. QRisk2 was developed within a population containing both diabetics and non-diabetics and contains a variable to denote this. However, it does not contain a variable denoting blood glucose levels. From the UKPDS dataset it has been shown that blood glucose levels affect CVD outcomes following diabetes diagnosis and we do not want to systematically bias against screening interventions over population prevention interventions. Rather than using the UKPDS equations following diabetes diagnosis which is likely to lead to inconsistencies, we plan to investigate the feasibility of using the UKPDS data to estimate a HbA1c covariate within the QRisk2 equation for the people with diabetes, adjusting for the mean diabetes HbA1c value within the QRisk2 dataset.

Key questions for stakeholders:

1) Do you think that this is reasonable?

The relationship between risk factors & microvascular complications

A review of studies assessing the relationship of blood glucose levels and microvascular complications was undertaken for the WHO consultation around the use of HbA1c in the diagnosis of diabetes.[30] This review suggests that there is a small risk of retinopathy prior to the current cut-off points for diabetes diagnosis. We have also identified evidence for retinopathy which suggests that other factors in addition to raised blood glucose levels affect the risk of the disease. The best evidence that we identified for this was a paper by Van Leiden et al. based upon the Hoorn study.[31] This describes the relative risk of retinopathy according to sex, age, diabetes status, HbA1c level and hypertension.

We have not identified any similar evidence for nephropathy and neuropathy. For nephropathy, we could either (a) use the UKPDS risk equations to estimate the risk of nephropathy and make the assumption that nephropathy does not occur until diabetes is diagnosed,[32] or (b) use the analysis by Selvin et al. (2011) which estimates hazard ratios of nephropathy according to blood glucose levels (and not other risk factors) within a combined diabetic and non-diabetic US population.[33]

Neuropathy is not included within UKPDS, although amputation is.[32] Thus, for neuropathy we could: (a) include only the risk of amputation following diabetes diagnosis from UKPDS[32]; (b) use a risk equation (including duration of diabetes, HbA1c, triclycerides, cholesterol, BMI, smoking, hypertension, albumin excretion rate) developed within a type I diabetes population from the European Diabetes (EURODIAB) Prospective Complications Study[34]; or (c) use a study by Bongaerts which assesses the association between blood glucose levels and polyneuropathy (and not other risk factors) in a German mixed diabetic and non-diabetic population.[35]

Key questions for stakeholders:

1) Which of the above do you think would be the most appropriate data sources for modelling the risk of retinopathy, nephropathy and neuropathy?

The relationship between the risk factors and cancer

A report by the World Cancer Research Fund (2007) ‘Food, nutrition, physical activity and the prevention of cancer: a global perspective’ has been identified which gives meta-analyses on each cancer in terms of a relative risk per 5kg/m^2 (I.e. BMI).[36] The EPIC trial aims to look at this, but many of the papers are too specific for our purpose. We have identified two potential papers;

Pischon (2006) and Lahmann (2004) which provide relative risks of colorectal cancer and breast cancer given different measures of body size.[37-39]

> Key questions for stakeholders:
>
> 1) Do you know of any multivariate statistical analysis which has been done relating colorectal cancer and breast cancer to weight gain from a longitudinal UK dataset?

The relationship between the risk factors and osteoarthritis

We have undertaken a literature search and identified a paper by Mork et al. which assesses the effect of BMI and physical exercise on risk of knee and hip osteoarthritis within a Norwegian population.[40]

> Key questions for stakeholders:
>
> 1) Do you know of any better evidence in this area?

Environmental outcomes

The inclusion of environmental outcomes will depend upon the interventions assessed within the model and the perspective of the analysis (see Section 6).

The relationship between the risk factors and blood glucose levels, cholesterol and blood pressure

The review of economic evaluations identified that most other models had assumed that there was a single risk factor for Type 2 diabetes (i.e. IGT or BMI).

- Most pre-diabetes models assumed a single transition rate to diabetes
    - Nine studies assumed a single transition rate to diabetes
    - Seven studies assumed differential risk for NGT, IGT, IFG, and IFT and IGT
    - One study assumed that risk varies by HbA1c score
- Models where risk was related to BMI tended to use observational cohort data to estimate baseline risk of diabetes
    - Two studies used data from trial
    - Seven studies used observational data
- Models that estimated multiple risk factors for diabetes used multivariate risk scores
    - One study assumed the metabolic syndrome increases risk
    - One study used the QDScore to estimate risk

- One study modified risk by positive risk factor score
- Two studies used a risk score that includes FPG, BMI, Systolic blood pressure and HDL

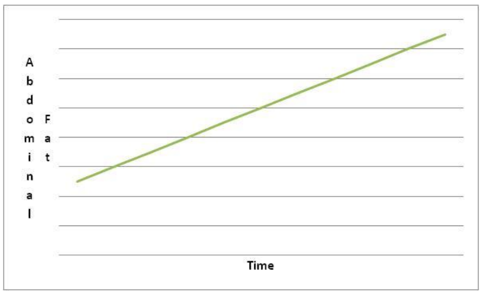
BMI, waist circumference, glucose regulation, physical activity, and diet are all risk factors associated with Type 2 diabetes. The risk factors are likely to be correlated, but may have independent and additive effects on the incidence of Type 2 diabetes. Therefore, there are benefits of using multiple risk factors to improve the accuracy of the incidence of Type 2 diabetes if the intervention affects multiple patient characteristics. Thus, we want to estimate multiple risk factors for diabetes and cardiovascular disease and describe the correlation between changes in risk factors over time.

These relationships are planned to be estimated using the Whitehall II dataset. This is a longitudinal dataset which follows a cohort of working men and women from 1985 (10,308 participants) to 2009 (6761 participants). It includes demographic information, behavioural factors, clinical measures (such as blood glucose levels, cholesterol and blood pressure) and some information about disease history. The main advantages of the Whitehall II dataset over other similar datasets are that it provides more follow up points and information on both FPG and HbA1c. This allows us to approximate, using statistical analyses, the relationship between diet and exercise and the clinical measures relating to diabetes and other related diseases over time. It is important to understand trajectories over time rather than at one point in time, because incidence of disease is dependent upon behaviours and other factors (such as age) over time rather than at one point in time. The following describes the analysis that is planned for the Whitehall II dataset.

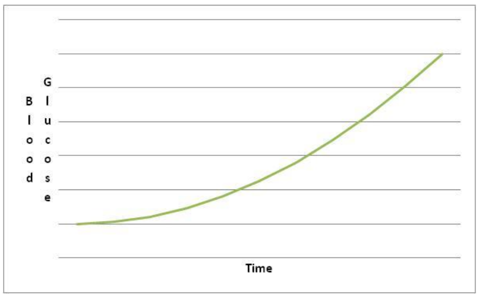
Diet and physical activity can be incorporated in terms of frequency of fruit and vegetable consumption and frequency of exercise per week respectively. Other measures of diet and physical activity may be considered depending upon the outcomes reported by the intervention studies. Soft drink consumption and fat intake have been reported as outcomes in intervention studies, and the impact of these outcomes on BMI or waist circumference may need to be estimated. These diet and exercise measures over time can be used to estimate abdominal fat over time since this has been shown to be the most appropriate measure of weight for estimating disease outcomes. BMI, waist circumference and waist to hip ratio can be used to approximate abdominal fat since abdominal fat is not measured within the Whitehall II study. Abdominal fat over time can then be used to predict blood glucose levels, blood pressure (total, systolic and diastolic) and cholesterol over time. Due to the data collected within the Whitehall II dataset, data for the OGTT will have to be used to estimate blood glucose levels. However, statistical analysis can be undertaken to relate FPG measures and

HbA1c measures to OGTT measures, incorporating some patient characteristics to allow for the fact that the different measures identify different people. Blood glucose levels, blood pressure and cholesterol over time can then be used to estimate the incidence of each of the relevant diseases (as described within the headings above). An assumption is that all trajectories are linear over time, apart from blood glucose levels which can be allowed to take alternative functions. Existing analysis of the Whitehall dataset suggests that the most appropriate function for blood glucose may be linear followed by a quadratic function as insulin resistance develops. Examples of these functions are shown below.

Linear function



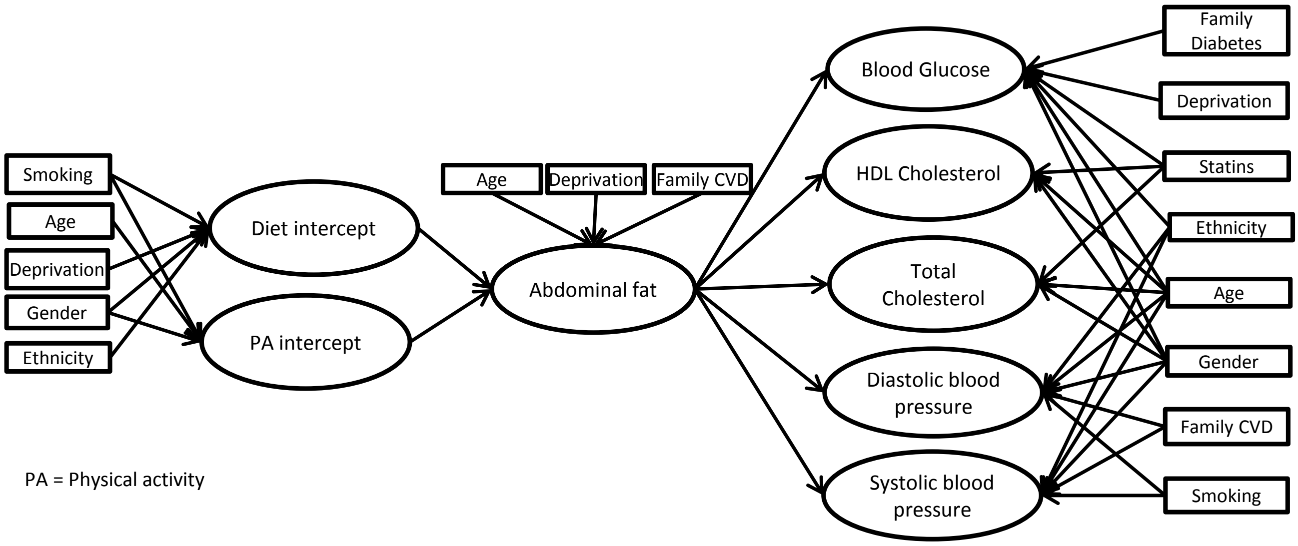
Quadratic function



After an individual has been diagnosed with CVD, treatment is likely to affect the risk factors and future risks of diabetes. To incorporate this, the use of statins can be included as a covariate. Other variables which may also affect the outcomes of interest including age, gender, ethnicity, family history of diabetes and CVD, smoker and Townsend score will be incorporated into the analysis. Whilst rheumatoid arthritis and atrial fibrillation are included within QRisk2, they have not been included as covariates within this analysis because existing evidence does not suggest that they have a direct impact upon blood glucose levels, cholesterol or blood pressure.

This analysis will allow us to estimate the causal relationships between these factors, taking into account the correlation between variables. It can also allow us to investigate differences in the relationships between subgroups and to estimate random variation between individuals. Figure 3 below illustrates the assumptions we are currently making about the pathways between risk factors, and the characteristics we are assuming affects them.

Figure 3: Assumptions about the pathways between risk factors



We assume the following relationships between covariates:

- Smoking, deprivation, gender and ethnicity directly affect diet.
- Smoking, age and gender directly affect physical activity.
- Diet, physical activity, age, deprivation and a family history of cardiovascular disease directly affect abdominal fat.
- Abdominal fat, family history of diabetes, deprivation, statins, ethnicity, age and gender directly affect blood glucose.
- Abdominal fat, statins, age, and gender directly affect HDL cholesterol.
- Abdominal fat, statins, age, and gender directly affect Total cholesterol.
- Abdominal fat, ethnicity, age, gender, family history of cardiovascular disease and smoking directly affect diastolic blood pressure.
- Abdominal fat, ethnicity, age, gender, family history of cardiovascular disease and smoking directly affect systolic blood pressure.

Key questions for stakeholders:

1) Do you have any concerns about using the Whitehall dataset for this analysis?
2) Do you disagree with any of the links we have made, and can you identify important predictors that we have missed?
3) Do you agree that abdominal fat is the best predictor of disease outcomes?
4) Should there be a direct link between physical activity or diet and blood glucose, cholesterol and/or blood pressure? I.e. would an increase in physical activity without a loss in abdominal fat reduce blood glucose levels/ cholesterol/ blood pressure? If so, if effectiveness studies report only weight change impacts, we would have to make assumptions about the extent to which these were affected by diet and exercise.
5) We have currently assumed that blood glucose, cholesterol and blood pressure are correlated through a common causal link with abdominal fat. Should blood pressure or cholesterol directly predict blood glucose?
6) Is it reasonable to assume that the blood pressure of an individual increases over time? Do you know of any evidence for this? Can you draw the shape of the change over time?
7) Is it reasonable to assume that the cholesterol of an individual increases over time? Do you know of any evidence for this? Can you draw the shape of the change over time?
8) FPG and HbA1c tests may identify different individuals; do you know of any key characteristics of the individual that are more likely to lead to being identified with one test than the other?

6. Model perspectives & outcomes

Following the discussion from Stakeholder Workshop 1, the suggested model perspectives and outcomes are listed in Table 4 below. The model perspective is what types of costs and outcomes should be included.

Table 4: Proposed model perspectives and outcomes

	NHS & Personal Social Services (PSS) perspective	**Employer perspective** *(given the number of workplace-based interventions)*	**Societal perspective**
The cost of…	The intervention and its delivery to the NHS and PSS	The intervention and its delivery to the employer	All costs of the intervention and its delivery (including to the patient*)
	Diagnosis, treatment and follow up of the relevant diseases (for each disease) to the NHS and PSS		Diagnosis, treatment and follow up of the relevant diseases (for each disease) to the NHS and PSS and patients and carers (including travel costs)
		Lost productivity	Lost productivity
			Lost leisure time
Outcomes	Life years (LY) of the patient		Life years (LY) of the patient
	Quality-adjusted life years (QALYs) of the patient and carers		Quality-adjusted life years (QALYs) of the patient and carers
	Incremental cost per LY gained		Incremental cost per LY gained
	Incremental cost per QALY gained		Incremental cost per QALY gained
			Environmental outcomes (if necessary)

*Patients who are diagnosed with chronic diseases get free prescriptions.

If transport interventions are included, we could also include transport-related outcomes including the value of deaths avoided using the statistical value of a life approach, as undertaken by Brennan et al. for their analysis developed for NICE for interventions to promote Walking and Cycling.[41]

Key questions for stakeholders:

1) Are there any outcomes/ cost savings which you think it would be useful for the model to report that are not included above? For example, would it be useful to estimate the budget impact of the interventions?
2) Should we maximise net benefit or should we be weighting equity in some way?

7. The costs and utilities of the factors included within Figure 2

We want to capture the life years, costs and quality of life associated with each of the diagnosed diseases within the model.

What are utility scores? A health utility score is used to reflect the quality of life associated with each health state within the model. It is a value which typically lies between 0 and 1, where 0 reflects a health state equivalent to death and 1 denotes a health state equivalent to full health.[42] Each health state within the model is assigned a utility score and these are weighted over the time frame of the model according to time in each state to produce total quality-adjusted life years (QALYs) associated with each intervention.

We do not plan to build into the model the flexibility to assess the cost-effectiveness of interventions given to patients once they have a disease. This means that we do not need to develop a formal natural history model for each disease; we can estimate when the person will die according to the probability of death from that disease given the age of diagnosis, and then calculate the costs and utilities associated with the time they are alive. This can be done by applying a cost per year from onset of disease (which could be constant or change over time) and a utility associated with the disease for each year that the person is alive. Whilst the time of death can vary by person according to the probability of death, these costs and utilities will be averages rather than varying by person. We have already estimated some relevant costs and utilities within previous ScHARR models and these will be described where appropriate for you to consider whether they are still valid. As for the model by Gillett et al., utility values for the baseline population who do not have a chronic disease can be obtained from the EQ5D scores within the Health Survey for England dataset.[28] The effect of weight on utility, estimated from the Health Survey for England dataset, is a decrement of 0.005 per unit increase in BMI.[28] Alternatively, there is also a paper by Maheswaran et al. which estimates EQ-5D utility values according to behavioural risk factors including BMI.[43]

<u>Costs and utilities associated with diabetes</u>

We plan to assume that the probability of dying does not increase due to a diagnosis of diabetes *per se* (it would be due to the increase in related diseases).

The resource use of antihyperglycaemic medication and annual monitoring for diabetes as described by Gillett et al. are shown in Table 5 and Table 6 below.[28] In order to estimate switching between therapies, the effectiveness of antihyperglycaemic medication will be based upon UKPDS33 as reported by Gillet et al.[44] For patients treated with chlorpromamide and glibenclamide, this study shows an initial drop in HbA1c followed by a linear increase of around 0.2% until patients receive insulin. We plan to assume that this pattern is the same for all therapies. Once patients are on insulin, Gillet et al. assume that HbA1c remains between 8% and 9%.

Table 5: Resource use associated with antihyperglycaemic medication

Therapy	Dose
Metformin	Three 500mg or 850mg per day
Sulphonylurea (gliclazide)	Average 210mg per day [45]
Sulphonylurea (gliclazide MR)	Assumed equivalent of 210mg gliclazide (30mg of MR formulation is approximately equal to 80mg of non-MR formulation as per BNF[46])
Sulphonylurea	Based on use of non-MR and MR formulations of gliclazide in ratio 8:1)
Insulin	The cost of glargine is considered to be a reasonable estimate of the average cost of insulins currently used for Type 2 diabetes in the UK. 60 units per day. Dose is variable according to year since initiation of insulin.

Table 6: Annual resource requirements for monitoring patients with Type 2 diabetes

Resource	Annual number of visits
Nurse at GP (to check HbA1c & proteinuria, pulse check, feet, flu jab)	2
GP clinic	2
Dietitian	0.5
HbA1c test	2
Eye screening	1

Uptake of annual monitoring following diabetes diagnosis can be based upon the National Diabetes Audit 2010-2011.[47]

The utility associated with complication-free diabetes is assumed to be the same as a person within the general population (age-adjusted) with a decrement of 0.005 per unit increase in BMI as described above.

Key questions for stakeholders:

1) What is current practice for providing pharmaceutical interventions for diabetes?
2) Do the above assumptions seem reasonable?

The costs and utilities associated with CVD events

Based upon Gillett et al., CVD events can be divided into coronary and stroke events using the dataset underpinning the QRisk2 score based upon gender. This can be further subdivided into stable angina, unstable angina, non-fatal myocardial infarction (MI), fatal MI, transcient ischaemic attack (TIA), non-fatal stroke or fatal stroke according to gender and age using a HTA assessment of statin therapy.[48] This is shown in Table 7 below.

Table 7: Probability of experiencing each CVD event

	Age	Stable angina	Unstable angina	MI rate	Fatal CHD	TIA	Stroke	Fatal CVD
Men	45	28.7%	10.0%	27.6%	6.6%	7.4%	15.9%	3.7%
	55	36.4%	7.9%	19.1%	9.6%	7.0%	16.2%	3.8%
	65	27.6%	10.7%	22.3%	12.5%	6.2%	16.8%	3.9%
	75	28.1%	11.9%	23.7%	9.3%	4.3%	18.4%	4.3%
	85	28.4%	12.7%	24.6%	7.3%	1.0%	21.1%	4.9%
Women	45	37.8%	13.6%	9.3%	4.3%	12.6%	18.1%	4.3%
	55	40.9%	8.6%	10.9%	4.6%	7.4%	22.4%	5.2%
	65	28.8%	7.4%	17.2%	11.5%	4.7%	24.5%	5.8%
	75	29.5%	6.7%	20.2%	8.5%	5.1%	24.2%	5.7%
	85	30.0%	6.4%	22.0%	6.6%	4.3%	24.9%	5.8%
Range for each CVD event		27.6%-40.9%	6.4%-13.6%	9.3%-27.6%	4.3%-12.5%	1.0%-12.6%	15.9%-24.9%	3.7%-5.8%

Secondary CVD events and the probability of death from these different types of CVD event by age can be based upon the HTA assessment of statin therapy.[48] We plan to assume that following the first CVD event, any interventions employed to prevent diabetes do not reduce secondary CVD events since we have no evidence on this.

The costs and utility impacts of CVD have been estimated in a previous HTA of Statins in cardiovascular disease.[48] These parameters are shown in Table 8 below. The costs can be uplifted to 2012 estimates.

Table 8: Costs and utilities for CVD events

CVD event	1st year cost	Subsequent cost	Fatality cost	Disutility
Stable Angina	£171	£171		0.808
Unstable Angina	£440	£171		0.77
MI	£4448	£171	£1166	0.76
TIA	£1064	£264		1
Stroke	£8046	£2163	£7041	0.629

Key questions for stakeholders:

1) Does the division of CVD events shown in Table 7 seem reasonable? Is the exclusion of peripheral arterial disease likely to be important?
2) Has treatment for CVD altered substantially since the above costs were estimated in 2007? If so, in what way?

<u>The costs and utilities associated with microvascular complications, cancer and osteoarthritis</u>

The review of existing economic evaluations suggested that those studies which included microvascular complications, colorectal cancer, breast cancer, and/ or osteoarthritis were generally non-transparent in terms of the costs and utilities that they employed. Thus, these will need to be established from other sources.

Retinopathy and neuropathy are not expected to substantial impact upon survival. Survival associated with nephropathy can be estimated based upon UKPDS64.[49] We propose using annual costs of treatment for microvascular disease based upon UKPDS65.[50] Utilities are assumed to be the same as those used within the model by Gillett et al. which were based upon UKPDS62, Coffey et al and data supplied from the Mount Hood IV conference.[51;52]

The survival of colorectal and breast cancer patients can be based upon data from the Office for National Statistics, which describes relative survival rates. Colorectal cancer costs and utilities can be based upon an economic model currently being developed within ScHARR for early awareness interventions for colorectal cancer. Breast cancer costs can be based upon the total programme budgeting estimates by the Department of Health for the years 2011-12 and the prevalence of breast cancer. Breast cancer utility estimates can be based upon an existing economic model for breast cancer screening recently developed within ScHARR.

Osteoarthritis is not expected to substantial impact upon survival compared with the general population. We plan to assume that the costs of osteoarthritis are mostly due to replacement surgery. We have estimated the cost of Hip and Knee surgery from NHS reference costs and identified UK studies of the lifetime risk of Hip and Knee replacement surgery. From this we have estimated the expected cost of Hip and Knee osteoarthritis assuming a single surgical procedure. The utility associated with osteoarthritis is reported in a HTA report for glucosamine in knee osteoarthritis. These are shown in Table 9.

Table 9: Cost and utility assumptions for osteoarthritis

Parameter	Hip	Knee	Source
Lifetime risk of Osteoarthritis	0.25	0.45	Culliford 2012
Lifetime risk of surgery women	0.11	0.11	Culliford 2012
Lifetime risk of surgery men	0.07	0.08	Culliford 2012
Lifetime risk of surgery	0.09	0.09	Imputed
Proportion of osteoarthritis with surgery	0.35	0.20	Imputed
NHS weighted average cost of surgery	6420.63	4802.13	NHS reference costs 2011
Total cost of osteoarthritis		**3249.34**	
Osteoarthritis utility		**0.69**	HTA: The clinical effectiveness of glucosamine and chondroitin supplements in slowing or arresting progression of osteoarthritis of the knee: a systematic review and economic evaluation (2009)

Other costs and utilities

Cost of the intervention

This will be calculated based upon the description of the interventions within the effectiveness studies. Sources such as NHS Reference Costs and Unit Costs of Health and Social Care will be used for unit healthcare costs.

Cost of productivity loss – if societal perspective taken

We plan to assume that this is equivalent to the average salary in England and Wales. A friction cost approach is planned which assumes that there are a sufficient number of unemployed members of society making it possible to replace a sick worker after a certain period of time to allow for the advertising and recruitment period, the 'friction period'.[42] Costs would be included for advertising and recruiting new workers, and for the salary of the new worker following the friction period. The cost of the employer's national insurance contributions which must be paid on top of the employee's salary would also been included. It would be assumed that the productivity and salary of the new employee would be the same as that of the person who they have replaced.

Costs of lost leisure time- if societal perspective taken

The cost of lost leisure time can be valued from zero to average overtime earnings. This could include the lost leisure time of carers and the lost leisure time of patients whilst undertaking the interventions (eg. physical activity). Utilities associated with carers can also be considered.

Other quality of life considerations

For patients experiencing more than one disease at a time, utilities can be multiplied, as recommended by the NICE Decision Support Unit.[53] We also plan to undertake some analysis of the EQ-5D data collected within the Whitehall II study and compare this with the above utilities.

Standard methodological assumptions

General mortality will be modelled using standard life tables, adjusted for the diseases included within the model.

Costs and utilities will be discounted at 1.5% as recommended by the NICE Public Health methods guide.[54] A discount rate of 3.5% will also be tested within sensitivity analysis.

Key questions for stakeholders:

1) For microvascular complications, are treatments likely to have changed substantially since the UKPDS resource use was estimated?
2) Do you know of any evidence around the average number of days spent with sickness absence from work per person with each disease?
3) Do the above assumptions and data sources seem reasonable?

Reference List

(1) Johnson M, Everson-Hock E, Jones R, Buckley Woods H, Goyder E, Chilcott J et al. Preventing the progression of pre-diabetes to type 2 diabetes in adults. Identification and risk assessment of adults with pre-diabetes. 2011.
Ref Type: Report

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Appendix D6: Outcomes of Stakeholder Workshop 2

Session 1: Interventions

The discussion within the workshop suggested that given the current rate of change in this area it is important that the model is flexible and not fixed within a static environment because it is likely to become outdated very quickly. It also suggested that the choice of interventions should not be limited by the evidence available. The NHS Health Checks should be incorporated into the model, but should be considered for possible disinvestment. The group suggested that we construct a set of interventions based on a stratification of intervention intensity and population risk. The spectrum of intervention types discussed were taxation, community education, agricultural policy, food retailer interventions, physical activity for transport, workplace interventions and risk assessment. Given the constraints of the project we need to limit the interventions included within the final model and based upon the discussion within the workshop we have attempted to select a subset of interventions for inclusion in the model. Table 1 reports the intervention types we have selected for inclusion and exclusion.

At the national level we opted to use a taxation policy. We have identified evidence for the effectiveness of the intervention and can use modelling studies to estimate the price elasticity of taxable products. A concern has been raised around considering taxation due to (i) the possibility of consumption of poor alternatives and (ii) implementation issues given the power of the food industry. We will attempt to address the former by using evidence which reports alternative consumption and including this within the model. For the latter, we will make sure that when assessing the impact of combinations of interventions, taxation is excluded within some of these analyses. We chose not to include agricultural policy at this point in the project. This is mainly due to the absence of evidence and the complexity of the systems relating policy to individual consumption. However, we are doing some work around the possibility of incorporation into the model in the future.

At the community level we have included workplace interventions, local transport policy, retailer policy and community education programmes.

At the individual level we plan to consider three targeted groups: (1) those identified as high-risk through a risk assessment and blood test strategy; (2) women with gestational diabetes; and (3) ethnic groups. Of the other targeted groups identified in the stakeholder meeting we have opted to exclude children (and other primordial prevention rather than primary prevention), due to the added complexity of modelling a life course, particularly as disease progression is currently based on the Whitehall cohort. We will note this as an area for further research within the model report. Jobseekers and attendees at food banks will not be included in the primary analysis since the workshop discussion suggested that, whilst these groups are important, the three groups above should be prioritised. However, the model will be sufficiently flexible to enable these to be explored in the future without requiring many changes to the model.

Table 1: Types of interventions considered for inclusion in the model

Intervention Coverage	Selected for Inclusion	Selected for Exclusion
General Population (Indiscriminate National Policy)	Taxation	Agricultural Policy
Communities	Workplace	
	Transport Policy	
	Retailer policy	
	Community education programme	
High-risk individuals*	Non-diabetic hyperglycaemic (including exploring frequency of repeat tests)	Children/ early years
	Gestational diabetes	Jobseekers
	Ethnicity	Food banks

*These will be interventions that are feasible within the real world (translational)

Within the intervention types listed in Table 1 there are a large number of interventions that could be implemented. We have described specific interventions in Table 2 for each of these intervention types. We have selected specific interventions from the studies that we listed in the discussion document, but have not limited our selection of interventions to those that were identified within the search for evidence.

For our taxation policy we plan to focus on the taxation of soft drinks.[1] An alternative study has assessed the effects of taxation and snacks, but the substitution effects of switching away from multiple products may be complex to estimate. For the workplace intervention, we propose focusing on environmental changes, rather than health checks or education programmes.[2] This will ensure that a broad range of intervention types are considered, rather than implementing similar interventions in different sub-groups of the population. The transport policy intervention will reflect the sustainable travel towns programme, which included walking and cycling promotion, public transport promotion, cycle lanes, and car-sharing programmes.[3] For the retailer policy, we plan to model opening a large supermarket in a deprived area to improve access to fruit and vegetables, rather than focusing on within store merchandising of healthy foods. We have identified studies from three community education programmes including promoting weight management in men from deprived areas, health promotion in ethnically diverse urban areas, and increasing fruit and vegetable consumption in deprived areas.[4-6]

The high risk identification strategy targeting non-diabetic hyperglycaemia will be a translation programme which would be feasible in practice. We plan to consider use of a study by Costa et al. and the 'New Life, New You' intervention for modelling this as suggested by stakeholders.[7-9] Identification of individuals is likely to be based upon the NHS Health Checks; however this will be flexible within the model to allow for variations to this. We have not identified a specific intervention for gestational diabetes but we will conduct searches for this. The intervention may be aimed at women who have gestational diabetes who are pregnant or those that have previously been pregnant with gestational diabetes, depending upon the evidence identified. The Wein study and the MAGDA trail have been highlighted for consideration for this. We plan to base the intervention targeting ethnic groups on the PADOSA trial in South Asian groups. It is noted that other ethnic groups, such as African, have an elevated risk, but there is a lack of intervention evidence.

We have tried to describe within column 2 of Table 2 a manageable number of interventions to assess within the model, which cover the key interventions and subpopulations which were discussed and prioritised within the workshop.

Table 2: Specific details of intervention programmes

Intervention type	Details of programmes to be assessed	Other programmes discussed that we have excluded
Taxation	Soft drinks	Soft drinks and snacks Taxing fat content Alcohol pricing
Workplace	Environmental changes	Health checks, education programmes
Transport Policy	Sustainable towns	Pedometer walking
Retailer policy	Access to fruit and veg	Merchandising within store
Community education programme	Group sessions	
Non-diabetic hyperglycaemic	Translational study	Efficacy study which is not feasible in practice
Gestational diabetes	To be identified	Gestational diabetes prevention
Ethnicity	PODOSA trial (South Asians)	Other ethnic groups

We will take into account the uncertainty around the outcomes within these studies that are self-reported. We will also undertake further work around possible approaches for modelling the maintenance profile of the interventions. The model will aim to be sufficiently flexible to allow assessment of the majority of the excluded interventions without substantial adaptation requirements of the model within future work.

Intervention combinations and interactions

We plan within the model to assess combinations of the above interventions, which is likely to include an intervention from each risk level (population, community and individual). This means that some individuals will be exposed to more than one intervention particularly if a soft drinks taxation is employed. Within the workshop we discussed the potentially interactive effects of a person receiving more than one intervention and the lack of evidence for quantifying these impacts. Therefore, we plan to construct the model structure so that it is possible to include these synergistic effects. However, it may be that refining these model parameters will require future work. One study by Salopuro et al. for facilitating this has been suggested which will be considered.

Session 2: Model boundary

This table has been updated to reflect the discussion within the workshop.

Factor	Include/ exclude	Reason for inclusion/ exclusion
Risk factors	Include	Key component of causal diagram
Gestational diabetes	Include	As a subgroup of the population who will be given intervention
Osteoarthritis	Include	From a random sample of 3664 members of the Dutch population aged >25 years, Tukker reports that 'for each unit increase in BMI respondents were 8% more likely to report OA or chronic pain' and the Foresight report highlights the high prevalence of osteoarthritis within the UK population. In addition, the report by Gillett et al. suggests that the cost of osteoarthritis is comparable to the cost of diabetes.
Risk factors of next generation	Exclude	Within the high risk group, only a minority of people will parent a young child due to the age of the people affected, thus there would be limited impact upon the next generation. Within the general population, Whitaker et al. suggest that parental obesity more than doubles the risk of adult obesity among their children. This could bear substantial future costs and effects; however because these costs and outcomes would occur so far in the future, by applying a discount rate to both costs and effects (a method recommended by NICE, where more weight is placed on current costs and effects than those in the future), there would be minimal impact upon the model results. Thus time would be better spent on other factors within the model. See Section 5a for a brief discussion of social network effects.
Blood glucose levels/ Non-diabetic hyperglycaemia/ Diabetes	Include	Key component of causal diagram.
Hypoglycaemia & weight gain associated with pharmacological interventions	Include (but not as a separate factor)	The quality of life implications of hypoglycaemia and weight gain are likely to be captured within the quality of life of people with diabetes. The costs of hypoglycaemia will be explicitly included within the cost of diabetes treatment.
Non-alcoholic fatty liver	Exclude as a seperate factor	This is likely to be implicitly included within the costs and quality of life estimates associated with diabetes and obesity.
Fatigue	Exclude as a separate factor	The quality of life implications of fatigue are likely to be captured within the quality of life of people with disease. Quality of life is planned to be based upon the EQ-5D which considers mobility, self care, usual activities, pain/ discomfort and anxiety/ depression. There are likely to be minimal additional costs associated with fatigue above those associated with treating disease.
Nephropathy	Include	Key outcome associated with diabetes.

Factor	Include/ exclude	Reason for inclusion/ exclusion
Retinopathy	Include	Key outcome associated with diabetes
Neuropathy	Include	Key outcome associated with diabetes.
Erectile dysfunction	Include (but not as a separate factor)	This is likely to be included within the costs and quality of life impacts of neuropathy.
Cancers (post-menopausal breast cancer, colorectal cancer)	Include	The report by the World Cancer Research Fund (WCRF) Panel on Food, Nutrition, Physical Activity and the Prevention of Cancer suggests that BMI has a significant impact upon the incidence and mortality of post-menopausal breast cancer, colorectal cancer, oesophagus cancer, kidney cancer, endometrial cancer, gall bladder cancer and pancreatic cancer. It also suggests that physical activity is associated with colorectal cancer, postmenopausal breast cancer and endometrial cancer. Prevalence of colorectal cancer and post-menopausal breast cancer within the UK population is high and they are associated with substantial impacts upon costs and quality of life. The EPIC trial also supports this.
CVD	Include	Has a substantial impact upon both costs and effects. This includes hypertension, coronary heart disease (leading to heart attacks & angina), congestive heart failure, peripheral artery disease (incl. leg claudication & gangrene) and cerebrovascular disease (incl. stroke & dementia).
Mental illness (incl. dementia)	Include	The relationship between mental illness and diabetes is complex and currently not completely understood. However, stakeholders have suggested that this is an important factor to include and evidence suggests that approx. 18-28% of diabetics have depression (Egede 2005), which is substantially higher than within the general population.
Obstructive sleep apnoea	Exclude as a seperate factor	The relationship between risk factors and CVD is expected to capture those events resulting from obstructive sleep apnoea. The quality of life associated with people who are overweight is likely to include poorer quality of life resulting from obstructive sleep apnoea. In the instances where sleep apnoea is treated, the cost is minimal.
Infectious diseases	Exclude	Relative to other model factors, this is likely to have a smaller impact upon the model outcomes.
Environmental outcomes (congestion, CO2, pollutants)	Exclude	The majority of the interventions considered would not substantially affect this outcome so we will focus upon the health-related outcomes.

Session 3: Predicting risk factors

We plan to speak with Irene Stretton regarding the choice of retinopathy risk models, and Andre Boulton and Soloman Tesafaye regarding neuropathy. We propose waiting to receive details of the updated UKPDS risk models before doing this so that this can be considered within the potential options.

From the stakeholder workshop an additional study from the United States was identified regarding the relationship between BMI and several cancers.[10] We plan to continue to model breast cancer and colorectal cancer only, but we will consider including the evidence from this study.

We proposed to relate osteoarthritis events to BMI and diabetes, due to the identification of a study which found an independent effect of diabetes in addition to BMI on the risk of osteoarthritis.[11] The feedback from the stakeholder workshop was that the independent effect is plausible and will be included in the model.

Stakeholders have suggested that there may be different relationships between the risk factors and the different types of CVD (eg. hypertension is more of a risk factor for stroke). Given current evidence it is unlikely that these differential effects will be fully taken into account within the model; however we will consider whether there is sufficient evidence to divide the different types of CVD by BMI, age and sex and we will highlight this issue within the report.

Based upon stakeholder feedback, we have decided to include depression explicitly within the model. We propose:

1) To use the HSE data to assign depression in the general population at baseline. The 2010 HSE asked respondents to report anxiety or depression.
2) To assume that depression develops in a proportion of patients without a history of depression on diagnosis of diabetes and/or CVD. We will estimate the prevalence of depression from published studies such as Egede 2005 and adjust them downwards to account for overlap in CVD and diabetes patients.
3) To estimate the additional healthcare costs of depression and utility decrement associated with depression and apply this to diabetics and non-diabetics in the model.

What will not be accounted for:

- We will not assume variation in the severity of depression;
- Following a diagnosis of diabetes, onset of depression will not be associated with demographic factors such as age, gender or socioeconomic status;
- Treatment effect will not be affected by depression, although uptake can be adjusted;
- Mortality will not be affected by depression.

What may be added in the future:

- We will investigate whether it will be appropriate to assume poor blood glucose control in diabetic patients with depression.
- We will investigate whether previous research has identified important risk factors for depression in diabetes and CVD.

Session 4: Risk factors analysis plan

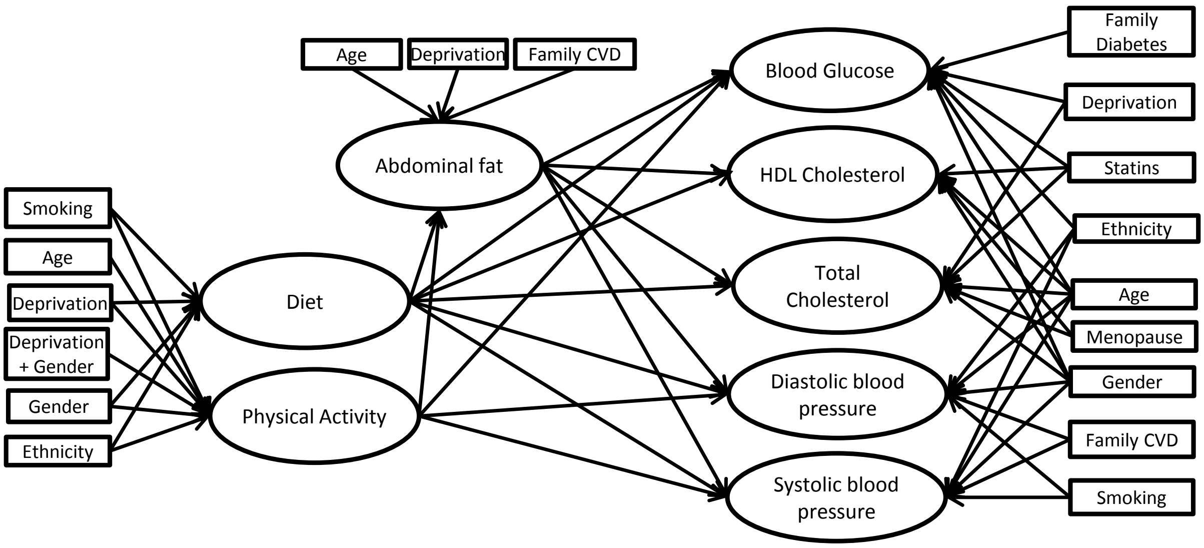
Whitehall Cohort

The discussion within the workshop suggested that the rationale for adopting the Whitehall cohort is acceptable, but more could be done to investigate the limitations of the dataset. The dataset will not be representative of women, unemployed and those living in the north of England. It would be beneficial if the model could be validated in a similar external dataset. We should note that the Whitehall cohort used the OGTT test so will have identified more cases of OGTT defined diabetes than would be identified in practice using the HbA1c test.

The revised diagram for the planned statistical analysis is presented below in Figure 1. The following changes have been made:

- Ethnicity has been linked to Physical Activity
- Deprivation has been linked to Physical Activity with an interaction term with gender to account for manual labour jobs.
- Diet and physical activity have been directly linked to the other risk factors except physical activity with cholesterol.
- Menopause has been linked to cholesterol
- Deprivation has been linked to total cholesterol.

Figure 1: Conceptual map for risk factor analysis plan



Abdominal fat

It is appropriate to include multiple measures for abdominal fat because there are limitations to all of the measures. Changes in waist circumference are often observed before changes in BMI, particularly if exercise increases the muscle mass. Waist-height ratio has also found to be a useful measure of obesity and the data are available in the dataset.

There was a discussion about the face validity of using abdominal fat since this is never measured in practice, and it will be important in the final report to explain clearly the advantages of using abdominal fat as a latent variable.

Physical Activity and Diet

Different types of changes in diet will have different impacts on the risk factors. For example salt intake will affect blood pressure more than a Mediterranean diet. We also know from the Finnish DPS data that different components (fibre, fat, saturated fat) have independent associations with diabetes incidence (over and above overall weight loss). Alcohol intake may also affect the risk factors. We will consider whether it is feasible (in terms of the evidence and time available) to model diet in terms of these different components rather than as a single variable.

It was highlighted that physical activity may also be associated with weight loss maintenance. We plan to review the literature around weight loss maintenance associated with the interventions.

Other covariates

Only statins were included in the model to describe the increased risk of diabetes. However, other treatment was identified in the discussions that are related to increased risk of diabetes. Beta-blockers and thiazides, oral steroids (not eye-drop steroids) and anti-psychotic drugs could be extracted from the data where possible. Ace-inhibitors do not increase the risk of diabetes, so do not need to be included. However, it was also noted that including these treatments might be making the model overly complex, given that they will have a much smaller impact compared with other covariates. For example, obesity massively outweighs all other variables apart from age. Therefore, given the additional work required to incorporate this, we anticipate that we will not include other treatments as covariates for blood glucose.

The group suggested that there may be interactions between changes in behavioural variables; for example diet and smoking may be linked. This is likely to be a minimal effect compared with some of the other considerations within the model and there is limited evidence around this so we will note this, but are unlikely to include the effect within the model.

Longitudinal trajectories

There is unlikely to be a gradient in Total Cholesterol and HDL cholesterol, however cholesterol may rise after menopause. This can be incorporated into the analysis. There is a paper titled ‘Life course trajectories of systolic blood pressure using longitudinal data from 8 UK cohorts’ by Wills et al. which could be used to understand the trajectory of blood pressure over time.[12]

Session 5: Perspectives, outcomes and equity

The following is compiled from the original discussion document with amendments arising from workshop discussion.

Model perspectives:

- Societal perspective
- Public service perspective (NHS & Personal Social Services (PSS), education, leisure etc)
- Interventions in the public health system will impact on, involve and be subject to different providers from the public, private and voluntary sectors. Outcomes (costs, benefits etc) should be identifiable by group.

Outcomes:

- Costs, including the costs where feasible of:
  - the intervention and its delivery to the public sector (NHS, PSS , other)
  - the intervention and its delivery to the private and voluntary sector agencies (eg including employers for workplace interventions,
  - diagnosis, treatment and follow up of the relevant diseases to the NHS and PSS,
  - diagnosis, treatment and follow up of the relevant diseases to the patients and carers,
  - lost productivity,
  - lost leisure time.
- Life years (LY) of the patient and carers
- Quality-adjusted life years (QALYs) of the patient and carers
- Incremental cost per LY gained
- Incremental cost per QALY gained

In addition to or expanding on the above stakeholders identified the Public Health Outcomes Framework as being an important set of indicators for agencies in the public health system. Table 3 presents the full indicator set and highlights those outcomes that may be relevant for the diabetes prevention model (light yellow indicates those outcomes which may be considered to be relevant to the scope of the model but that we are not currently planning to include).

Where there is uncertainty around who pays for the intervention (NHS, workplace, individual), a sensitivity analysis can be undertaken to assess the impacts of alternative options.

Table 3: Public Health Outcomes Framework

VISION
To improve and protect the nation's health and wellbeing, and improve the health of the poorest fastest.
Outcome measures
Outcome 1: Increased healthy life expectancy, ie taking account of the health quality as well as the length of life.
Outcome 2: Reduced differences in life expectancy and healthy life expectancy between communities (through greater improvements in more disadvantaged communities).

1. IMPROVING THE WIDER DETERMINANTS OF HEALTH
Objective
Improvements against wider factors that affect health and wellbeing and health inequalities Indicators
Indicators
• Children in poverty
• School readiness (Placeholder)
• Pupil absence
• First time entrants to the youth justice system
• 16-18 year olds not in education, employment or training
• People with mental illness or disability in settled accommodation
• People in prison who have a mental illness or significant mental illness (Placeholder)
• Employment for those with a long-term health condition including those with a learning difficulty/disability or mental illness
• Sickness absence rate
• Killed or seriously injured casualties on England's roads
• Domestic abuse (Placeholder)
• Violent crime (including sexual violence) (Placeholder)
• Re-offending
• The percentage of the population affected by noise (Placeholder)
• Statutory homelessness
• Utilisation of green space for exercise/health reasons
• Fuel poverty
• Social connectedness (Placeholder)
• Older people's perception of community safety (Placeholder)

2. HEALTH IMPROVEMENT
Objective
People are helped to live healthy lifestyles, make healthy choices and reduce health inequalities
Indicators
• Low birth weight of term babies
• Breastfeeding
• Smoking status at time of delivery
• Under 18 conceptions
• Child development at 2-2.5 years (Placeholder)
• Excess weight in 4-5 and 10-11 year olds
• Hospital admissions caused by unintentional and deliberate injuries in under 18s
• Emotional wellbeing of looked-after children (Placeholder)
• Smoking prevalence – 15 year olds (Placeholder)
• Hospital admissions as a result of self-harm
• Diet (Placeholder)
• Excess weight in adults
• Proportion of physically active and inactive adults
• Smoking prevalence – adult (over 18s)
• Successful completion of drug treatment
• People entering prison with substance dependence issues who are previously not known to community treatment
• Recorded diabetes
• Alcohol-related admissions to hospital
• Cancer diagnosed at stage 1 and 2 (Placeholder)
• Cancer screening coverage
• Access to non-cancer screening programmes
• Take up of the NHS Health Check Programme – by those eligible
• Self-reported wellbeing
• Falls and injuries in the over 65s

3. HEALTH PROTECTION
Objective
The population's health is protected from major incidents and other threats, while reducing health inequalities
Indicators
• Air pollution
• Chlamydia diagnoses (15-24 year olds)
• Population vaccination coverage
• People presenting with HIV at a late stage of infection
• Treatment completion for tuberculosis
• Public sector organisations with board-approved sustainable development management plans
• Comprehensive, agreed inter-agency plans for responding to public health incidents (Placeholder)

4. HEALTHCARE PUBLIC HEALTH AND PREVENTING PREMATURE MORTALITY
Objective
Reduced numbers of people living with preventable ill health and people dying prematurely, while reducing the
gap between communities
Indicators
• Infant mortality
• Tooth decay in children aged five
• Mortality from causes considered preventable
• Mortality from all cardiovascular diseases (including heart disease and stroke)
• Mortality from cancer
• Mortality from liver disease
• Mortality from respiratory diseases
• Mortality from communicable diseases (Placeholder)
• Excess under 75 mortality in adults with serious mental illness (Placeholder)
• Suicide
• Emergency readmissions within 30 days of discharge from hospital (Placeholder)
• Preventable sight loss
• Health-related quality of life for older people (Placeholder)
• Hip fractures in over 65s
• Excess winter deaths
• Dementia and its impacts (Placeholder)

Equality considerations are at the heart of the Public Health Outcomes Framework, explicitly agencies are required to focus on:

- socioeconomic group
- area deprivation (or postcode)>
- age
- disability
- ethnicity
- gender
- religion
- sexual orientation.

Session 6: Resource use and Utilities

We have translated our understanding of the workshop discussion around resource use for monitoring diabetes into Table 4. We are uncertain about whether we have reflected this discussion appropriately, so would greatly appreciate any corrections to this table.

Table 4: Revised estimates of diabetes monitoring costs

Resource	Previous estimate	Revised estimate
Nurse at GP	2	3
GP clinic	2	3
Health care assistant	0	3
Dietician	0.5	0.33
HbA1c test	2	3
Urine test	0	3
Eye screening	1	1
Screen for lipids, microalbuminuria, dipstick haematuria, liver function test, renal function (eGFR), creatinine. B12.	0	3
Smoking cessation	0	3

We had initially intended to cost individual treatment strategies for patients with diabetes. However, it was suggested at the workshop that treatment practices are variable across the country and that the NICE guidelines were not representative of real world practice. In order to simplify the modelling it was recommended that we obtain data on the mean prescription costs per patient and apply these in the model without needing to make assumptions about the specific treatments administered. However, we have discussed the potential of doing this since the workshop and one of the benefits of high risk identification may be that diabetes is diagnosed at an earlier stage. This means that people may be diagnosed when they have a lower HbA1c such that they may be able to control their HbA1c level on metformin for a longer period prior to moving on to the more expensive drugs than in the absence of high risk identification. In order to capture this effect whilst keeping the treatment model as simple as possible, we propose dividing treatment into three groups; (i) metformin, (ii) other more expensive treatment, followed by (iii) insulin. With this approach, individuals would remain on metformin until they reached a level of HbA1c which would trigger other more expensive treatment options. Thus, if they are diagnosed with diabetes at a lower level of HbA1c due to high risk identification, it would take them longer to reach the trigger to switch to a more expensive treatment option.

Within the workshop we proposed to assume that diabetes is associated with no additional mortality risk or utility decrement compared with the general population in individuals who have no associated complications. The workshop discussion suggested that this would be inappropriate and as a result we will modify these assumptions. We will explore recent literature on the excess mortality associated with Diabetes from the GPRD dataset.

The workshop discussion also suggested that it is inappropriate to assume that diabetes patients who do not have any complications have the same utility as those people in the general population, even after adjusting for weight. The main reasons stated for this were the disutility associated with the label of diabetes and having the monitoring and treatment, and depression associated with the diabetes label. It is thus important to incorporate these quality of life decrements, preferably explicitly but alternatively implicitly within a utility associated with diabetes (but avoiding double counting of disutilities associated with the explicitly included complications).

It was suggested that treatment for CVD has changed since the 2007 statins report. The total cholesterol level for statins is now accepted to be 4 rather than 5.

It was discussed that the costs and utilities of the relevant diseases may be estimated using the updated UKPDS when it is available.

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Appendix E: Conceptual modelling framework

Appendix E1: Conceptual modelling framework for focus group meeting

1. Introduction

This document describes a conceptual modelling framework for Public Health economic evaluation. A conceptual modelling framework is defined as: *'A methodology that helps to guide modellers through the development of a model structure, from developing and describing an understanding of the decision problem to the abstraction and non-software specific description of the quantitative model, using a transparent approach which enables each stage to be shared and questioned.'*

Aim of the conceptual modelling framework

In 2011, Chilcott *et al.* highlighted the lack of formal methods for model development within health economics.[1] The aim of this framework is to provide a methodology, which can be moulded according to different situations by different users,[2] to help modellers develop structures for Public Health economic models. It acts as a tool to help modellers make decisions about the model structure, but it does not provide automated solutions to these choices. It is intended to be used by any modellers undertaking Public Health economic evaluations; for inexperienced modellers it provides a transparent process to follow; for experienced modellers it provides Public Health-specific considerations such as the determinants of health and understanding and describing dynamically complex systems, as well as a standardised approach which will help decision makers/ clients to input into and use the model developed.

It does not aim to provide a specific, prescriptive process. The processes followed will be dependent upon the decision making context, the resources available and the preferences and judgements of the project team. However, process suggestions are included in italics within boxes throughout. An example to illustrate the methods is employed using a case study assessing the cost-effectiveness of interventions to prevent diabetes.

Benefits of the conceptual modelling framework

Conceptual modelling is the first part of a modelling project, which guides and impacts upon all other stages. This means that if this is done poorly, all subsequent analysis, no matter how mathematically sophisticated, is unlikely to be useful for decision makers.[3] Key potential benefits of this conceptual modelling framework and what pitfalls these aim to avoid, developed based upon a review of conceptual modelling frameworks, are shown within Table 1 below.

Table 1: Potential benefits of the conceptual modelling framework

Potential benefit	What pitfalls can be avoided
To aid the development of modelling objectives	➢ Answering the wrong (or less useful) question with the model.
To provide tools for communication with stakeholders	➢ Representing a contextually naïve and uninformed basis for decision-making, including misunderstandings about the problem, producing unhelpful model outcomes, and incorporating inappropriate and/ or biased model assumptions. ➢ Ignoring important variations between stakeholders' views. ➢ Producing model results which are not trusted by stakeholders.
To guide model development and experimentation	➢ Inefficient model implementation (i.e. repeatedly making structural changes to the implemented model) ➢ Inadequate analyses
To improve model validation (developing the right model)	➢ Answering the wrong (or less useful) question with the model. ➢ Misunderstanding the key issues associated with the problem. ➢ Using the first theories identified from the evidence to develop the model. ➢ Not having a basis for justifying the model assumptions and simplifications.
To improve model verification (developing the model correctly)	➢ Not having an intended model with which to compare the implemented model.
To allow model reuse	➢ Other experts not being able to identify or correctly interpret key model assumptions and simplifications and why these have been made.

Development of the framework

The conceptual modelling framework was informed by two literature reviews, qualitative research with modellers and a pilot study. The literature reviews aimed to: (1) describe the key challenges in Public Health economic modelling and (2) review existing conceptual modelling frameworks within the broader literature. The qualitative research aimed to understand the experiences of modellers when developing Public Health economic model structures and their views about the barriers and benefits of using a conceptual modelling framework. This involved; (i) following the development of a Public Health economic model including observing key meetings and undertaking in-depth interviews with the modellers involved; (ii) systematically analysing my own notes from a previous Public Health economic project; and (iii) holding a focus group meeting with modellers. A draft version of the conceptual modelling framework was piloted within a project assessing the cost-effectiveness of interventions for diabetes screening and prevention.

2. The conceptual modelling framework

The conceptual modelling framework is made up of four key principles of good practice and a methodology consisting of four phases: (A) Aligning the framework with the decision making process; (B) Identifying relevant stakeholders; (C) Understanding the problem; and (D) Developing and justifying the model structure. Each of these will be described.

2.1 Key principles of good practice

The four key principles of good practice are that; (1) a systems approach to Public Health modelling is appropriate; (2) developing a thorough documented understanding of the problem is valuable prior to and alongside developing and justifying the model structure; (3) strong communication with stakeholders and members of the team throughout model development is essential; and (4) a systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling.

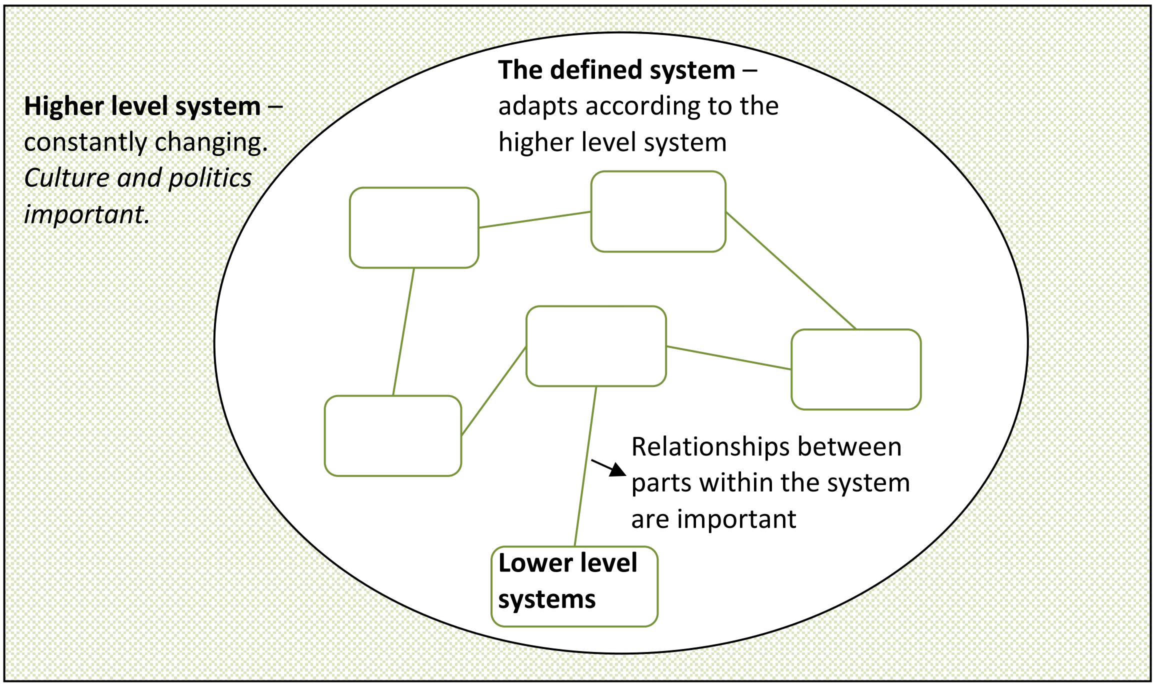
1) A systems approach to Public Health modelling is appropriate

Public Health economic modelling generally involves understanding dynamically complex systems.[4] This means that they are non-linear systems where the whole is not equal to the sum of the parts, they are history dependent, there is no clear boundary around the system being analysed, heterogeneity and self-organisation impact upon the outcomes, and people affected by Public Health interventions may learn over time and change their behaviour accordingly.[5]

Within complex systems there may be positive feedback loops, whereby if Factor A increases [decreases], the number of Factor B increases [decreases], which leads to Factor A increasing [decreasing] further, which would lead to exponential growth [decay] if no other factors were present.[5] For example, an increase in population obesity might lead to an increase in population mental illness which in turn leads to an increase in obesity, and so on. There may also be negative feedback loops, where an increase [decrease] in Factor A leads to an increase [decrease] in Factor B which in turn leads to a decrease [increase] in Factor A.[5] For example, an increase in eating will lead to an increase in weight gain (all other things being equal) which may lead to a decrease in eating. The dynamics of complex systems arise from the interaction between positive and negative feedback loops, and this may occur over a long period of time, often producing counter-intuitive behaviour.[5] The economy is an example of a complex system which displays such behaviour. Within these dynamically complex systems, factors are constantly changing over time, and a sudden change in behaviour may arise as a result of a number of smaller heterogeneous changes, such as a stock market crash. Making assumptions of simple cause and effect may lead to inappropriate results. See the paper 'Learning from Evidence in a Complex World' by Sterman (2006) for a good discussion of dynamic complexity.[5]

A systems approach, or systems thinking, is a holistic way of thinking about the interactions between parts within a system and with its environment.[6] Within systems thinking there are multiple system levels, whereby the system of interest is subjectively defined and there is always a higher level system within which it belongs and a lower level system which describes detailed aspects. The challenge within health economic modelling is to determine which level will be that of the system of interest (the model), by having sufficient knowledge about the higher level system (the broader understanding of the problem), and subsequently to be able to define an appropriate level of detail for the system of interest. Within systems thinking, the importance of not considering one aspect of a system in isolation is emphasised to avoid ignoring unintended consequences. Soft systems thinking also recognises the impact of culture and politics upon a situation,[2] which is interlocked with Public Health policy evaluation. Culture and politics affect the process by which decisions are made, what is modelled (eg. the identification of the problem, stakeholder involvement, the interventions assessed and the perspectives and outcomes of the analysis) and the effectiveness of the interventions (eg. service provision and the behaviour of individuals and society). Thus, a systems approach is suited to modelling these dynamically complex public health systems. Figure 1 has been developed to depict key elements of a systems approach.

Figure 1: Systems thinking



2) **The modeller should develop a thorough documented understanding of the problem prior to and alongside developing and justifying the model structure in order to develop a valid, credible and feasible model**

It is valuable to have an initial understanding of the problem and to document this understanding prior to making simplifications when developing the model structure because of both theoretical and practical reasons. Theoretically, it provides a basis for validation by facilitating the specification of an appropriate scope and structural assumptions, and for credibility by supporting stakeholder involvement and producing clear documentation when developing the model structure.[7] We learn by building upon what we already know, and how we see the world or a problem is constrained by our previous 'knowledge'.[8] As such, if a model is data-led and/or based only upon the analyst's interpretation of the data, it may lead to a narrow view of what should be included within the model. Documenting an understanding of the problem prior to analysing available datasets allows that understanding to be reflected upon and shared. This reduces the risk of ignoring something which may be important to the model outcomes, which is particularly important given the potential dynamic complexity of the system. In terms of systems thinking (see key principle of good practice 1), documenting an understanding of the problem (the higher level system) allows the modeller to be able to define the boundary of the system of interest for modelling (see Figure 1). This description of the understanding of the problem should also help the modeller to understand the impact of potential simplifying assumptions they are making within the model.

Practically, if the problem is not sufficiently understood an inappropriate model structure may be developed which, if recognised at a later stage of model development, may take a long time to alter within the computer software. This is particularly true if an alternative model type needs to be developed (for example, a DES rather than a Markov model). Thus taking the time at the beginning of the project to understand the problem could reduce overall time requirements. Documenting the understanding of the problem also enables communication with stakeholders and the project team (see key principle of good practice 3). An additional benefit is that the documentation of the understanding of the problem could be used (alongside any logic models developed) to help stakeholders understand all of the impacts of the interventions in order to inform the scoping and/or the interpretation of systematic reviews of intervention effectiveness. Finally, documenting the understanding of the project will enable researchers and policy makers who are not involved within the project to understand the problem and the basis for decisions about the model structure.

Thus, as also proposed by Kaltenthaler *et al.* (2011) within the context of clinical economic modelling,[7] it is recommended that the model structure be developed in two phases. The first is to develop an understanding of the decision problem which is sufficiently formed to tackle the above theoretical and practical issues and should not be limited by what empirical evidence is available (see Section C). The second is to specify a model structure for the decision problem that is feasible within the constraints of the decision making process (see Section D).

The understanding of the problem will inevitably continue to form during model development; however this initial documented understanding provides a basis for comparison and any major changes to this understanding can subsequently be documented.

3) **Strong communication with stakeholders and members of the team throughout model development is important for model transparency, validity and credibility**

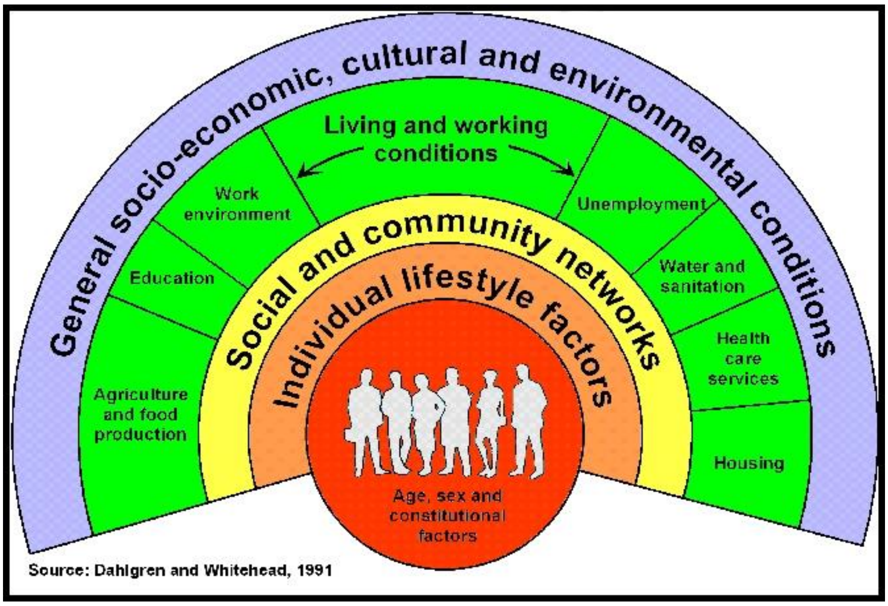
Literature suggests that stakeholders can encourage learning about the problem (including geographical variation of healthcare provision and stakeholders' values and preferences), help to develop appropriate model objectives and requirements, facilitate model verification and validation, help to develop credibility and confidence in the model and its results, guide model development and experimentation, encourage creativity in finding a solution and facilitate model re-use.[7;9-14] Additionally, stakeholders can help to define the meaning of subject-specific terminology which has a different lay meaning. Pidd has used the metaphor of taking a photograph of a scene, whereby each person involved might see different aspects of the scene and frame the photo differently.[15] The more frames provided by people with different interests (which may be affected by culture and politics), the better our understanding of the scene, and differences between perspectives can be discussed explicitly. Section B of the framework describes the types of stakeholders which may be involved.

The modeller is encouraged to question the assumptions of the stakeholders[16] and the project team throughout the model development process in order to uncover inconsistent, biased and invalid assumptions. Within topics where the project team have existing 'knowledge', it is important for them to be aware of the tendency to anchor to initial beliefs and be open to accepting new theories in order to develop valid models.[2;17] Effective ways of communicating information such as using clear diagrams should be used in order to share information and describe assumptions.

4) **A systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling**

The determinants of health which include the social, economic and physical environment, as well as the person's individual characteristics, are central in the consideration of Public Health interventions. The determinants of health as described by Dahlgren and Whitehead are shown within Figure 2.[18] Individual behaviours (or lifestyle factors) impact upon the broader determinants of health, which in turn impact upon individual behaviours.[19] Thus, it is important to consider these broader determinants of health in order to be able to predict the full impact of the interventions upon health outcomes. In addition, the determinants of health could be used to think through all of the non-health costs and outcomes associated with the interventions that it might be useful to report, such as those within transport or employment. Consideration of the broader determinants of health also facilitates identification of potential intervention types to assess within the model including those which might impact upon individual health through making community and population-level changes, such as food production, as well as those which might impact upon health through changing individual lifestyle factors. Similarly, subpopulations that might benefit from the intervention could be identified. Finally, the consideration of social network effects could affect the analytical model type chosen, and subsequently the predicted impact of the interventions.

Figure 2: Determinants of health

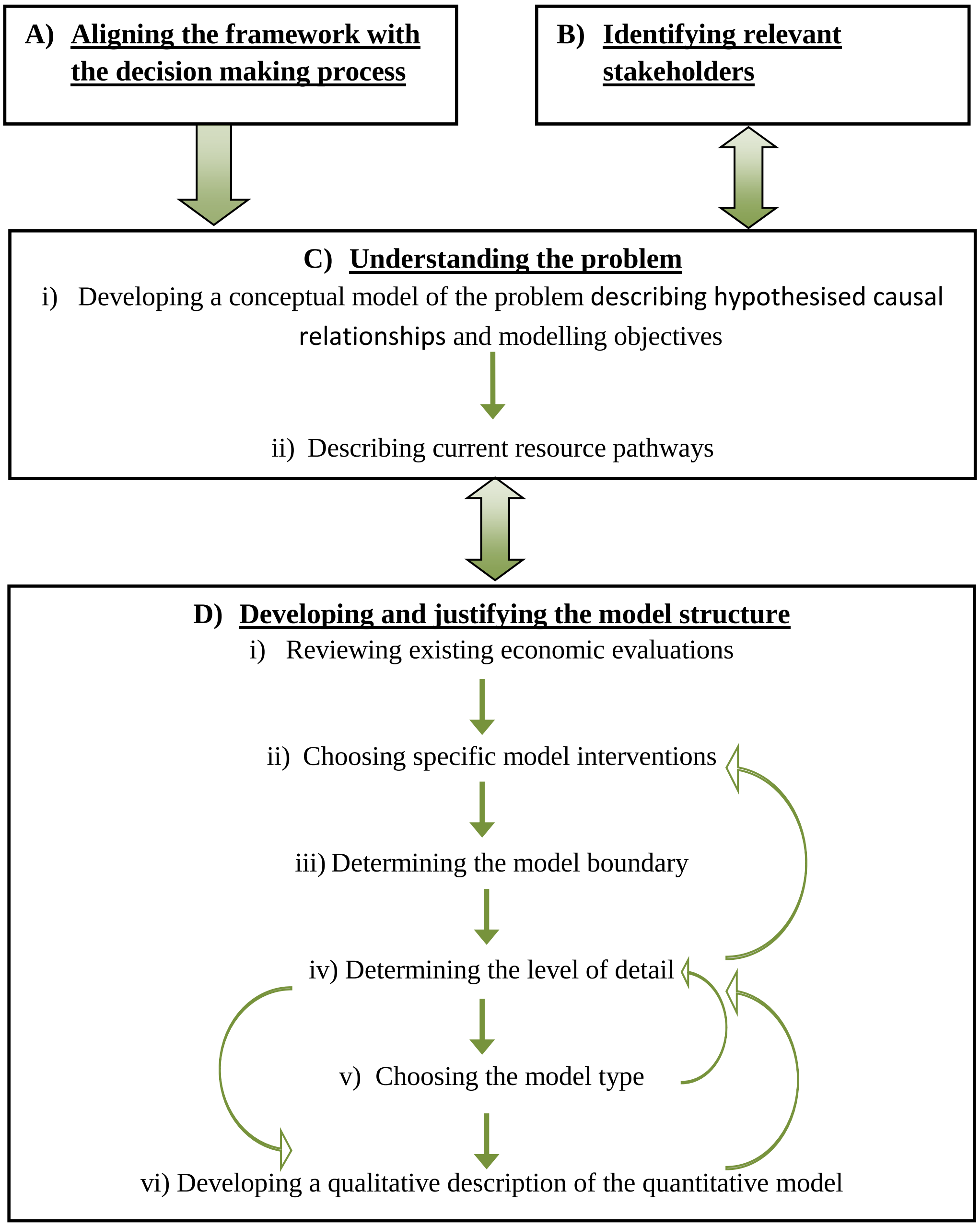


It would not be appropriate or feasible to include all of the determinants of health within the model; however, they should be systematically reflected upon during the understanding of the problem phase to consider which determinants it might be important to include within the model so that all important mechanisms and outcomes of the interventions can be captured.

2.2 Overview of the phases within the conceptual modelling framework

Figure 3 describes an outline of the phases within the conceptual modelling framework, which includes (A) Aligning the framework with the decision making process; (B) Identifying relevant stakeholders; (C) Understanding the problem; and (D) Developing and justifying the model structure.

Figure 3: Overview of conceptual modelling framework for Public Health economic modelling



An iterative approach

Choosing stakeholders and aligning the framework with the decision making process will generally need to be undertaken in parallel because the choice of stakeholders and their ideal level of involvement will depend upon the decision making process, but the availability of the stakeholders may have a substantial impact upon the process which is followed. It may be necessary to iterate between choosing relevant stakeholders and developing the understanding of the problem since the understanding of the problem phase may highlight the need to include stakeholders with specific expertise. Similarly, whilst it is important to develop an understanding of the problem prior to developing and justifying the model structure (see principle of good practice 2), in practice the understanding of the problem is never complete and it may be necessary to transparently revise this understanding at a later stage. These iterations are described by double headed arrows within Figure 3. The steps within the developing and justifying the model structure phase are also iterative as shown within Figure 3. Evidence identification is not described as a separate stage within Figure 3 (apart from reviewing existing models) since it is an activity required within the majority of the outlined stages. However, iterations are inevitable between appropriate conceptualisation and data collection because there is unlikely to be the exact evidence available that has been specified by the conceptual model.

2.3 Detailed methods of the framework

A) Aligning the framework with the decision making process

The conceptual modelling framework is intended to be flexible for different decision making arenas which means that decisions about how to employ the framework within the process are required. For example, the project team may need to operate differently according to the nature of the engagement with decision makers and clients within the project. If the client is the decision maker, then the scope of the model in terms of the interventions, comparators, populations, outcomes and perspectives may be better defined at the start of the project than if the client is not the decision maker (eg. a research funding body). This may influence the approach to evidence searching (in particular the search for intervention effectiveness evidence) and the time and resources required for model scoping. If the client is not the decision maker, the project team will need to identify the relevant decision makers and include them within the stakeholder group (see phase B of the framework).

A protocol document outlining the project plan can be produced using the framework, as a basis for discussion between the project team and stakeholders. This helps the clients to understand whether the project is planned to run appropriately and the project team with project planning. Key process decisions to be made during this phase relate to the relevant modes of stakeholder engagement, the approach to evidence searching, and the time and resources available for the modelling project and each step of the framework.

B) Identifying relevant stakeholders

There are a number of different types of stakeholder within any Public Health project including clinical experts, decision makers and lay members, all of which provide different expertise. The choice of stakeholders involved with the development of the model will inevitably affect the model developed and the interventions assessed because modelling is subjective. For instance, stakeholders help define the model scope, make value judgements, use their expertise to recommend structural assumptions such as extrapolating short term trial data over the long term, and choose which interventions to assess within the model. These will be affected by what is considered to be culturally and politically acceptable, which is entirely appropriate in order for the model to be useful, but provides an additional reason to obtain input from a range of stakeholders. Within some projects, the experts who inform the model development are chosen by the modelling team, whilst within others a group of experts are chosen by a decision making body, such as within the NICE process (see Section A). There is, however, usually the opportunity to involve additional experts chosen by the project team. A group of experts who will provide different expertise over a range of perspectives can be identified (see below). Practically, the approach to stakeholder communication needs to be flexible and some stakeholders will provide more input than others.

Based upon Soft Systems Methodology (SSM)[2] and a conceptual modelling paper by Roberts *et al.*[9], the types of stakeholders to involve are:

1) *Customers* which might include patient representatives and lay members;
2) *Actors* which might include methods experts, clinical and epidemiologic experts;
3) *System owners* which might include policy experts.

DIABETES PROJECT EXAMPLE

Within the diabetes project, stakeholders that might be involved could be a diabetic patient and a non-diabetic lay member (the customers), a general practitioner, experts in diabetes, cardiovascular disease, microvascular disease, cancer and osteoarthritis and an expert in statistical analysis of longitudinal data (the actors), and local and national commissioners (the system owners). The relationships between the customers, actors and system owners can be considered in order to identify relevant stakeholders. For example, if a general practitioner (actor) has been identified as a stakeholder, this could help identify the non-diabetic lay member (customer). The person with the power to stop the actor giving the customer a service is the local commissioners (system owners). Stakeholders should be involved during both the understanding of the problem phase and the development and justification of the model structure phase.

Process suggestions which may be helpful to modellers

<u>*Resource requirements for stakeholder recruitment:*</u> *It may require substantial time and effort to engage stakeholders. It may be necessary to approach more stakeholders than required as some will not have the time to be involved. Stakeholder workshops are useful if there are sufficient resources within the project budget because they allow stakeholders to debate and question the assumptions and beliefs of each other. Substantial administrative time is likely to be required to organise stakeholder workshops due to the probable busy schedules of the stakeholders. For this reason, it is also likely that any workshops will need to be organised at least two months before they are due to take place.*

<u>*Stakeholder worldviews and motivations:*</u> *Checkland suggests defining the worldviews of each stakeholder in order to understand conflicts between them.*[2] *An understanding of the possible worldviews and motivations of each of the potential stakeholders allows the project team to compare these with the project aims. Potential stakeholders may be more willing to be involved if the initial request is phrased in a way which aligns the aims of the project with the expected motivations of the stakeholders. For example, some stakeholders may be more interested in the outcomes of the project than the methods being employed so the initial information provided could describe the potential outcomes of the project. Another potential approach is for a more senior colleague involved in the project who is renowned in their field to contact the experts, potentially raising the prestige of the project and increasing the perceived benefits to the expert of being involved.*

<u>*Stakeholder expectations:*</u> *Stakeholders who are unfamiliar with modelling may not expect to be involved in shaping the modelling work. At the start of the project it is valuable to be clear with all of the stakeholders about the expectations of their involvement throughout the model development process and the importance of their input. Assumptions being made by the decision makers and other stakeholders throughout model development should be questioned.*[16]

<u>*Lay members:*</u> *Lay members are involved to ensure that views and experiences of the wider public inform the group's work. Where possible, lay members should represent different types of people within society where those differences are likely to be important to the topic area (eg. lower socioeconomic status). If this is not possible, the project team should be aware that the perspectives provided by the lay members do not necessarily represent those of all patients in that disease area/ the general population. In particular, they may not represent the more vulnerable groups within society who are unlikely to volunteer for such a role.*[20] *If these relevant groups are not represented, then the views and experiences of the wider public may not be heard by the stakeholders and project team. This could lead to unrealistic assumptions about a particular subgroup of the population who behave differently to those represented within the stakeholder group. Modellers should consider whether the assumed chains of behavioural causation are likely to be different within particular subpopulations.*

C) Understanding the problem

One of the four principles of this framework is that developing and documenting an understanding of the problem is at the core of developing an appropriate model structure. This is about understanding what is relevant to the problem, and should not be limited by what empirical evidence is available.[7] The understanding of the problem phase within Figure 3 includes (i) developing a conceptual model of the problem describing hypothesised causal relationships and (ii) describing current resource pathways.

i) <u>Developing a conceptual model of the problem describing hypothesised causal relationships</u>

This section outlines a methodology for developing a conceptual model of the problem by using the notation of causal diagrams, borrowing some of the methods from cognitive mapping,[21] and ensuring that the worldview of each of the stakeholders is considered.[2;21] This provides a systematic approach for developing an understanding of the problem at an appropriate and manageable level of relevance.

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A causal diagram depicts the relationships between factors by arrows, using a + or – sign to indicate a positive or negative causal relationship. Causal diagrams allow feedback loops to be described which depict the dynamic complexity of the system. Each factor is a quantity such that one factor leads to an increase or decrease in another factor. For example,

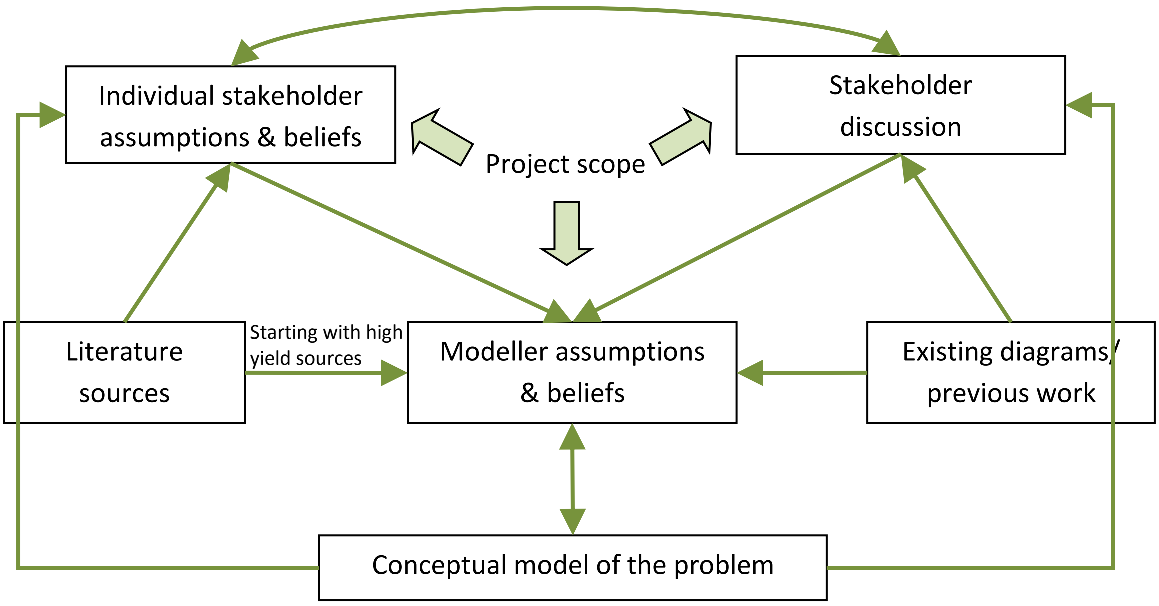
$$\text{CVD event} \xrightarrow{+} \text{Cost} \quad \text{and} \quad \text{CVD event} \xrightarrow{-} \text{Quality of life}$$

mean an increase in CVD events leads to an increase in costs and a decrease in quality of life respectively. The hypothesised causal relationships associated with the problem can be depicted using this notation, bringing together the understanding of relevant diseases, human behaviour and societal influences. Drawing upon cognitive mapping, the ultimate aims can be stated at the top of the diagram (by asking 'why is x a problem?'), with intermediate outcomes below and options for change underneath (by asking 'how can the problem be avoided?').[21] Detailed steps to develop the diagram are described overleaf.

<u>Evidence for developing the conceptual model of the problem</u>

Causal assumptions for policy prediction will be based upon experience and judgement since observational data can only be used to assess the statistical association between the specified causal relationships.[22] The proposed diagram can provide an explicit description of our hypotheses about causal relationships and the challenge is to be able to justify the causal assumptions made. The causal hypotheses can be developed based upon a range of sources including the project scope, literature, stakeholder input, the team's previous work in the area and any other diagrams which have been developed by the rest of the current project team or the decision makers to depict their understanding of the problem, as described within Figure 4 below. By developing the diagram with input from stakeholders, it allows their assumptions and beliefs to be made explicit so that they can be agreed upon or questioned. The iterative process using all of the evidence sources outlined within Figure 4 provides multiple opportunities to question and adapt the causal assumptions. Ultimately, the diagram will depict the modeller's assumptions and beliefs about the causal relationships based upon all of these sources of evidence. In doing so, some forms of information may dominate over others according to the modeller's views of the validity of the information.

Figure 4: Sources used for developing the conceptual model of the problem



Step 1: What is the problem?

The first step, based upon cognitive mapping,[21] is to ask 'what is the problem?' This is the key problem from the decision makers' perspective and could be based upon the project scope if available. The cause of the problem described should include a potentially modifiable component. The model objective is likely to be (although not necessarily) to assess the effectiveness and cost-effectiveness of interventions which might decrease this problem. Beginning the development of the diagram by identifying the key problem encourages a focused boundary around the understanding of the problem.

DIABETES PROJECT EXAMPLE

What is the problem?

Blood glucose levels/ diabetes

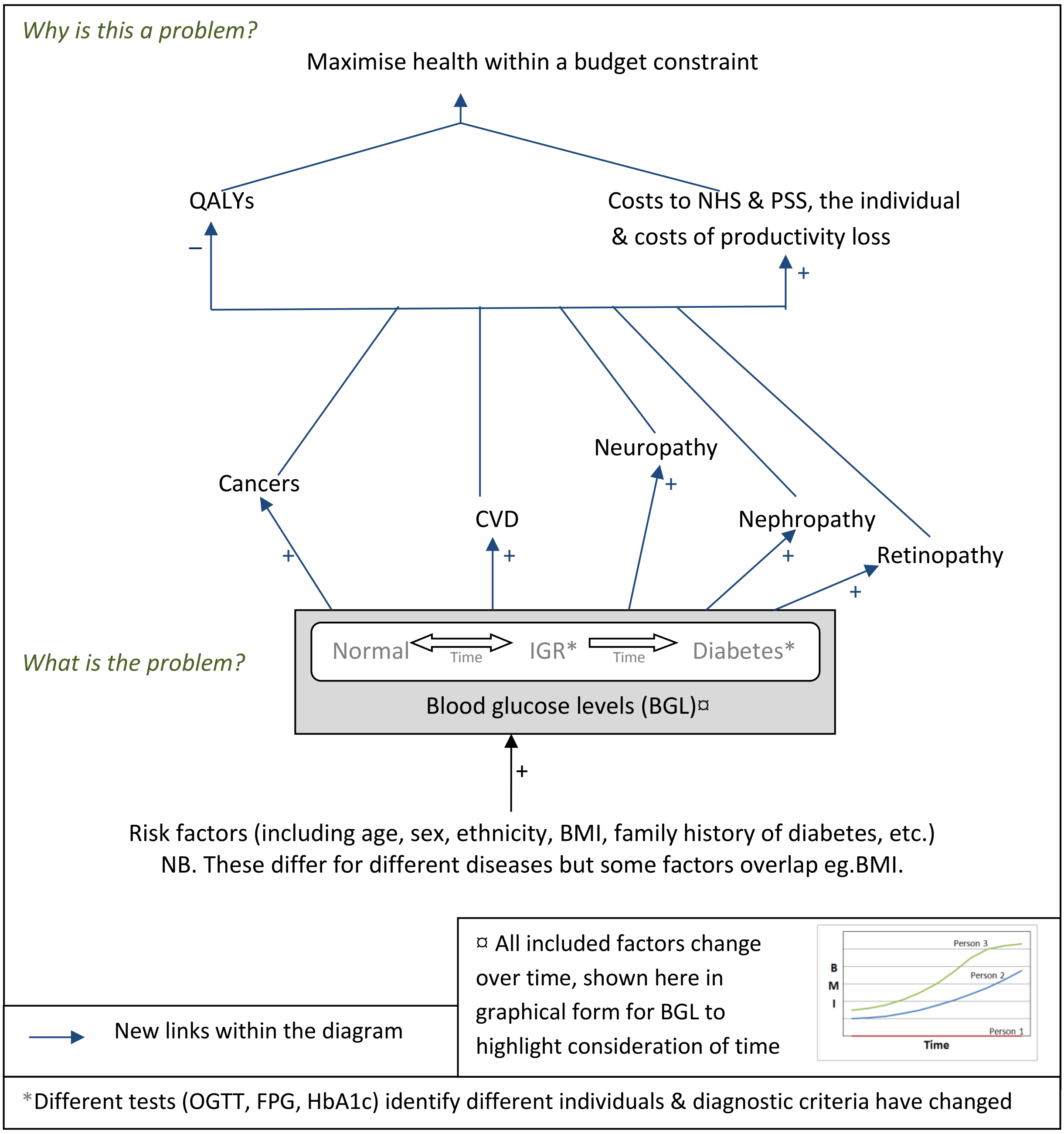
$\uparrow +$

Risk factors (including age, sex, a measure of physical activity and diet, family history of diabetes, ethnicity, etc.)

Step 2: Why is this a problem?

The modeller can then ask 'why is this a problem?', and continue to ask 'why?' or 'what are the implications of this?' until no more factors are identified, again based upon the methods of cognitive mapping.[21] Within Public Health economic modelling the goal may be to maximise net benefit by maximising health and minimising costs or equity may be considered of primary importance.

DIABETES PROJECT EXAMPLE



Step 3: Developing additional causal links

A set of questions have been constructed which may be useful to help develop the diagram further, as shown in Box 1. The development of the understanding of the problem is iterative, and hence it may be useful to continually revisit these questions.

Incorporating disease natural history

Any relevant disease natural histories will not be causal in that having a 'normal' health state does not cause a disease to develop. For example, moving from having normal blood glucose levels to having diabetes is not causally related. However, the interventions being assessed within Public Health tend to be those which reduce morbidity and mortality by aiming to change behaviour. Thus where there is a disease natural history, it is likely to be affected by behaviour and as such the causal chain can show the relationship between the behaviour and the disease. For example, a decrease in physical activity might lead to an increase in blood glucose levels. Following the onset of disease, the disease natural history can be described by probabilistic causation. For instance, somebody with impaired glucose regulation has an increased probability of developing diabetes.

Defining factors for inclusion

The arrows between the factors within the diagram would ideally be definable by one relationship. For example, if the relationship between risk factors and stroke and risk factors and heart disease is known to be different, then it is preferable for these factors to be separated out within the diagram rather than being combined within the factor CVD. If this is not possible in order for the diagram to remain clear, then a note could be added to describe the different subsets within that factor.

Box 1: Questions about the decision problem to help with developing the diagram

A1. Questions relating to the disease and the determinants of health include:

- Have any relevant disease natural histories been captured?

  Example: Disease natural history associated with diabetes

- Are the following determinants of health (taken from Dahlgren and Whitehead) important in determining effects and in what way:
  - Age, sex and other inherent characteristics of the population of interest?
  - Individual lifestyle factors? (incl. diet, physical activity, smoking, alcohol/ drug misuse)
  - Social and community networks? (incl. friends, family including intergenerational impacts, wider social circles)
  - Living and working conditions and access to essential goods and services? (incl. unemployment, work environment, agriculture & food production, education, water & sanitation, health care services, housing)
  - General socioeconomic, cultural and environmental conditions? (incl. economic activity, government policies, climate, built environment including transportation, crime)

  Example: Relationship between age, ethnicity, BMI, smoking and blood glucose levels

A2. Questions to help ensure the understanding of the problem is sufficiently broad include:

- Are there any other (positive or negative) consequences of each concept?

  Example: Increases in BMI may also lead to increases in osteoarthritis incidence.

A3. Questions to ensure that the dynamic complexity of the system has been captured are:

- Could there be any other factors which explain two outcomes, for links which may not be causal, but correlated.

  Example: BMI may help explain both CVD incidence and increased blood glucose levels rather than CVD causing increased blood glucose levels directly.

- Are there any other possible causal links between the factors? (with the aim of establishing whether there are any feedback loops)

  Example: increased BMI leads to increased diabetes incidence which leads to an increase in mental illness which may lead to increased BMI.

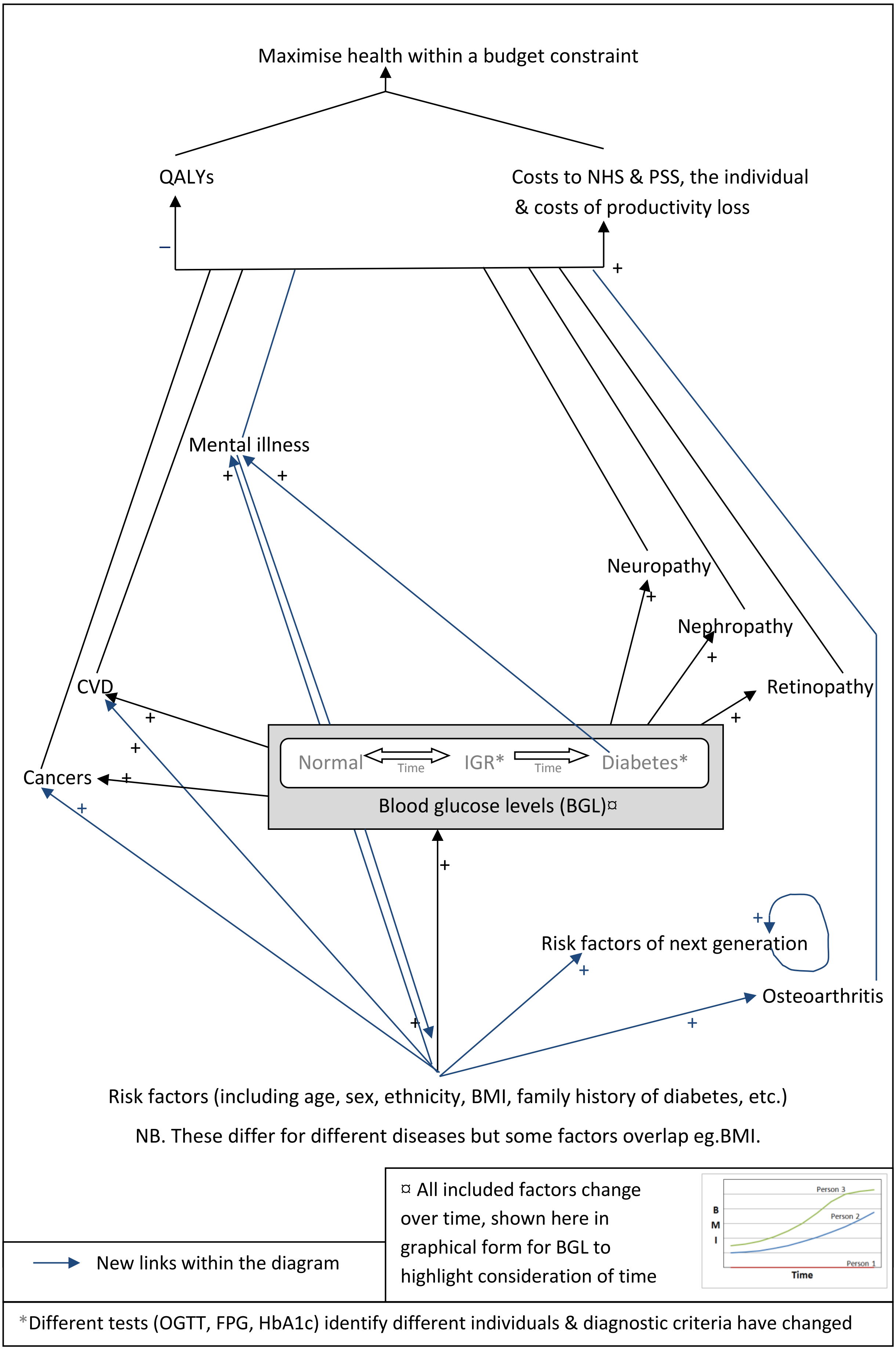
- Are there interactions between people which affect outcomes? (see social networks above)

  Example: People interacting with friends and family with higher BMI are more likely to have a higher BMI.

- Is timing/ ordering of events important?

  Example: Timing and type of CVD events may affect other disease outcomes.

DIABETES PROJECT EXAMPLE



Step 4: Incorporating types of intervention

Within dynamically complex systems like Public Health systems, the possible types of interventions may not be easily definable at the start of the project prior to developing a sufficient understanding of the problem. Thus, the modeller can ask how to avoid or reduce the impact of the described problem. It is useful to firstly know what is considered to be current practice. Potential types of interventions can then be added based upon the project scope, any effectiveness studies identified, and by considering within the diagram where interventions may be beneficial. One way of doing this is to consider which of the potentially modifiable determinants of health (individual lifestyle factors; living and working conditions and access to essential goods; and general socioeconomic, cultural and environmental conditions) affect the decision problem. Combinations of individual, community and population interventions may be considered.[23] It is not expected that the final interventions being assessed within the model will have been chosen at this stage. However, it is important to define the types of interventions which might be assessed within the model so that their impact upon model factors, including those not already incorporated into the diagram, may be considered.

A set of questions have been constructed which may be useful for considering the impacts of the interventions, shown in Box 2. These should be considered in the context of each type of intervention potentially being assessed within the model.

Box 2: Questions about the interventions and their impacts

B1. Questions relating to the constraints of the decision making process are:

- Are there constraints on the project scope? (eg. are we constrained by the types of interventions we are assessing? What about the population?)

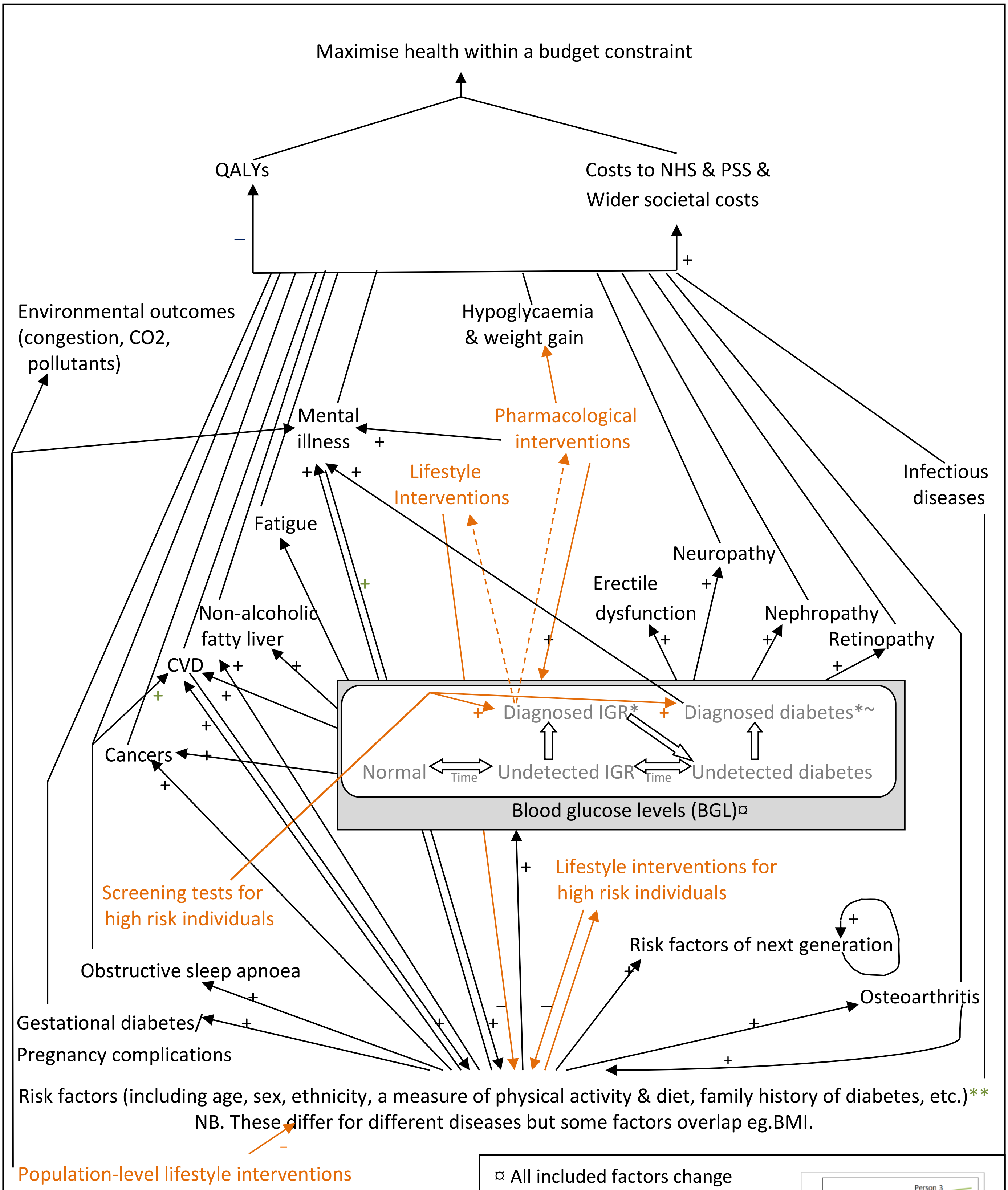
B2. Questions relating to the goals and mechanisms associated with the interventions are:

- What is considered to be a good outcome?
  Example: Would it be a good outcome if the intervention led to people understanding the benefits of healthy behaviours but chose not to adopt them?
- What would happen in the absence of the interventions versus as a result of the interventions – would negative outcomes be prevented or delayed?
- *Example: Would there be fewer diabetes and related-disease outcomes in total or would they simply be delayed by x years? What might x be?*
- What evidence exists to describe the outcomes of the intervention/ comparator over time? Are behavioural outcomes important? If so, do any relevant models of behaviour from psychology, sociology or behavioural economics exist to help describe the behaviour resulting from the intervention or the comparator? This will require additional targeted literature searches.
- Are there any determinants of health reported by the effectiveness studies which are not included within the causal diagram? Can such a relationship be described?
  Example: Access to healthy foods may be reported rather than diet, physical activity or weight-related outcomes.

B3. Questions relating to the dynamic complexity of the system are:

- Might a third party act to reduce the impact of interventions?
  Example: Might fast food restaurants increase advertising if sales drop as a result of the intervention?
- Are there any substantial impacts of social and/or community networks upon intervention effectiveness? Will these impacts be captured over the long term within the effectiveness evidence?
  Example: The intervention may be more effective if friends and family are also receiving it.
- Are there any substantial impacts of the interventions upon other lifestyle factors?
  Example: Healthy eating could also be linked to reduction in binge drinking.
- Might the interventions have other impacts not already considered?
  Example: Walking/ cycling interventions may be associated with environmental outcomes.

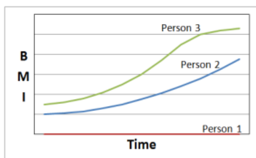
DIABETES PROJECT EXAMPLE



Potential interventions

Affects usage of alternative intervention

¤ All included factors change over time, shown here in graphical form for BGL to highlight consideration of time



*Different tests (OGTT, FPG, HbA1c) identify different individuals & diagnostic criteria have changed

~This leads to screening for CVD & microvascular complications which will affect these outcomes. If BGL are decreased, the risk of complications may decrease even if the individual is still termed 'diabetic'.

**Risk factors may be worse in the future as lifestyles become more sedate

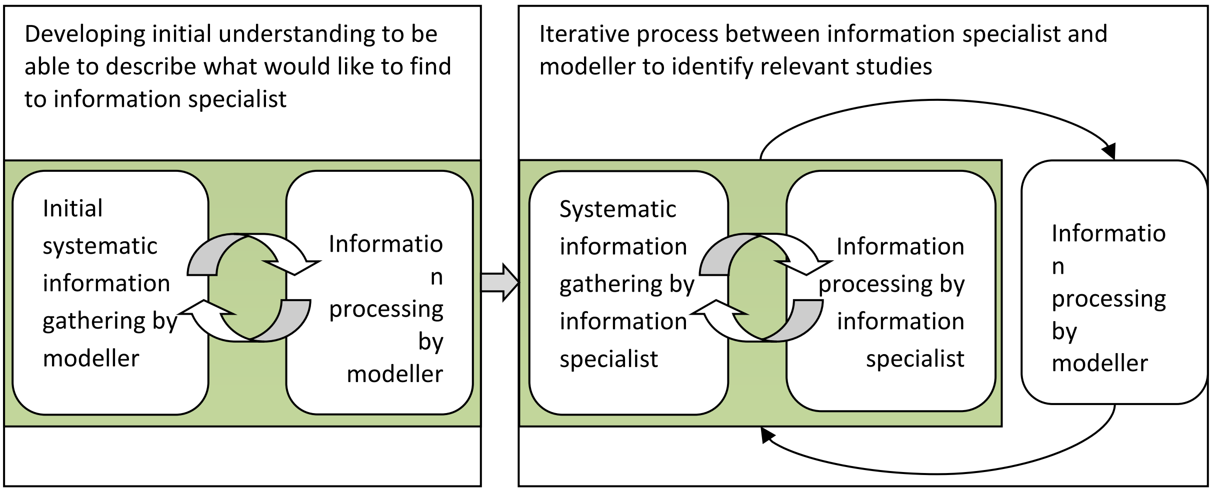
CVD, retinopathy & hypoglycaemia may affect driving ability

Process suggestions which may be helpful to modellers

<u>Literature searching for developing the conceptual model of the problem:</u> There is a dearth of defined methodology associated with searching for evidence to inform the understanding of the problem and model development. A doctoral thesis by Paisley investigates how evidence to inform clinical intervention model development might be identified.[24] This thesis suggests that a range of methods are likely to be required, which may include using known sources of information such as a previous model (direct acquisition), a formal literature search to identify specific information (directed acquisition) and/or identifying information on one topic during a search for information on a different topic which allows new ideas and options to emerge, as well as evidence which may not be picked up by a standard search such as grey literature (indirect retrieval).[24] This process will be cyclical in that literature will increase the modeller's understanding of the problem which will in turn direct where to search next for data. The modeller may begin this cyclical process by thinking about which sources of information may provide an initial high yield of information about the decision problem.[24] For example, the modeller might begin by examining previous similar models and undertaking a broad search for reviews of the topic area. It is useful during this process to flag any literature which is identified which may be useful in specifying the structure of the model or model parameters.[24]

Paisley suggests that literature search strategies should focus on maximising the retrieval of relevant information using an efficient, dynamic approach such as Berry Picking or Information Foraging.[24] It is important to work closely with information specialists and reviewers and ensure that there is a shared understanding of what is required, particularly due to the dynamic nature of this type of search. The modeller has greater knowledge about the higher level goal, whilst the information specialist holds the searching expertise. Thus, a possible approach to information retrieval for understanding the problem and developing the model structure, based upon information theory, is described by Figure 5 below. Methods for reducing the iterations between the systematic reviewer and the modeller, such as the two working together in real time to identify appropriate search strategies, might be useful.

Figure 5: Information retrieval for developing the understanding of the problem and model structure



<u>Use of existing economic models:</u> One of the sources of evidence for understanding the problem may be existing economic models since they can provide useful information about the problem in an efficient way. It is important to be mindful that these may have been developed for a slightly different problem/ context. Moreover, it is important to understand the current decision problem in its own right without being led by how others have modelled the topic.

<u>Mapping review for potential interventions:</u> A useful approach which has been employed within the School of Health and Related Research at the University of Sheffield to facilitate the identification of potential types of interventions is to undertake a mapping review.[25] This involves carrying out an initial broad search to understand what sort of evidence is available for interventions which fall into the project scope in order to define a more specific search. If there are too many possible types of interventions to assess within the constraints of the decision making process, decisions about which types of interventions to focus upon should be made through discussion with the stakeholders. If stakeholders broaden the potential types of interventions being assessed, the conceptual model of the problem may need to be expanded accordingly to capture any additional impacts of the interventions.

<u>Use of existing diagrams of the problem:</u> The decision makers or other parts of the project team may have developed diagrams of their understanding of the problem. For example, within the NICE process, logic models are developed by the decision makers to describe the relationships between actions and outcomes, incorporating relevant theory, in order to inform the project scope, including highlighting areas for potential interventions.[26] The conceptual model of the problem may therefore build upon any other diagrams which have been developed by the rest of the project team or the decision makers, and importantly it should be consistent with them. If these diagrams were inconsistent, the reasons for these differences should be explained. Where such diagrams have not been developed, the conceptual model of the problem could be used for a similar purpose in terms of identifying potential interventions (according to potentially modifiable determinants of health) and informing the searches for intervention effectiveness evidence.

<u>Stakeholder involvement:</u> The extent to which stakeholders can be involved in the development of the conceptual model of the problem will depend upon the specific project as discussed previously, but it could be developed or validated during a workshop with experts and decision makers (as in Strategic Options Development and Analysis[21]). Group judgements tend to be more accurate than individual judgements, particularly if a facilitator ensures that all people have chance to input.[17] By each stakeholder sharing their beliefs and assumptions these can be questioned and discussed.[21] However, practically it is likely that more than one way of communicating with stakeholders and a flexible approach will be necessary. For example, if holding stakeholder workshops, those that cannot attend the full workshop may be able to join for part of it by tele- or video-conference, and/or to provide comments upon circulated documents so that these can feed into the workshop. It may be appropriate to hold workshops/ meetings around relevant conferences or meetings to

increase attendance. One-to-one meetings, telephone conversations and/or email communication may be employed in addition to, or instead of, workshops.

<u>Stakeholder introductions:</u> Drawing upon Checkland,[2] understanding the worldviews of the stakeholders can help to:

-Explore different views and the reasons for these between the stakeholders;

-Identify concerns which may not otherwise have been identified;

-Assess the stakeholders' potential contribution towards the project rather than our expectation around what they may be able to input;

-Identify who it may be most appropriate to contact to ask specific questions or for clarifications;

-Put what the stakeholders say into the context of their worldview so that any biases or assumptions about the world can be more easily identified;

-Ensure that future workshops/ correspondence aims to address the aims and motivations of the stakeholders so that they remain engaged within the project.

Thus, it may be valuable for each stakeholder to describe their perspective, what they think they can give to the project and what they would like out of their involvement either for 2-3 minutes at the start of the first workshop or within a paragraph of written text and for the modeller to refer back to these throughout the project. Within workshops, a 2-3 minute introduction also encourages each stakeholder to feel valued and gives each stakeholder chance to talk in order to promote later involvement in discussions.[2]

<u>Handling stakeholder disagreement:</u> Throughout this process it is important to question the assumptions of the stakeholders involved. If discussion does not resolve any disagreements between stakeholders, and there is no evidence to suggest a preference, then it may be due to value judgements, in which case it would be most appropriate to incorporate all alternatives within the understanding of the problem.

<u>Suggested processes if running workshops - project team requirements:</u> Providing some sort of description of the degree of consensus/ disagreement between stakeholders could help with model validity and credibility. A3 diagrams (eg. of the conceptual model of the problem at various stages of development) are a useful tool for stakeholders to share ideas and record them within workshops. When choosing whether or not to run workshops, the project team should be aware that the resource requirements during the workshops are substantial in order to facilitate, maintain engagement with the stakeholders, record what is said and process and collate information developed during the workshop. If the conceptual model of the problem is developed during the workshop, it could be developed using specialist computer software such as Group Explorer (which allows each member of the group to anonymously add to the diagram) or using a pen, post-it notes and a white board.[21]

<u>Suggested processes if not running workshops:</u> If resources, time requirements and/or availability of stakeholders do not allow for a workshop to take place, then it would be possible for the modeller to develop a

diagram of their perception of the problem based upon background reading and any previous diagrams developed for the project, and then circulate this initial version of the conceptual model of the problem for comment from the stakeholders.

Causal assumptions: *It is likely that several versions of the conceptual model of the problem will be developed due to the iterative process of building up the understanding of the project team and stakeholders. Some evidence may suggest, or stakeholders may perceive, factors as causal (where one factor directly causes another) when in fact they are correlated (there may be a third factor which causes both outcomes so that they appear to be causal but are not). Causality might be well established for some relationships, such as the relationship between CVD events and mortality. For other relationships, background knowledge and literature should be used to be able to justify the causal assumptions made (see Figure 4). Econometric studies (for example, least squares regression, instrumental variables, structural equation models, propensity score matching) can be used to establish the statistical association between these specified causal relationships. Causality could be graded according to the strength of evidence which might be done visually within the diagram, for example, by varying the width of arrows as was done within the Foresight map of obesity.[27] In contrast to facilitation for problem structuring methods where the main benefits might be in terms of the learning that takes place whilst developing the diagram rather than the output of the diagram, the modeller needs to complete a diagram which will be useful for specifying and justifying the quantitative model structure.*

Depicting time: *Time lags between discrete factors could be highlighted by adding the term 'delay' to the arrows if there are substantial time delays between cause and effect, as for causal loop diagrams within system dynamics.[8] An illustrative graph depicting time could also be incorporated where time effects are unclear from the causal structure.*

Reporting the causal diagram: *Different colours, dotted lines and/ or types of arrow can be used to depict different characteristics of the problem, accompanied by a key. More detailed notes can accompany the diagram. If the diagram becomes too unwieldy the ultimate aims could be removed and considered within a separate diagram or table since many of the factors are likely to link to these. The conceptual model of the problem can be input into the final report. The understanding of the problem may change; however, the diagram of the group's initial understanding provides a foundation for comparison should the understanding of the problem change at a later stage within the project, and this can then be documented.*

Modelling objective

The modelling objective should be clearly defined and regularly referred to during the design-oriented conceptual modelling phase (see Phase D of the framework) so that the model is built for purpose. This can be developed based upon the conceptual model of the problem, and may comprise the ultimate goals, the types of interventions being assessed and the population(s) of interest. As Roberts *et al*. suggest, the policy context of the modelling project needs to be clear, particularly in terms of the funder, the policy audience and whether the model is planned to be for single or multiple use.[9]

DIABETES PROJECT EXAMPLE

Modelling objective: To compare interventions for screening and prevention of type 2 diabetes within the general population and high-risk groups to maximise cost-effectiveness.

ii) Describing current resource pathways

The conceptual model of the problem can be used to inform what resources might need to be considered. This does not need to be a detailed description of resource use at this stage, since some factors within the conceptual model may be excluded from the quantitative model and hence it would be inefficient to collect detailed information. It also means that the general pathways can be validated with stakeholders prior to collecting detailed information. Flow diagrams, tables and/or a textual description of the resource pathways can be useful to inform consideration of the potential impact of the factors within the conceptual model of the problem upon the model results. This can be used to help choose which factors to include and exclude from the model as is discussed within the model boundary stage of the framework (see Section D(iii)).

DIABETES PROJECT EXAMPLE

For the diabetes case study, a number of flow diagrams were used from existing NICE guidance to describe the different elements of screening and treatment of disease.

D) Developing and justifying the model structure

This section aims to outline an approach for specifying an appropriate model structure that is feasible, valid and credible to develop into a quantitative model. As described within Figure 3, this includes: (i) reviewing existing health economic models; (ii) choosing model interventions and comparators; (iii) determining the model boundary (deciding what factors are included within the model rather than being part of its external environment); (iv) determining the level of detail (the breakdown of what is included for each factor within the model boundary and how the relationships between factors are defined); (v) choosing the model type (the analytic modelling technique employed, for example a Markov model), and (vi) developing a qualitative description of the quantitative model. This may be described as the design-oriented conceptual modelling phase.[7]

i) Reviewing existing health economic models

It is standard practice within health economic evaluation to undertake a systematic review of existing health economic models in the same area. Some existing models may have been used to develop the understanding of the problem, but a systematic review of models at this stage can be used in a number of ways[28]:

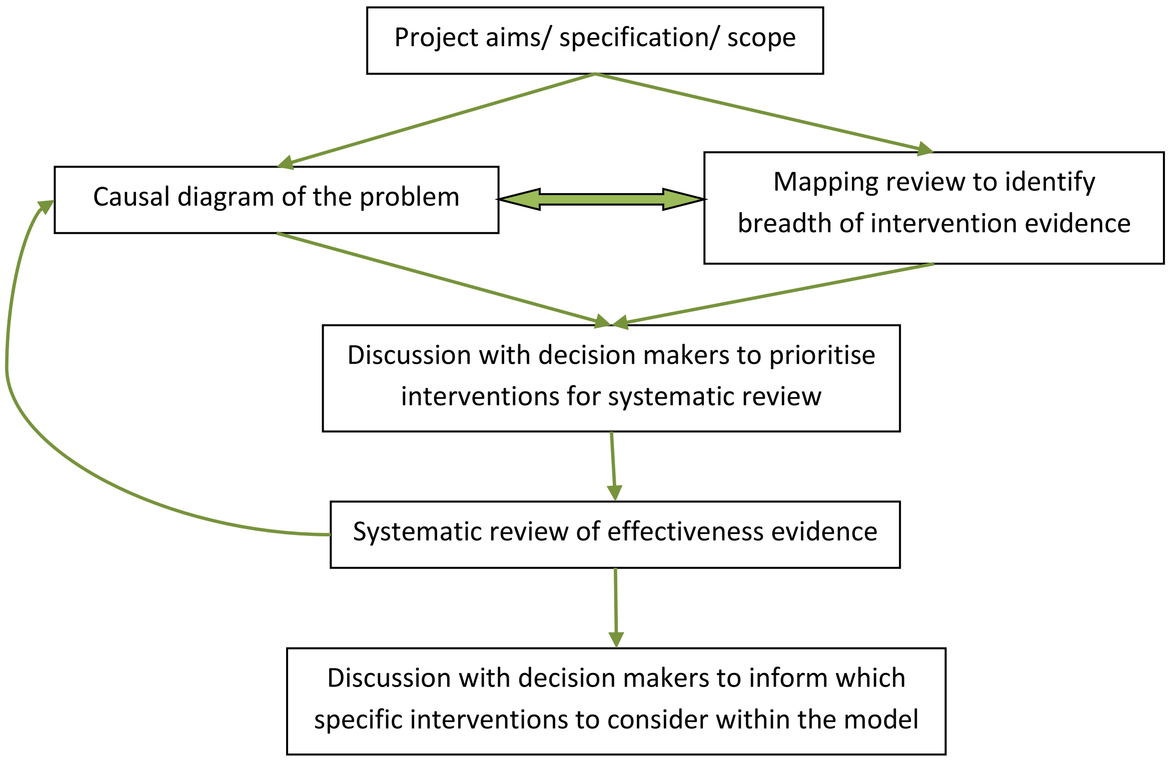
- To determine whether there is already a model which could be used, either in part or as a whole, based upon your understanding of the problem;
- To consider the strengths and limitations of existing economic evaluations, which can be used to inform the model development, including considering the strengths and limitations of different model types in that area;
- To compare and contrast how other modellers have chosen to structure the model and estimate key variables, and how the model results differ based upon these choices. This may involve considering the use of mathematical relationships such as risk equations or parameters which have been included within previous models if their source and justification has been appropriately explained;
- To identify which variables are important in influencing model results (including any which have not been highlighted during the understanding of the problem phase) and which do not substantially affect the differences in outcomes between the interventions and comparators;
- To provide an insight into the sort of data available which may inform the level of detail included within the model.

ii) Choosing model interventions and comparators

Method for choosing model interventions to assess within the model

The decision makers (with consideration of the clients' needs if they are not the decision makers) should define which specific interventions to model grounded within the results of an evidence review and according to expertise from other stakeholders. Figure 7 shows how the specific interventions may be chosen based upon the project aims, the understanding of the problem and the intervention evidence review. Not all stages may be required depending upon the breadth of the study. If it was not possible to systematically review all potentially relevant interventions, then decision makers may have been asked to prioritise interventions to determine the inclusion and exclusion criteria for the systematic review at the understanding of the problem phase. The decision makers may use the systematic review of effectiveness evidence to further limit interventions by discussing trial populations, outcomes and other possible biases such as trial design associated with the effectiveness studies. It is possible that one good study or a number of studies can be used to estimate the short term effectiveness, depending upon the evidence available. As far as possible, the comparator can be based upon the same studies as the interventions if this is representative in practice. If practice is substantially different, then an adjustment on the effectiveness estimate would be required. Given that economic evaluation is a comparative analysis, the model results are only meaningful in relation to the comparators chosen.[9]

Figure 7: Choosing model interventions



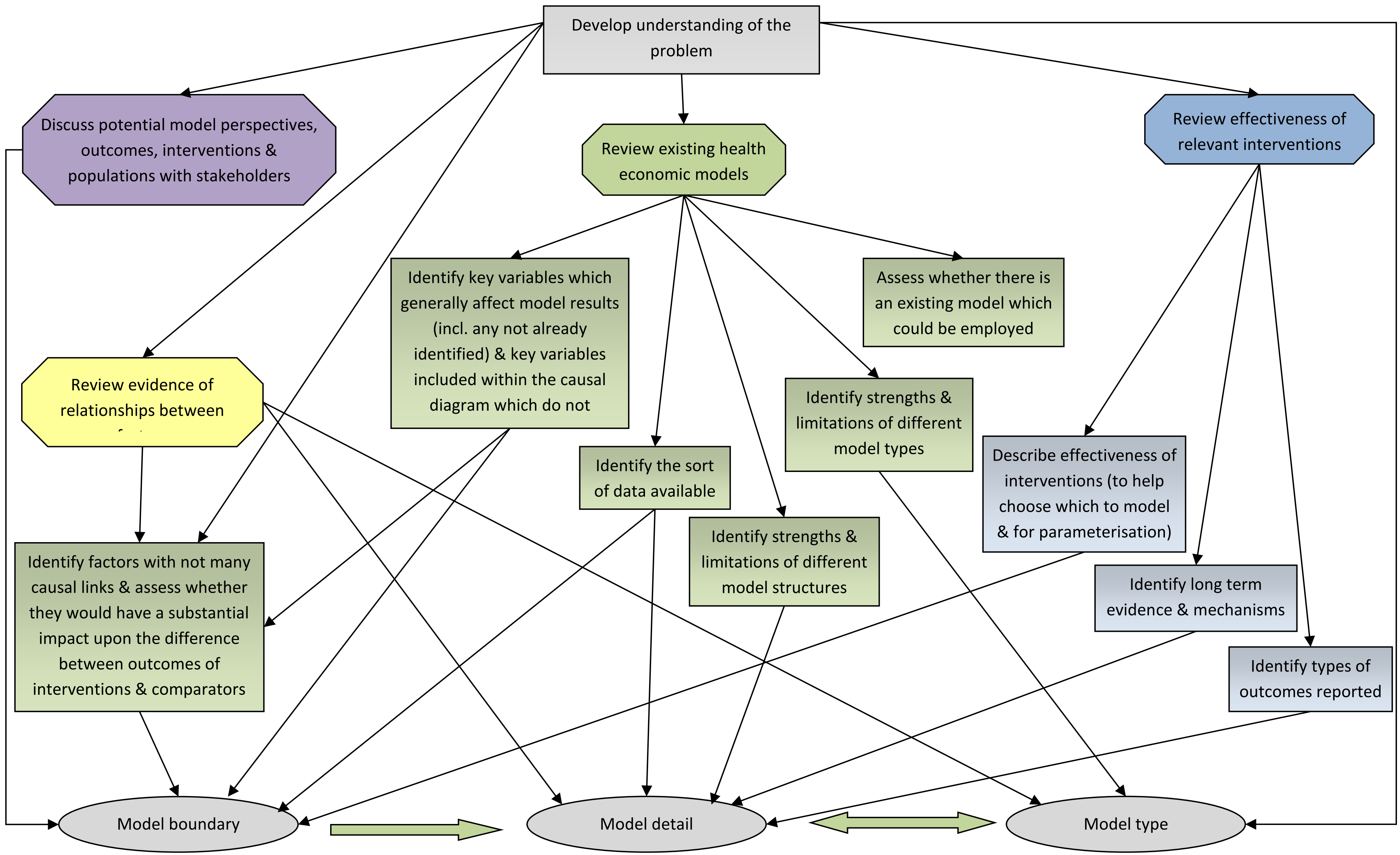
Extrapolation of study outcomes

Which outcomes the effectiveness studies report will guide the development of the model structure. For example, within the diabetes project, if all of the studies reported disease outcomes rather than physical activity/ diet outcomes, it may be appropriate to exclude these behaviours as explicit factors from the model structure. If the intervention has an effect, the mechanism behind the effectiveness can be discussed to develop assumptions for extrapolating these effects beyond the trial data (see level of detail section).

Use of the reviews to develop the model boundary, level of detail and model type

The review of existing economic evaluations and the review of intervention effectiveness can be used to facilitate decisions around the model boundary, level of detail and model type as shown within Figure 8 below.

Figure 8: Defining the model boundary, level of detail and model type



iii) Determining the model boundary

Determining the model boundary is about deciding, based upon the understanding of the problem, what factors should be judged as relevant for inclusion within the model and which can be excluded given the time and resource constraints of the decision making process. The boundary of the model structure must differ from the boundary of the understanding of the problem in order to be able to make informed judgements about what it is important to include within the model structure (see Figure 1). It is important to define the boundary of the model such that all important interactions between the elements of the system identified within the understanding of the problem are captured.[16]

Model population and subgroups

The model populations can be discussed with the stakeholders, informed by the populations within the studies identified by the effectiveness review. The modelling team and the stakeholders could consider whether there is a bigger problem in a particular subgroup or whether the intervention is more effective in a particular subgroup and if there is sufficient data to undertake any subgroup analysis. These subgroups might be based upon the determinants of health outlined within Figure 2 including age, sex and other inherent characteristics of the population of interest, individual lifestyle factors, living and working conditions and access to essential goods, and general socioeconomic, cultural and environmental conditions.

DIABETES PROJECT EXAMPLE

The populations and subgroups of interest were:

- General population;
- Local communities;
- High-risk individuals including
    - Non-diabetic hyperglycaemic;
    - Women with gestatational diabetes;
    - South Asian individuals.

Model perspectives and outcomes

Often within health economic evaluation, the NHS and PSS perspective is employed.[29] However, within Public Health economic modelling, other perspectives are likely to be relevant because substantial costs and benefits may extend beyond these sectors. Alternative perspectives include (but are not limited to) a societal perspective, a Public Sector perspective or the perspective of the particular agencies involved within the system. The perspectives of the system owners identified within Section B of the framework are likely to be appropriate. For example, if employers are considered to be system owners, then it is likely to be useful to consider an employer perspective. The choice of perspectives will also depend upon the modelling objectives. It should be noted that there are currently unresolved issues around using these alternative perspectives in terms of (i) whether it is possible or desirable to make social value judgements associated with the value of health relative to the value of other costs and benefits and (ii) the practicality of transferring costs and benefits between sectors.[30] Nonetheless, if substantial costs and benefits are expected to fall outside of the NHS and PSS, presenting these alternative perspectives is likely to be informative for decision makers.

In order to be able to compare interventions across different populations in terms of health costs and outcomes, the incremental cost per QALY may be employed, based upon New Welfare Economics.[31] Where the model boundary extends beyond health, it may be useful to understand the modelling requirements in other sectors so that relevant outcomes may be presented. One way of presenting multiple outcomes for different sectors is to present a cost-consequence analysis alongside the cost-effectiveness analysis.[32-34] Decision makers can suggest which model outcomes it would be useful to report. For both model perspectives and outcomes, the modeller should follow any specific requirements of the decision makers such as the use of the NICE Public Health Methods Guide. A method for choosing model outcomes and perspectives has been outlined within Figure 8.

Figure 8: Method for choosing appropriate modelling perspectives and outcomes

1) Consider what is theoretically appropriate and what is required under a reference case if applicable for (a) perspectives and (b) outcomes.
When considering (b) model outcomes, how do the model perspectives affect this?

↓

2) Consider by whom the results of the research will be used to consider whether additional (a) perspectives and (b) outcomes may be useful.

↓

3) Discuss with stakeholders those perspectives and outcomes identified within (1) and (2) and ask if there are any additional (a) perspectives and (b) outcomes that it might be useful to consider.

DIABETES PROJECT EXAMPLE

	NHS & Personal Social Services (PSS) perspective	**Employer perspective** *(given the number of workplace-based interventions)*	**Societal perspective**
The cost of…	The intervention and its delivery to the NHS and PSS	The intervention and its delivery to the employer	All costs of the intervention and its delivery (including to the patient)
	Diagnosis, treatment and follow up of the relevant diseases (for each disease) to the NHS and PSS		Diagnosis, treatment and follow up of the relevant diseases (for each disease) to the NHS and PSS and patients and carers (including travel costs)
		Lost productivity	Lost productivity
			Lost leisure time
Outcomes	Life years (LY) of the patient		Life years (LY) of the patient
	Quality-adjusted life years (QALYs) of the patient and carers		Quality-adjusted life years (QALYs) of the patient and carers
	Incremental cost per LY gained		Incremental cost per LY gained
	Incremental cost per QALY gained		Incremental cost per QALY gained
			Environmental outcomes (if necessary)

<u>Other model boundary considerations</u>

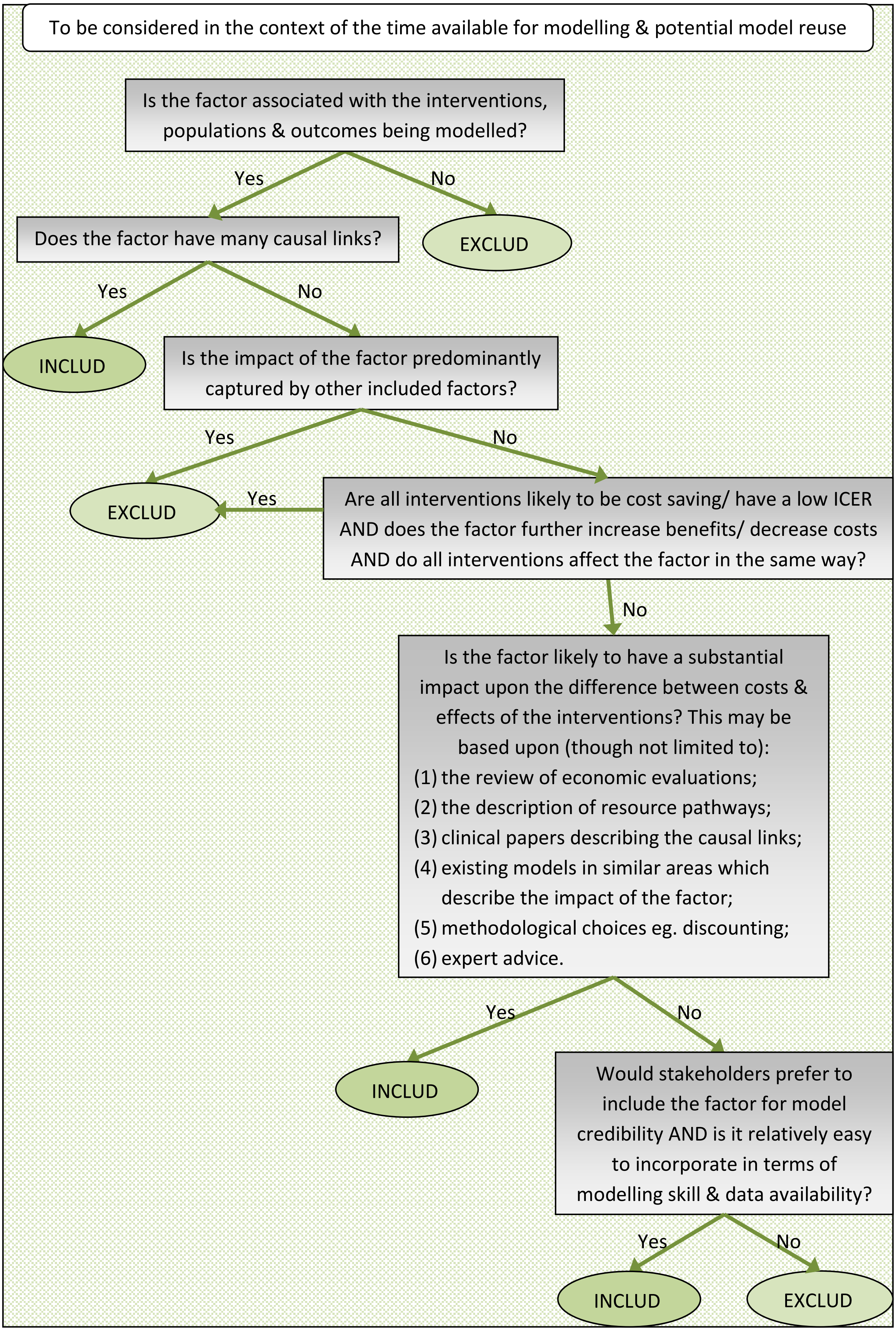
An algorithm to help define the model boundary is shown within Figure 9 and can be considered for each factor within the conceptual model of the problem. Within Figure 9, the question 'does the factor have many causal links?' aims to identify which factors are central and should be included within the model, even in the absence of data (lots of links), and which factors are less important (not many links to other factors). This can be done formally within computer software if preferred.[21] The question around whether the impact of a factor is substantially captured by other factors attempts to exclude any double counting within the understanding of the problem phase (for example, including fatigue and diabetes) as far as possible from the quantitative model.

It is valuable to predict very approximately the results of the model to facilitate model verification. These predictions can also help with defining the model boundary. Figure 9 encourages the modeller to think about whether it is worthwhile including non-central factors given the expected results of the model and the anticipated direction of effect of the factor upon those results, as well as the differential impacts of the interventions upon that factor. If different interventions impact the factor by different mechanisms, then including or excluding the factor may lead to different conclusions based upon the incremental analysis.

In terms of the question within Figure 9 around whether the factor is likely to have a substantial impact upon the difference between costs and effects of the interventions, this entails having an understanding of the magnitude of the cost and outcomes associated with the factor and the extent to which the interventions might change these. These subjective judgements will inevitably be considered in the context of the time available for modelling and the potential future uses of the model. Whether or not the factor will impact substantially upon the model results is a subjective judgement which, practically, may be influenced by the time available to develop the model. However, the model boundary stage should not be overly dependent upon the evidence or time available as this can be accommodated for by the level of detail incorporated. It is likely to be more appropriate to crudely include a factor which is expected to substantially affect the model results than to exclude it from the model completely.

Finally, in order to maintain the credibility of the model, stakeholders can be asked whether they are happy, given the above justifications, with the exclusion of factors. One way of reporting this stage is to produce a table stating whether each factor is included or excluded and the justification for exclusion, as suggested by Robinson.[35] An example of this is illustrated below Figure 9. A figure may also be useful to show which factors and relationships are planned to be included within the model.

Figure 9: Defining the model boundary



DIABETES PROJECT EXAMPLE

Factor	Include/ exclude	Reason for inclusion/ exclusion
Risk factors	Include	Key component.
Blood glucose levels/Diabetes	Include	Key component.
Gestational diabetes	Include	As a subgroup of the population who will be given intervention.
Osteoarthritis	Include	From a random sample of 3664 members of the Dutch population aged >25 years, Tukker reports that 'for each unit increase in BMI respondents were 8% more likely to report OA or chronic pain' and the Foresight report highlights the high prevalence of osteoarthritis within the UK population. In addition, the report by Gillett et al. suggests that the cost of osteoarthritis is comparable to the cost of diabetes.
Risk factors of next generation	Exclude	Within the high risk group, only a minority of people will parent a young child due to the age of the people affected. Within the general population, Whitaker et al. suggest that parental obesity more than doubles the risk of adult obesity among their children, but because these costs and outcomes would occur so far in the future, by applying a discount rate to both costs and effects, there would be minimal impact upon the model results.
Hypoglycaemia & weight gain	Include (but not as a separate factor)	The quality of life implications of hypoglycaemia and weight gain will be captured within the quality of life of people with diabetes. The costs of hypoglycaemia will be explicitly included within the cost of diabetes treatment.
Non-alcoholic fatty liver	Exclude as a seperate factor	This is likely to be implicitly included within the costs and quality of life estimates associated with diabetes and obesity.
Fatigue	Exclude as a separate factor	The quality of life implications of fatigue are likely to be captured within the quality of life of people with disease. There will be minimal additional costs associated with fatigue above those associated with treating disease.
Nephropathy	Include	Key outcome associated with diabetes.
Retinopathy	Include	Key outcome associated with diabetes
Neuropathy	Include	Key outcome associated with diabetes.
Erectile dysfunction	Include (but not as a separate factor)	This is likely to be included within the costs and quality of life impacts of neuropathy.
Infectious diseases	Exclude	Relative to other model factors, this is likely to have a smaller impact upon the model outcomes.
Cancers (post-menopausal breast cancer, colorectal cancer)	Include	The report by the World Cancer Research Fund (WCRF) Panel on Food, Nutrition, Physical Activity and the Prevention of Cancer suggests that BMI and physical activity is associated with colorectal cancer, postmenopausal breast cancer and endometrial cancer. Prevalence of colorectal cancer and post-menopausal breast cancer within the UK population is high and they are associated with substantial impacts upon costs and quality of life.
CVD	Include	Has a substantial impact upon both costs and effects.
Mental illness (incl. dementia)	Include	The relationship between mental illness and diabetes is complex and currently not completely understood. Evidence suggests that approx. 18-28% of diabetics have depression (Egede 2005), which is substantially higher than within the general population and this has substantial impacts upon costs and QALYs.
Obstructive sleep apnoea	Exclude as a seperate factor	The relationship between risk factors and CVD is expected to capture those events resulting from obstructive sleep apnoea.
Environmental outcomes	Exclude	Majority of the interventions would not substantially affect this outcome; focus upon health-related outcomes.

iv) Determining the level of detail

The level of detail is defined as the breakdown of what is included for each factor within the model boundary and how the relationships between factors are defined. A decision about which parts of the model are likely to benefit from a more detailed analysis can be made *a priori* in order to avoid situations in which the modeller focuses upon specific parts of the model because they are more easily dealt with and subsequently run out of time to develop other parts in detail. Essentially, determining the level of detail involves a mini cost-benefit analysis within which modellers can weigh up, based upon the documented understanding of the problem and the defined model boundary, whether the time required to do one analysis at a specific level of detail within the model is likely to have more of an impact upon the model results compared with the same time period spent upon other analysis, given the current evidence available and the overall time constraints. During model analysis, more detail can be incorporated if part of the model is shown to substantially affect the results.

Box 3 summarises key questions for the modeller to help choose an appropriate level of detail.

<u>Searching for evidence</u>

Data for inclusion for specifying the model structure and for the parameters will need to be identified at this point if it has not been already. This could be based upon literature identified during the development of the conceptual model of the problem for which specific literature was noted as useful, although additional specific searches may also be required. Data collection and the development of a description of the level of detail for the model will be a highly iterative process. Sufficient evidence is required to be able to justify why the modelling choices have been made.[24] It is important to note that elements for which there is a lack of empirical data which are considered to have key differential impacts upon the comparator(s) and the intervention(s) may be informed by expert elicitation. One consideration at this stage is likely to be the derivation of the disease natural history parameters which may be taken from existing studies or calibrated using statistical methods such as the Metropolis Hastings algorithm.[36]

Box 3: Questions to help in making judgements about the model level of detail

General

1) Is the time required to do the analysis at a specific level of detail likely to have more of an impact upon the model results than the same time period spent upon other analyses, given the evidence available and the overall time constraints?

To describe the relationship between the included factors over time

- What outcomes are reported within the review of intervention effectiveness? (to help choose which causal links to include)
- What evidence is available to model the causal links and the outcomes of the factor? (to avoid relying on the first available evidence)
- What do other economic evaluations suggest are the strengths and limitations of different mathematical relationships between model factors?
- Which determinants of health are key drivers of the problem according to relevant theory?

To extrapolate study outcomes

- What outcomes are reported within the review of intervention effectiveness?
- What evidence is available for long term follow up?
- Is there sufficient evidence and time available to model social networks given the expected impact upon model results (based upon the understanding of the problem)?

The level of detail used to describe each included factor

- Which are the specific aspects of each factor that are likely to have a substantial impact upon the model results?
    - Is all costly resource use captured?
    - Are all substantial health benefits and disbenefits captured using measures acceptable to the decision maker given the available evidence?
- Are impacts included within both costs and benefits where appropriate?

How interventions will be implemented in practice

1) What do the effectiveness studies describe?
2) What do stakeholders suggest would happen in practice and is this likely to lead to different estimates of effectiveness to those within the study?

Distinction between model assumptions and simplifications

Robinson highlights the distinction between model assumptions and simplifications; model assumptions 'are made either when there are uncertainties or beliefs about the real world being modelled' and model simplifications 'are incorporated in the model to enable more rapid model development and use, and to improve transparency'.[37] Thus, model assumptions are uncertain and alternative plausible assumptions can be tested within the model, whilst model simplifications are chosen because they are likely to have limited impact upon the model results. It is important to be explicit about both of these when describing the level of detail and highlight model assumptions which could be tested within sensitivity analyses.

Reporting level of detail

The simplifications and assumptions should be described and explained, initially for communication purposes with stakeholders and the project team to develop model validity and credibility, but also to facilitate future modelling projects in the same area. A document can be developed which specifies all of the key model simplifications and assumptions for discussion with stakeholders, ideally during a second workshop. This can help to identify the most appropriate evidence for the model and also improve model validity and credibility. Writing down all of the key simplifications and assumptions and their justification provides a mechanism for systematically questioning them within project team discussions and with the stakeholders; thus enhancing the appropriateness of the model simplifications and assumptions.

Expressing structural uncertainty

It may be that where there is more than one plausible assumption it is appropriate to develop model structures for each assumption in order to undertake posterior analysis of structural uncertainty, for example model averaging. This would be undertaken by creating a parameter to be included within the probabilistic sensitivity analysis to represent the probability of each structure being appropriate. This parameter and its distribution could then be estimated by elicitation with experts.[38]

The level of detail will be affected by the model type chosen, and hence it will be an iterative process between identifying an appropriate level of detail and choosing the model type.

v) Choosing the model type

Most appropriate method given the characteristics of the problem

It is important to understand the most appropriate method given the characteristics of the problem, even if it is not practical to develop this model type, so that the modeller can understand the simplifications they are making. A number of existing papers outline taxonomies for deciding upon appropriate model types given the characteristics of the problem for health economic modelling.[39-41] The taxonomy developed by Brennan *et al.* (2006) is used here,[39] although others may be employed. It can be summarised by asking whether interaction, timing and stochasticity are important, and whether there is sufficient data for an individual level model rather than a cohort model, each of which leads to a preferred model type (see Table 2 over page). Whilst decision trees and Markov models are most often employed within Health Technology Assessment,[40] because of the complexity associated with Public Health systems it is likely that alternative model types may be more appropriate.

Agent-based simulation (ABS) is not included within the taxonomy by Brennan *et al.* (or any other health economic modelling taxonomies identified); however it may be useful for modelling dynamically complex Public Health systems and so has been added to the taxonomy. ABS is an individual-level simulation modelling approach and is compared with the individual-level simulation approach DES which is included within the taxonomy.

DES is a top-down approach where the behaviour of the centralised system is defined by the modeller and entities within the model are passively affected by the rules of the system. Conversely, ABS is a bottom-up approach where the behaviour of the system is a result of the defined behaviour (based upon a set of rules) of individual agents and their interactions within the system.[42] These agents can learn over time. Therefore, DES may be preferable when the interaction between the agent and the environment is important (for example, a person has surgery which changes the probability of subsequent outcomes); whilst ABS may be preferable when the interactions between heterogeneous agents are important in addition to their interactions with the environment (for example, infectious disease modelling). Importantly, ABS more easily allows the analyst to capture spatial aspects in order to model appropriate interactions (for example, family and friend networks for transmission of a contagious disease).[42] Studies have shown such social network impacts of Public Health behaviours such as physical activity and diet.[43] Table 2 shows a revised version of Brennan's taxonomy with an additional row incorporated for ABS.

Table 2: Revised version of Brennan's taxonomy

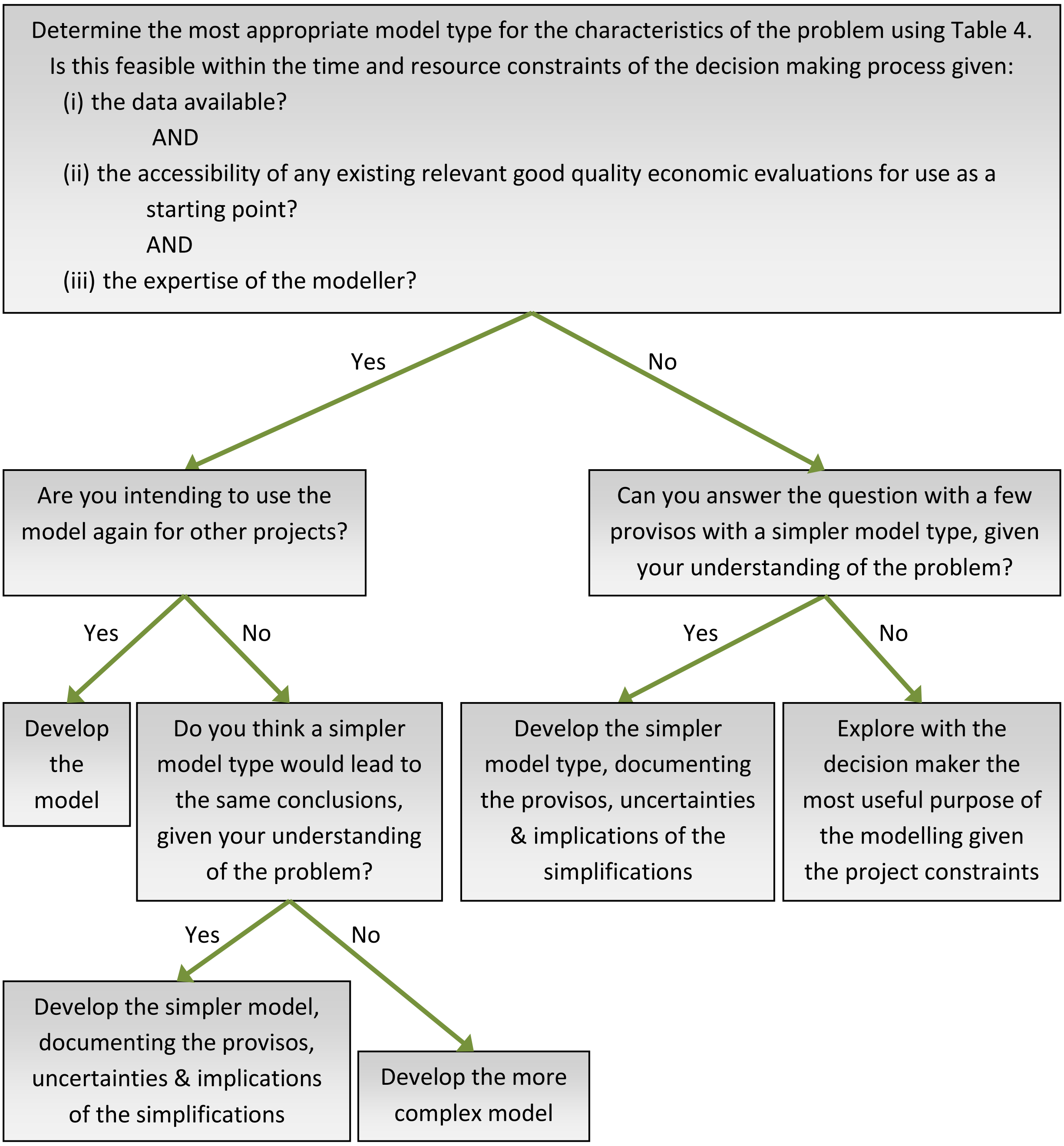
			A	B	C	D
			Cohort/ aggregate level/ counts		Individual level	
			Expected value, continuous state, deterministic	Markovian, discrete state, stochastic	Markovian, discrete state	Non-Markovian, discrete state
1	No interaction	Untimed	Decision tree rollback	Simulation decision tree	Individual sampling model: Simulated patient-level decision tree	
2		Timed	Markov model (deterministic)	Simulation Markov model	Individual sampling model: Simulated patient-level Markov model	
3	Interaction between entity and environment	Discrete time	System dynamics (finite difference equations)	Discrete time Markov chain model	Discrete-time individual event history model	Discrete individual simulation
4		Continuous time	System dynamics (ordinary differential equations)	Continuous time Markov chain model	Continuous time individual event history model	Discrete event simulation
5	Interaction between heterogeneous entities/ Spatial aspects important		X	X	X	Agent-based simulation

It is important to note that the choice of model type is not completely clear cut.[39] For example, it would be possible to incorporate some timing into a decision tree or to develop a system dynamics model with some individual level behaviour; however many of these 'work arounds' often become more time consuming to program than employing the more complex model type.

Most appropriate model type based upon broader considerations

It may not always be practical to employ the model type which is most appropriate for the characteristics of the problem. Figure 10 provides an outline of how the modeller might decide on the most appropriate model type according to broader practical issues.

Figure 10: Choosing the model structure



DIABETES PROJECT EXAMPLE

Within the diabetes project, the most appropriate model type, based upon the understanding of the problem and the revised version of Brennan's taxonomy was an agent-based simulation model. However, given the constraints of the project, a discrete event simulation was considered to be most appropriate and the provisos, uncertainties & implications of not modelling the social network effects of obesity were documented and highlighted as areas of further research.

vi) Qualitative description of the quantitative model

A qualitative diagram of the quantitative model alongside the development of the model structure can facilitate clear communication of the final model structure to stakeholders, other members of the team and people who may want to understand the model in the future. This will depend upon the model type developed but may take the forms outlined in Table 3.

Table 3: Suggested diagrams to represent the implemented model

Model type developed	Suggested diagram
Decision tree	Decision tree diagram
Markov model	State transition diagram
System dynamics	Influence diagram / stock and flow diagram
Individual event history model	State transition diagram
DES	Activity cycle diagram
Agent based model	A flow diagram

Whilst the design-oriented conceptual modelling can be described prior to the quantitative model development, it may be iteratively revised according to data availability and/or inconsistencies identified during the development of the quantitative model.[7;11;12;35] These modifications should be documented throughout so that there is transparent justification for the final model developed.

3. Further information

For more information about how the conceptual modelling framework was developed and the evaluation of the framework please see the doctoral thesis by Squires (in preparation).[44]

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Appendix E2: HESG paper

A conceptual modelling framework for developing the structure of Public Health economic models

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Abstract

Background: Public Health interventions tend to operate within dynamically complex systems and require consideration of a broader range of determinants of health than clinical interventions, including aspects of human behaviour and estimating impacts upon non-health costs and outcomes. The structural development of Public Health economic models is currently based upon *ad hoc* non-transparent methods. A conceptual modelling framework is a set of steps which can help to guide modellers through the development of a model structure. Key advantages of a conceptual modelling framework are to: aid the development of modelling objectives; provide tools for communication with stakeholders; guide model development and experimentation; improve model validation and verification; and allow model reuse. This paper describes a conceptual modelling framework for Public Health economic models.

Methods: The framework was informed by two literature reviews, qualitative research with modellers and a pilot study. The literature reviews aimed to: (1) describe the key challenges in Public Health economic modelling and (2) review existing conceptual modelling frameworks within the broader literature. The qualitative research aimed to understand the experiences of modellers when developing Public Health economic model structures and their views about the barriers and benefits of using a conceptual modelling framework. This involved; (i) following the development of a Public Health economic model including observing key meetings and undertaking in-depth interviews with the modellers involved; (ii) systematically analysing my own notes from a previous Public Health economic project; and (iii) holding a focus group meeting with modellers. A draft version of the conceptual modelling framework was piloted within a project assessing the cost-effectiveness of interventions for diabetes screening and prevention.

Results: Four key principles of good practice were identified; (1) that a systems approach to Public Health modelling is appropriate (feedback loops & unintended consequences are important); (2) developing a thorough documented understanding of the problem is valuable prior to and alongside developing and justifying the model structure; (3) that a systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling; and (4) that strong communication with stakeholders and members of the team throughout model development is essential. The conceptual modelling framework is described within the paper.

Discussion: A framework has been developed as a helpful tool for modellers of Public Health economic models. Initial evaluation will be via a focus group with modellers. It is offered for further testing within case studies.

1. Introduction

This paper describes a conceptual modelling framework for Public Health economic evaluation. A conceptual modelling framework is defined as: *'A methodology that helps to guide modellers through the development of a model structure, from developing and describing an understanding of the decision problem to the abstraction and non-software specific description of the quantitative model, using a transparent approach which enables each stage to be shared and questioned.'*

1.1 Aim of the conceptual modelling framework

The aim of this framework is to provide a methodology, which can be moulded according to different situations by different users,[1] to help modellers develop structures for Public Health economic models. It acts as a tool to help modellers make decisions about the model structure, but it does not provide automated solutions to these choices. It is intended to be used by any modellers undertaking Public Health economic evaluations; for inexperienced modellers it provides a transparent process to follow; for experienced modellers it provides Public Health-specific considerations such as the broader determinants of health and understanding and describing dynamically complex systems, as well as a standardised approach which will help decision makers/ clients to input into and use the model developed. Process suggestions and an example to illustrate the methods can be supplied upon request.

1.2 Benefits of the conceptual modelling framework

Conceptual modelling is the first part of a modelling project, which guides and impacts upon all other stages. This means that if this is done poorly, all subsequent analysis, no matter how mathematically sophisticated, is unlikely to be useful for decision makers.[2] Key potential benefits of this conceptual modelling framework and what pitfalls these aim to avoid are shown within Table 1 below.

Table 1: Potential benefits of the conceptual modelling framework

Potential benefit	What pitfalls can be avoided
To aid the development of modelling objectives	➢ Answering the wrong (or less useful) question with the model.
To provide tools for communication with stakeholders	➢ Representing a contextually naïve and uninformed basis for decision-making, including misunderstandings about the problem, producing unhelpful model outcomes, and incorporating inappropriate and/ or biased model assumptions. ➢ Ignoring important variations between stakeholders' views. ➢ Producing model results which are not trusted by stakeholders.
To guide model development and experimentation	➢ Inefficient model implementation (i.e. repeatedly making structural changes to the implemented model) ➢ Inadequate analyses
To improve model validation	➢ Answering the wrong (or less useful) question with the model. ➢ Misunderstanding the key issues associated with the problem. ➢ Using the first theories identified from the evidence to develop the model. ➢ Not having a basis for justifying the model assumptions and simplifications.
To improve model verification	➢ Not having an intended model with which to compare the implemented model.
To allow model reuse	➢ Other experts not being able to identify or correctly interpret key model assumptions and simplifications and why these have been made.

2. Methods for developing the framework

The conceptual modelling framework was informed by two literature reviews, qualitative research with modellers and a pilot study. The literature reviews aimed to: (1) describe the key challenges in Public Health economic modelling and (2) review existing conceptual modelling frameworks within the broader literature. The qualitative research aimed to understand the experiences of modellers when developing Public Health economic model structures and their views about the barriers and benefits of using a conceptual modelling framework. This involved; (i) following the development of a Public Health economic model including observing key meetings and undertaking in-depth interviews with the modellers involved; (ii) systematically analysing my own notes from a previous Public Health economic project; and (iii) holding a focus group meeting with modellers. A draft version of the conceptual modelling framework was piloted within a project assessing the cost-effectiveness of interventions for diabetes screening and prevention. A more detailed description of the methods of development is available within the PhD thesis by Squires (in preparation).[3]

3. The conceptual modelling framework

The conceptual modelling framework is made up of four key principles of good practice and a methodology consisting of four phases: (A) Aligning the framework with the decision making process; (B) Identifying relevant stakeholders; (C) Understanding the problem; and (D) Developing and justifying the model structure. Each of these will be described.

3.1 Key principles of good practice

The four key principles of good practice are that; (1) a systems approach to Public Health modelling is appropriate; (2) developing a thorough documented understanding of the problem is valuable prior to and alongside developing and justifying the model structure; (3) strong communication with stakeholders and members of the team throughout model development is essential; and (4) a systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling.

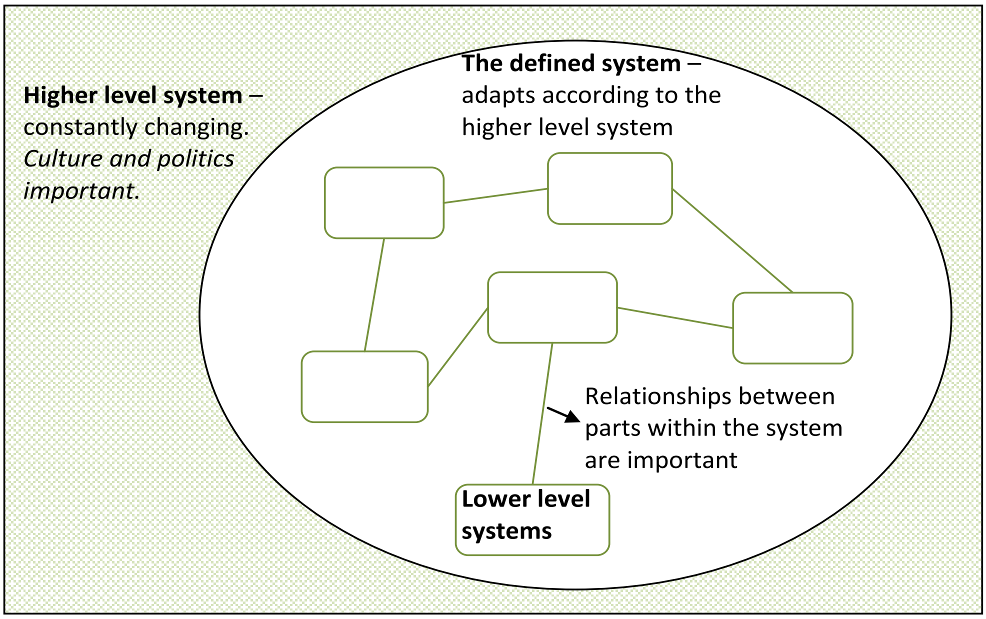
(1) A systems approach to Public Health modelling is appropriate

Public Health economic modelling generally involves understanding dynamically complex systems.[4] This means that they are non-linear systems where the whole is not equal to the sum of the parts, they are history dependent, there is no clear boundary around the system being analysed, heterogeneity and self-organisation impact upon the outcomes, and people affected by Public Health interventions may learn over time and change their behaviour accordingly.[5]

Within complex systems there may be positive feedback loops, whereby if Factor A increases [decreases], the number of Factor B increases [decreases], which leads to Factor A increasing [decreasing] further, which would lead to exponential growth [decay] if no other factors were present.[5] For example, an increase in population obesity might lead to an increase in population mental illness which in turn leads to an increase in obesity, and so on. There may also be negative feedback loops, where an increase [decrease] in Factor A leads to an increase [decrease] in Factor B which in turn leads to a decrease [increase] in Factor A.[5] For example, an increase in eating will lead to an increase in weight gain (all other things being equal) which may lead to a decrease in eating. The dynamics of complex systems arise from the interaction between positive and negative feedback loops, and this may occur over a long period of time, often producing counter-intuitive behaviour.[5] The economy is an example of a complex system which displays such behaviour. Within these dynamically complex systems, factors are constantly changing over time, and a sudden change in behaviour may arise as a result of a number of smaller heterogeneous changes, such as a stock market crash. Making assumptions of simple cause and effect may lead to inappropriate results. See the paper 'Learning from Evidence in a Complex World' by Sterman (2006) for a good discussion of dynamic complexity.[5]

A systems approach, or systems thinking, is a holistic way of thinking about the interactions between parts within a system and with its environment.[6;7] Within systems thinking there are multiple system levels, whereby the system of interest is subjectively defined and there is always a higher level system within which it belongs and a lower level system which describes detailed aspects. The challenge within health economic modelling is to determine which level will be that of the system of interest (the model), by having sufficient knowledge about the higher level system (the broader understanding of the problem), and subsequently to be able to define an appropriate level of detail for the system of interest. Within systems thinking, the importance of not considering one aspect of a system in isolation is emphasised to avoid ignoring unintended consequences. Soft systems thinking also recognises the impact of culture and politics upon a situation,[1] which is interlocked with Public Health policy evaluation. Culture and politics affect the process by which decisions are made, what is modelled (eg. the identification of the problem, stakeholder involvement, the interventions assessed and the perspectives and outcomes of the analysis) and the effectiveness of the interventions (eg. service provision and the behaviour of individuals and society). Thus, a systems approach is suited to modelling these dynamically complex public health systems. Figure 1 has been developed to depict key elements of a systems approach.

Figure 1: Systems thinking



(2) The modeller should develop a thorough documented understanding of the problem prior to and alongside developing and justifying the model structure in order to develop a valid, credible and feasible model

It is valuable to have an initial understanding of the problem and to document this understanding prior to making simplifications when developing the model structure because of both theoretical and practical reasons. Theoretically, it provides a basis for validation by facilitating the specification of an appropriate scope and structural assumptions, and for credibility by supporting stakeholder involvement and producing clear documentation when developing the model structure.[8] We learn by building upon what we already know, and how we see the world or a problem is constrained by our previous 'knowledge'.[9] As such, if a model is data-led and/or based only upon the analyst's interpretation of the data, it may lead to a narrow view of what should be included within the model. Documenting an understanding of the problem prior to analysing available datasets allows that understanding to be reflected upon and shared. This reduces the risk of ignoring something which may be important to the model outcomes, which is particularly important given the potential dynamic complexity of the system. In terms of systems thinking (see key principle of good practice 1), documenting an understanding of the problem (the higher level system) allows the modeller to be able to define the boundary of the system of interest for modelling (see Figure 1). This description of the understanding of the problem should also help the modeller to understand the impact of potential simplifying assumptions they are making within the model.

Practically, if the problem is not sufficiently understood an inappropriate model structure may be developed which, if recognised at a later stage of model development, may take a long time to alter within the computer software. This is particularly true if an alternative model type needs to be developed (for example, a discrete event simulation rather than a Markov model). Thus taking the time at the beginning of the project to understand the problem could reduce overall time requirements. Documenting the understanding of the problem also enables communication with stakeholders and the project team (see key principle of good practice 3). An additional benefit is that the documentation of the understanding of the problem could be used (alongside any logic models developed) to help stakeholders understand all of the impacts of the interventions in order to inform the scoping and/or the interpretation of systematic reviews of intervention effectiveness. Finally, documenting the understanding of the project will enable researchers and policy makers who are not involved within the project to understand the problem and the basis for decisions about the model structure.

Thus, as also proposed by Kaltenthaler *et al.* (2011) within the context of clinical economic modelling,[8] it is recommended that the model structure be developed in two phases. The first is to develop an understanding of the decision problem which is sufficiently formed to tackle the above theoretical and practical issues and should not be limited by what empirical evidence is available (see Section C). The second is to specify a model structure for the decision problem that is feasible within the constraints of the decision making process (see Section D). The understanding of the problem will inevitably continue to form during model development; however this initial documented understanding provides a basis for comparison and any major changes to this understanding can subsequently be documented.

(3) Strong communication with stakeholders and members of the team throughout model development is important for model transparency, validity and credibility

Literature suggests that stakeholders can encourage learning about the problem (including geographical variation of healthcare provision and stakeholders' values and preferences), help to develop appropriate model objectives and requirements, facilitate model verification and validation, help to develop credibility and confidence in the model and its results, guide model development and experimentation, encourage creativity in finding a solution and facilitate model re-use.[8;10-15] Additionally, stakeholders can help to define the meaning of subject-specific terminology which has a different lay meaning. Pidd has used the metaphor of taking a photograph of a scene, whereby each person involved might see different aspects of the scene and frame the photo differently.[16] The more frames provided by people with different interests, the better our understanding of the scene, and differences between perspectives can be discussed explicitly. Section B of the framework describes the types of stakeholders which may be involved.

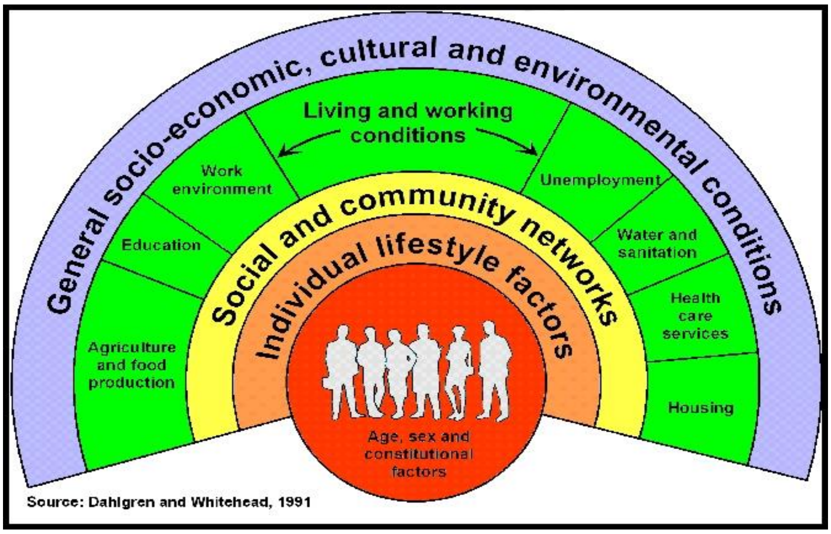
The modeller is encouraged to question the assumptions of the stakeholders[17] and the project team throughout the model development process in order to uncover inconsistent, biased and invalid assumptions. Within topics where the project team have existing 'knowledge', it is important for them to be aware of the tendency to anchor to initial beliefs and be open to accepting new theories in order to develop valid models.[1;18] Effective ways of communicating information such as using clear diagrams should be used in order to share information and describe assumptions.

(4) A systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling

The determinants of health which include the social, economic and physical environment, as well as the person's individual characteristics, are central in the consideration of Public Health interventions. The determinants of health as described by Dahlgren and Whitehead are shown within Figure 2.[19] Individual behaviours (or lifestyle factors) impact upon the broader determinants of health, which in turn impact upon individual behaviours.[20] Thus, it is important to consider these broader determinants of health in order to be able to predict the full impact of the interventions upon health outcomes. In addition, the determinants of health could be used to think through all of the non-health costs and outcomes associated with the interventions that it might be useful to report, such as those within transport or employment. Consideration of the broader determinants of health also facilitates identification of potential intervention types to assess within the model including those which might impact upon individual health through making community and population-level changes, such as food production, as well as those which might impact upon health through changing individual lifestyle factors. Similarly, subpopulations that might benefit from the intervention could be identified. Finally, the consideration of social network effects could affect the analytical model type chosen, and subsequently the predicted impact of the interventions.

It would not be appropriate or feasible to include all of the determinants of health within the model; however, they should be systematically reflected upon during the understanding of the problem phase to consider which determinants it might be important to include within the model so that all important mechanisms and outcomes of the interventions can be captured.

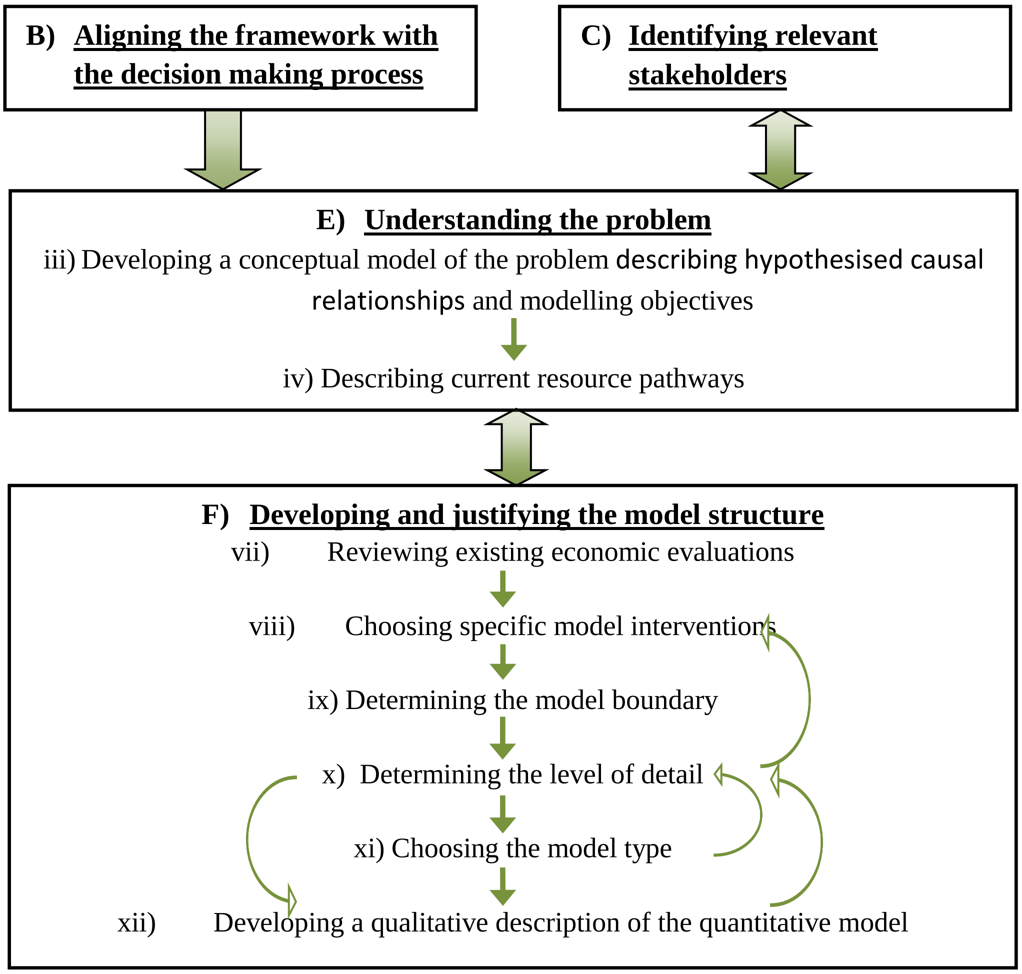
Figure 2: Determinants of health



3.2 Overview of the phases within the conceptual modelling framework

Figure 3 describes an outline of the phases within the conceptual modelling framework.

Figure 3: Overview of conceptual modelling framework for Public Health economic modelling



An iterative approach

Choosing stakeholders and aligning the framework with the decision making process will generally need to be undertaken in parallel because the choice of stakeholders and their ideal level of involvement will depend upon the decision making process, but the availability of the stakeholders may have a substantial impact upon the process which is followed. It may be necessary to iterate between choosing relevant stakeholders and developing the understanding of the problem since the understanding of the problem phase may highlight the need to include stakeholders with specific expertise. Similarly, whilst it is important to develop an understanding of the problem prior to developing and justifying the model structure (see principle of good practice 2), in practice the understanding of the problem is never complete and it may be necessary to transparently revise this understanding at a later stage. These iterations are described by double headed arrows within Figure 3. The steps within the developing and justifying the model structure phase are also iterative as shown within Figure 3. Evidence identification is not described as a separate stage within Figure 3 (apart from reviewing existing models) since it is an activity required within the majority of the outlined stages. However, iterations are inevitable between appropriate conceptualisation and data collection because there is unlikely to be the exact evidence available that has been specified by the conceptual model.

3.3 Detailed methods of the framework

C) Aligning the framework with the decision making process

The conceptual modelling framework is intended to be flexible for different decision making arenas which means that decisions about how to employ the framework within the process are required. For example, the project team may need to operate differently according to the nature of the engagement with decision makers and clients within the project. If the client is the decision maker, then the scope of the model in terms of the interventions, comparators, populations, outcomes and perspectives may be better defined at the start of the project than if the client is not the decision maker (eg. a research funding body). This may influence the approach to evidence searching (in particular the search for intervention effectiveness evidence) and the time and resources required for model scoping. If the client is not the decision maker, the project team will need to identify the relevant decision makers and include them within the stakeholder group (see Section B).

A protocol document outlining the project plan can be produced using the framework, as a basis for discussion between the project team and stakeholders. This helps the clients to understand whether the project is planned to run appropriately and the project team with project planning. Key process decisions to be made during this phase relate to the relevant modes of stakeholder engagement, the approach to evidence searching, and the time and resources available for the modelling project and each step of the framework.

D) Identifying relevant stakeholders

There are a number of different types of stakeholder within any Public Health project including clinical experts, decision makers and lay members. The choice of stakeholders involved with the development of the model will inevitably affect the model developed and the interventions assessed because modelling is subjective. For instance, stakeholders help define the model scope, make value judgements, use their expertise to recommend structural assumptions such as extrapolating short term trial data over the long term, and choose which interventions to assess within the model. Within some projects, the experts who inform the model development are chosen by the modelling team, whilst within others a group of experts are chosen by a decision making body, such as within the NICE process (see Section A). There is, however, usually the opportunity to involve additional experts chosen by the project team. A group of experts who will provide different expertise over a range of perspectives can be identified (see below). Practically, the approach to stakeholder communication needs to be flexible and some stakeholders will provide more input than others.

Customers, actors and system owners

Based upon Soft Systems Methodology (SSM)[1] and a conceptual modelling paper by Roberts et al.[10], the types of stakeholders to involve are:

4) Customers which might include patient representatives and lay members;
5) Actors which might include clinical experts and epidemiologic experts for all relevant diseases and methods experts;
6) System owners which might include policy experts (in addition to some of the people identified as actors).

E) <u>Understanding the problem</u>

One of the four principles of this framework is that developing and documenting an understanding of the problem is at the core of developing an appropriate model structure. This is about understanding what is relevant to the problem, and should not be limited by what empirical evidence is available.[8] The understanding of the problem phase within Figure 3 includes (i) developing a conceptual model of the problem describing hypothesised causal relationships and (ii) describing current resource pathways.

iii) Developing a conceptual model of the problem describing hypothesised causal relationships

This section outlines a methodology for developing a conceptual model of the problem by using the notation of causal diagrams, borrowing some of the methods from cognitive mapping,[21] and ensuring that the worldview of each of the stakeholders is considered.[1;21] This provides a systematic approach for developing an understanding of the problem at an appropriate and manageable level of relevance.

A causal diagram depicts the relationships between factors by arrows, using a + or – sign to indicate a positive or negative causal relationship. Causal diagrams allow feedback loops to be described which depict the dynamic complexity of the system. Each factor is a quantity such that one factor leads to an increase or decrease in another factor. For example,

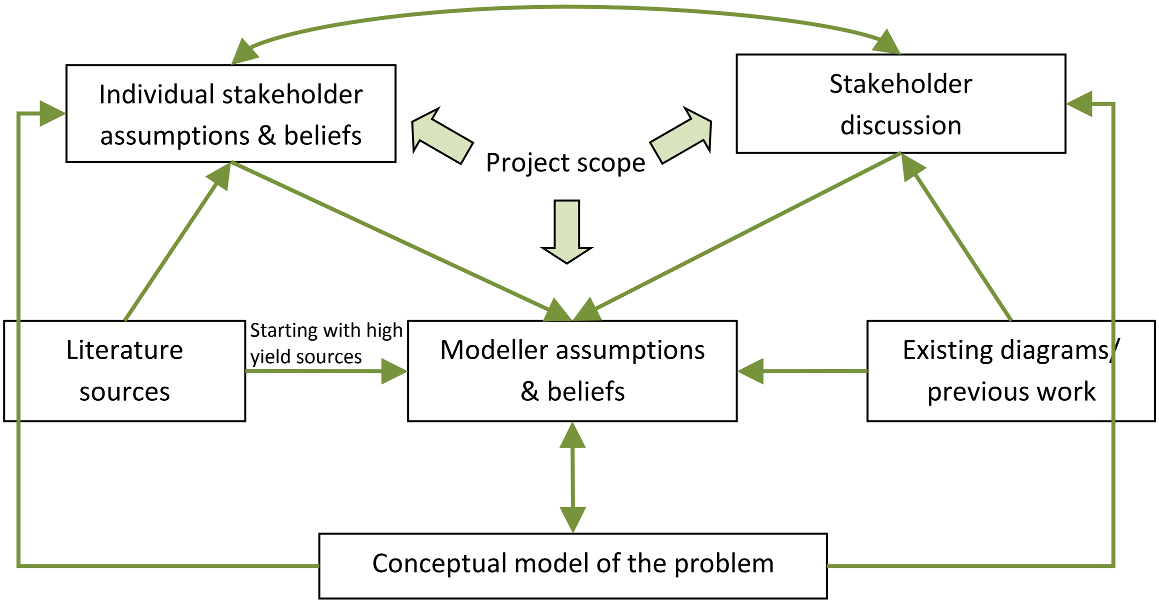
$$\text{CVD event} \xrightarrow{+} \text{Cost} \quad \text{and} \quad \text{CVD event} \xrightarrow{-} \text{Quality of life}$$

mean an increase in CVD events leads to an increase in costs and a decrease in quality of life respectively. The hypothesised causal relationships associated with the problem can be depicted using this notation, bringing together the understanding of relevant diseases, human behaviour and societal influences. Drawing upon cognitive mapping, the ultimate aims can be stated at the top of the diagram (by asking 'why is x a problem?'), with intermediate outcomes below and options for change underneath (by asking 'how can the problem be avoided?').[21] Detailed steps to develop the diagram are described overleaf.

<u>Evidence for developing the conceptual model of the problem</u>

Causal assumptions for policy prediction will be based upon experience and judgement since observational data can only be used to assess the statistical association between the specified causal relationships.[22] The proposed diagram can provide an explicit description of our hypotheses about causal relationships and the challenge is to be able to justify the causal assumptions made. The causal hypotheses can be developed based upon a range of sources including the project scope, literature, stakeholder input, the team's previous work in the area and any other diagrams which have been developed by the rest of the current project team or the decision makers to depict their understanding of the problem, as described within Figure 4 below. By developing the diagram with input from stakeholders, it allows their assumptions and beliefs to be made explicit so that they can be agreed upon or questioned. The iterative process using all of the evidence sources outlined within Figure 4 provides multiple opportunities to question and adapt the causal assumptions. Ultimately, the diagram will depict the modeller's assumptions and beliefs about the causal relationships based upon all of these sources of evidence. In doing so, some forms of information may dominate over others according to the modeller's views of the validity of the information.

Figure 4: Sources used for developing the conceptual model of the problem



Step 1: What is the problem?

The first step, based upon cognitive mapping,[21] is to ask 'what is the problem?' This is the key problem from the decision makers' perspective and could be based upon the project scope if available. The cause of the problem described should include a potentially modifiable component. The model objective is likely to be (although not necessarily) to assess the effectiveness and cost-effectiveness of interventions which might decrease this problem. Beginning the development of the diagram by identifying the key problem encourages a focused boundary around the understanding of the problem.

Step 2: Why is this a problem?

The modeller can then ask 'why is this a problem?', and continue to ask 'why?' or 'what are the implications of this?' until no more factors are identified, again based upon the methods of cognitive mapping.[21] Within Public Health economic modelling the goal may be to maximise net benefit by maximising health and minimising costs, or equity may be considered of primary importance.

Step 3: Developing additional causal links

A set of questions have been constructed which may be useful to help develop the diagram further, as shown in Box 1. The development of the understanding of the problem is iterative, and hence it may be useful to continually revisit these questions.

Box 1: Questions about the decision problem to help with developing the diagram

A1. Questions relating to the disease and the determinants of health include:
- Have any relevant disease natural histories been captured?
- Are the following determinants of health (taken from Dahlgren and Whitehead) important in determining effects and in what way:
    - Age, sex and other inherent characteristics of the population of interest?
    - Individual lifestyle factors? (incl. diet, physical activity, smoking, alcohol/ drug misuse)
    - Social and community networks? (incl. friends, family including intergenerational impacts, wider social circles)
    - Living and working conditions and access to essential goods and services? (incl. unemployment, work environment, agriculture & food production, education, water & sanitation, health care services, housing)
    - General socioeconomic, cultural and environmental conditions? (incl. economic activity, government policies, climate, built environment including transportation, crime)

A2. Questions to help ensure the understanding of the problem is sufficiently broad include:
- Are there any other (positive or negative) consequences of each concept?

A3. Questions to ensure that the dynamic complexity of the system has been captured are:
- Could there be any other factors which explain two outcomes, for links which may not be causal, but correlated.
- Are there any other possible causal links between the factors? (with the aim of establishing whether there are any feedback loops)
- Are there interactions between people which affect outcomes? (see social networks above)
- Is timing/ ordering of events important?

Step 4: Incorporating types of intervention

Within dynamically complex systems like Public Health systems, the possible types of interventions may not be easily definable at the start of the project prior to developing a sufficient understanding of the problem. Thus, the modeller can ask how to avoid or reduce the impact of the described problem. It is useful to firstly know what is considered to be current practice. Potential types of interventions can then be added based upon the project scope, any effectiveness studies identified, and by considering within the diagram where interventions may be beneficial. One way of doing this is to consider which of the potentially modifiable determinants of health (individual lifestyle factors; living and working conditions and access to essential goods; and general socioeconomic, cultural and environmental conditions) affect the decision problem. Combinations of individual, community and population interventions may be considered.[23] It is not expected that the final interventions being assessed within the model will have been chosen at this stage. However, it is important to define the types of interventions which might be assessed within the model so that their impact upon model factors, including those not already incorporated into the diagram, may be considered.

A set of questions have been constructed which may be useful for considering the impacts of the interventions, shown in Box 2. These should be considered in the context of each type of intervention potentially being assessed within the model.

Box 2: Questions about the interventions and their impacts

B1. Questions relating to the constraints of the decision making process are:

- Are there constraints on the project scope? (eg. are we constrained by the types of interventions we are assessing? What about the population?)

B2. Questions relating to the goals and mechanisms associated with the interventions are:

- What is considered to be a good outcome?
- What would happen in the absence of the interventions versus as a result of the interventions – would negative outcomes be prevented or delayed?
- What evidence exists to describe the outcomes of the intervention/ comparator over time? Are behavioural outcomes important? If so, do any relevant models of behaviour from psychology, sociology or behavioural economics exist to help describe the behaviour resulting from the intervention or the comparator? This will require additional targeted literature searches.
- Are there any determinants of health reported by the effectiveness studies which are not included within the causal diagram? Can such a relationship be described?

B3. Questions relating to the dynamic complexity of the system are:

- Might a third party act to reduce the impact of interventions?
- Are there any substantial impacts of social and/or community networks upon intervention effectiveness? Will these impacts be captured over the long term within the effectiveness evidence?
- Are there any substantial impacts of the interventions upon other lifestyle factors?
- Might the interventions have other impacts not already considered?

<u>Modelling objectives</u>

The modelling objective should be clearly defined and regularly referred to during the design-oriented conceptual modelling phase (see Section D) so that the model is built for purpose. This can be developed based upon the conceptual model of the problem, and may comprise the ultimate goals, the types of interventions being assessed and the population(s) of interest. As Roberts *et al*. suggest, the policy context of the modelling project needs to be clear, particularly in terms of the funder, the policy audience and whether the model is planned to be for single or multiple use.[10]

iv) Describing current resource pathways

The conceptual model of the problem can be used to inform what resources might need to be considered. This does not need to be a detailed description of resource use at this stage, since some factors within the conceptual model may be excluded from the quantitative model and hence it would be inefficient to collect detailed information. It also means that the general pathways can be validated with stakeholders prior to collecting detailed information. Flow diagrams, tables and/or a textual description of the resource pathways can be useful to inform consideration of the potential impact of the factors within the conceptual model of the problem upon the model results. This can be used to help choose which factors to include and exclude from the model as is discussed within the model boundary stage of the framework (see Section D(iii)).

F) Developing and justifying the model structure

This section aims to outline an approach for specifying an appropriate model structure that is feasible, valid and credible to develop into a quantitative model, which may be described as the design-oriented conceptual modelling phase.[8] As outlined within Figure 3, this includes: (i) reviewing existing health economic models; (ii) choosing model interventions and comparators; (iii) determining the model boundary (deciding what factors are included within the model rather than being part of its external environment); (iv) determining the level of detail (the breakdown of what is included for each factor within the model boundary and how the relationships between factors are defined); (v) choosing the model type (the analytic modelling technique employed, for example a Markov model), and (vi) developing a qualitative description of the quantitative model.

vii)Reviewing existing health economic models

It is standard practice within health economic evaluation to undertake a systematic review of existing health economic models in the same area. Some existing models may have been used to develop the understanding of the problem, but a systematic review of models at this stage can be used in a number of ways[24]:

- To determine whether there is already a model which could be used, either in part or as a whole;
- To consider the strengths and limitations of existing economic evaluations, which can be used to inform the model development;
- To compare and contrast how other modellers have chosen to structure the model and estimate key variables, and how the model results differ based upon these choices. This may involve considering the use of mathematical relationships such as risk equations or parameters which have been included within previous models if their source and justification has been appropriately explained;
- To identify which variables are important in influencing model results (including any which have not been highlighted during the understanding of the problem phase) and which do not substantially affect the differences in outcomes between the interventions and comparators;
- To provide an insight into the types of data available which may inform the model level of detail.

viii) Choosing model interventions and comparators

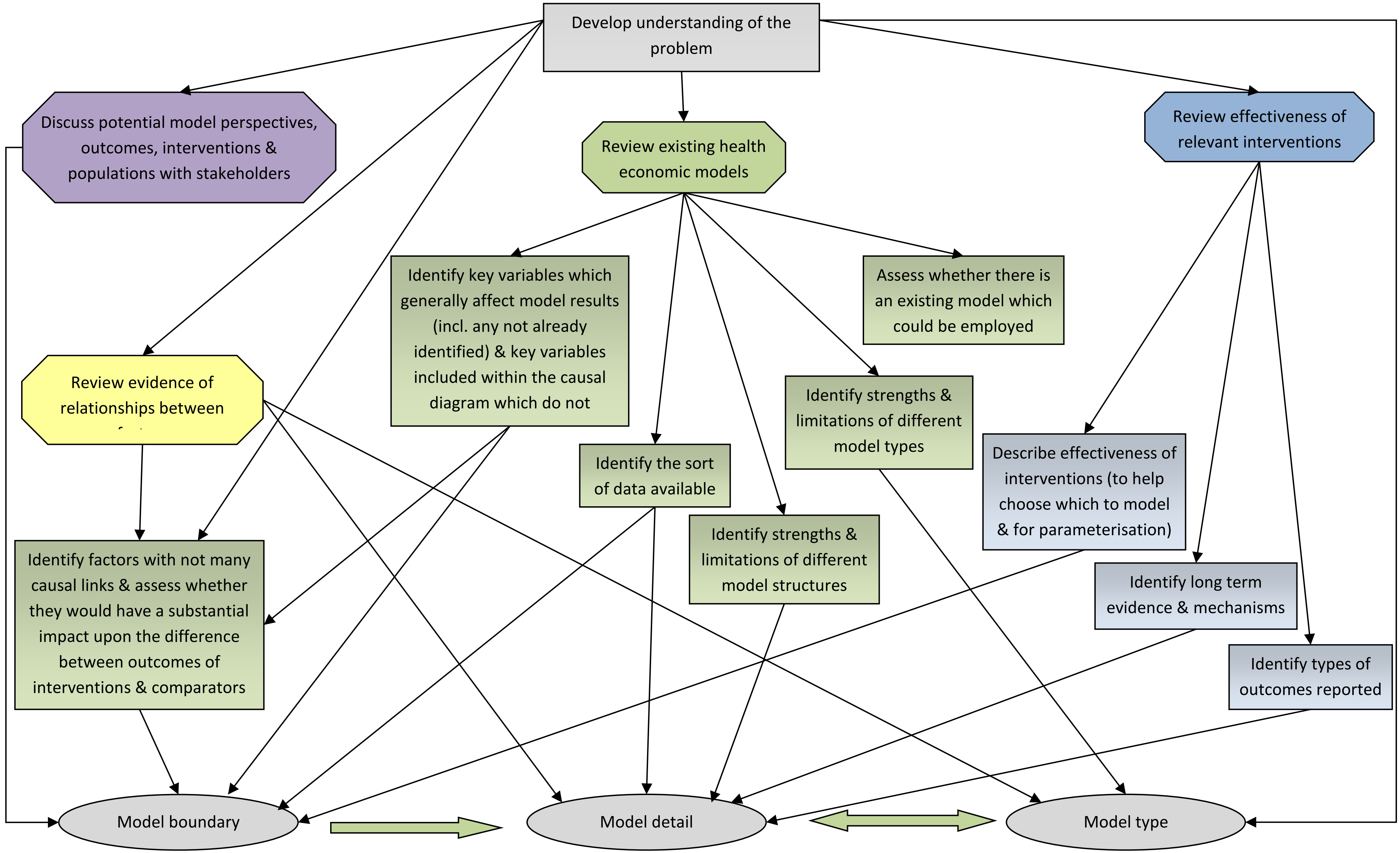
Method for choosing model interventions to assess within the model

The decision makers (with consideration of the clients' needs if they are not the decision makers) should define which specific interventions to model grounded within the results of an evidence review and according to expertise from other stakeholders. The decision makers may use the systematic review of effectiveness evidence to further limit interventions by discussing trial populations, outcomes and other potential biases. It is possible that one good study or a number of studies can be used to estimate the short term effectiveness. As far as possible, the comparator can be based upon the same studies as the interventions if this is representative in practice. If practice is substantially different, then an adjustment on the effectiveness estimate would be required. Given that economic evaluation is a comparative analysis, the model results are only meaningful in relation to the comparators chosen.[10] Which outcomes the effectiveness studies report will guide the development of the model structure.

Use of the reviews to develop the model boundary, level of detail and model type

The review of existing economic evaluations and the review of intervention effectiveness can be used to facilitate decisions around the model boundary, level of detail and model type as shown within Figure 5 below.

Figure 5: Defining the model boundary, level of detail and model type



ix) Determining the model boundary

Determining the model boundary is about deciding, based upon the understanding of the problem, what factors should be judged as relevant for inclusion within the model and which can be excluded given the time and resource constraints of the decision making process. The boundary of the model structure must differ from the boundary of the understanding of the problem in order to be able to make informed judgements about what it is important to include within the model structure (see Figure 1). It is important to define the boundary of the model such that all important interactions between the elements of the system identified within the understanding of the problem are captured.[17]

Model population and subgroups

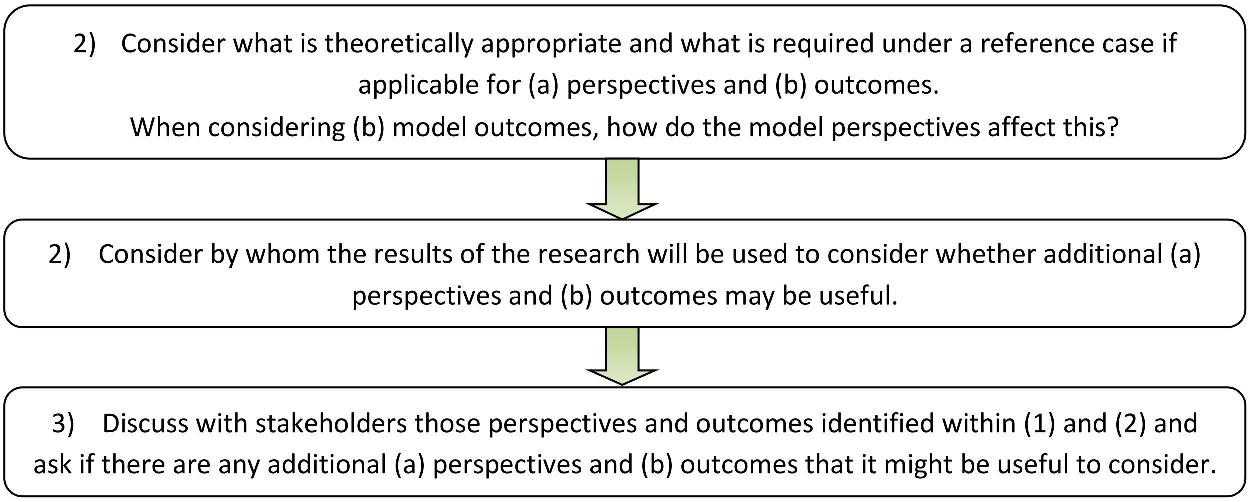
The model populations can be discussed with the stakeholders, informed by the populations within the effectiveness studies. The modelling team and the stakeholders could consider whether there is a bigger problem in a particular subgroup or whether the intervention is likely to be more effective in a particular subgroup and if there is sufficient data to undertake any subgroup analysis. These subgroups might be based upon the determinants of health outlined within Figure 2 including age, sex and other inherent characteristics of the population of interest, individual lifestyle factors, living and working conditions and access to essential goods, and general socioeconomic, cultural and environmental conditions.

Model perspectives and outcomes

Often within health economic evaluation, the NHS and PSS perspective is employed.[25] However, within Public Health economic modelling, other perspectives are likely to be relevant because substantial costs and benefits may extend beyond these sectors. Alternative perspectives include (but are not limited to) a societal perspective, a Public Sector perspective or the perspective of the particular agencies involved within the system. The perspectives of the system owners identified within Section B of the framework are likely to be appropriate. For example, if employers are considered to be system owners, then it is likely to be useful to consider an employer perspective. The choice of perspectives will also depend upon the modelling objectives. It should be noted that there are currently unresolved issues around using these alternative perspectives in terms of (i) whether it is possible or desirable to make social value judgements associated with the value of health relative to the value of other costs and benefits and (ii) the practicality of transferring costs and benefits between sectors.[26] Nonetheless, if substantial costs and benefits are expected to fall outside of the NHS and PSS, presenting these alternative perspectives is likely to be informative for decision makers.

In order to be able to compare interventions across different populations in terms of health costs and outcomes, the incremental cost per QALY may be employed, based upon New Welfare Economics.[27] Where the model boundary extends beyond health, it may be useful to understand the modelling requirements in other sectors so that relevant outcomes may be presented. One way of presenting multiple outcomes for different sectors is to present a cost-consequence analysis alongside the cost-effectiveness analysis.[28-30] Decision makers can suggest which model outcomes it would be useful to report. For both model perspectives and outcomes, the modeller should follow any specific requirements of the decision makers such as the use of the NICE Public Health Methods Guide. A method for choosing model outcomes and perspectives has been outlined within Figure 6.

Figure 6: Method for choosing appropriate modelling perspectives and outcomes



<u>Other model boundary considerations</u>

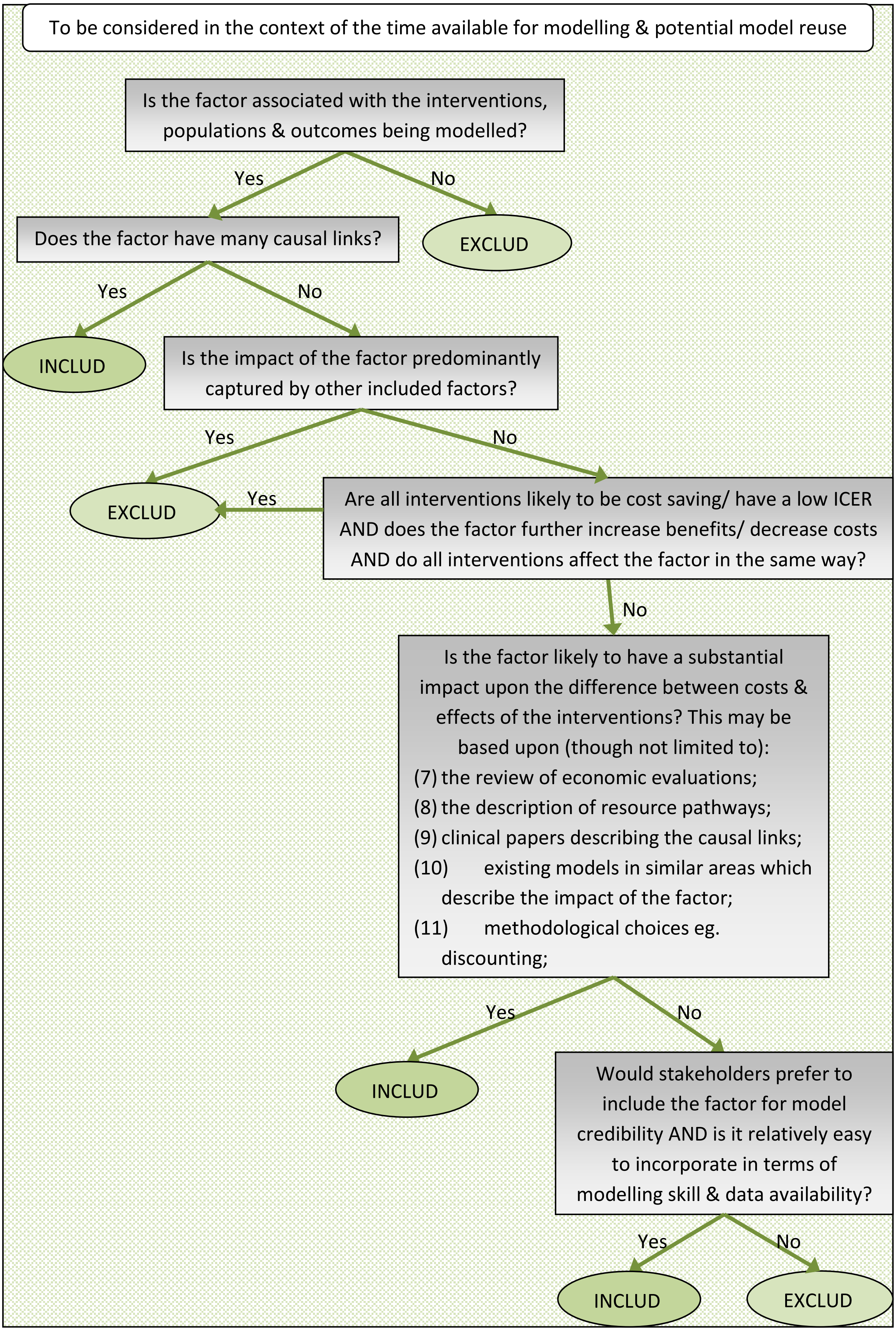
An algorithm to help define the model boundary is shown within Figure 7 and can be considered for each factor within the conceptual model of the problem. Within Figure 7, the question 'does the factor have many causal links?' aims to identify which factors are central and should be included within the model, even in the absence of data (lots of links), and which factors are less important (not many links to other factors). This can be done formally within computer software if preferred.[21] The question around whether the impact of a factor is substantially captured by other factors attempts to exclude any double counting within the understanding of the problem phase (for example, including fatigue and diabetes) as far as possible from the quantitative model.

It is valuable to predict very approximately the results of the model to facilitate model verification. These predictions can also help with defining the model boundary. Figure 7 encourages the modeller to think about whether it is worthwhile including non-central factors given the expected results of the model and the anticipated direction of effect of the factor upon those results, as well as the differential impacts of the interventions upon that factor. If different interventions impact the factor by different mechanisms, then including or excluding the factor may lead to different conclusions based upon the incremental analysis.

In terms of the question within Figure 7 around whether the factor is likely to have a substantial impact upon the difference between costs and effects of the interventions, this entails having an understanding of the magnitude of the cost and outcomes associated with the factor and the extent to which the interventions might change these. These subjective judgements will inevitably be considered in the context of the time available for modelling and the potential future uses of the model. Whether or not the factor will impact substantially upon the model results is a subjective judgement which, practically, may be influenced by the time available to develop the model. However, the model boundary stage should not be overly dependent upon the evidence or time available as this can be accommodated for by the level of detail incorporated. It is likely to be more appropriate to crudely include a factor which is expected to substantially affect the model results than to exclude it from the model completely.

Finally, to maintain model credibility, stakeholders can be asked whether they are happy, given the above justifications, with the exclusion of factors. One way of reporting this stage is to produce a table stating whether each factor is included or excluded and the justification for exclusion as suggested by Robinson.[31]

Figure 7: Defining the model boundary



x) Determining the level of detail

The level of detail is defined as the breakdown of what is included for each factor within the model boundary and how the relationships between factors are defined. A decision about which parts of the model are likely to benefit from a more detailed analysis can be made *a priori* in order to avoid situations in which the modeller focuses upon specific parts of the model because they are more easily dealt with and subsequently run out of time to develop other parts in detail. Essentially, determining the level of detail involves a mini cost-benefit analysis within which modellers can weigh up, based upon the documented understanding of the problem and the defined model boundary, whether the time required to do one analysis at a specific level of detail within the model is likely to have more of an impact upon the model results compared with the same time period spent upon other analysis, given the current evidence available and the overall time constraints. During model analysis, more detail can be incorporated if part of the model is shown to substantially affect the results. Box 3 summarises key questions for the modeller to help choose an appropriate level of detail.

Box 3: Questions to help in making judgements about the model level of detail

General

- Is the time required to do the analysis at a specific level of detail likely to have more of an impact upon the model results than the same time period spent upon other analyses, given the evidence available and the overall time constraints?

To describe the relationship between the included factors over time

- What outcomes are reported within the review of intervention effectiveness? (to help choose which causal links to include)
- What evidence is available to model the causal links and the outcomes of the factor? (to avoid relying on the first available evidence)
- What do other economic evaluations suggest are the strengths and limitations of different mathematical relationships between model factors?
- Which determinants of health are key drivers of the problem according to relevant theory?

To extrapolate study outcomes

- What outcomes are reported within the review of intervention effectiveness?
- What evidence is available for long term follow up?
- Is there sufficient evidence and time available to model social networks given the expected impact upon model results (based upon the understanding of the problem)?

The level of detail used to describe each included factor

- Which are the specific aspects of each factor that are likely to have a substantial impact upon the model results?
    - Is all costly resource use captured?
    - Are all substantial health benefits and disbenefits captured using measures acceptable to the decision maker given the available evidence?
- Are impacts included within both costs and benefits where appropriate?

How interventions will be implemented in practice

- What do the effectiveness studies describe?
- What do stakeholders suggest would happen in practice and is this likely to lead to different estimates of effectiveness to those within the study?

Searching for evidence

Data for inclusion for specifying the model structure and for the parameters will need to be identified at this point if it has not been already. This could be based upon literature identified during the development of the conceptual model of the problem for which specific literature was noted as useful, although additional specific searches may also be required. Data collection and the development of a description of the level of detail for the model will be a highly iterative process. Sufficient evidence is required to be able to justify why the modelling choices have been made.[32] It is important to note that elements for which there is a lack of empirical data which are considered to have key differential impacts upon the comparator(s) and the intervention(s) may be informed by expert elicitation. One consideration at this stage is likely to be the derivation of the disease natural history parameters which may be taken from existing studies or calibrated using statistical methods such as the Metropolis Hastings algorithm.[33]

Distinction between model assumptions and simplifications

Robinson highlights the distinction between model assumptions and simplifications; model assumptions 'are made either when there are uncertainties or beliefs about the real world being modelled' and model simplifications 'are incorporated in the model to enable more rapid model development and use, and to improve transparency'.[34] Thus, model assumptions are uncertain and alternative plausible assumptions can be tested within the model, whilst model simplifications are chosen because they are likely to have limited impact upon the model results. It is important to be explicit about both of these when describing the level of detail and highlight model assumptions which could be tested within sensitivity analyses.

Reporting level of detail

The simplifications and assumptions should be described and explained, initially for communication purposes with stakeholders and the project team to develop model validity and credibility, but also to facilitate future modelling projects in the same area. A document can be developed which specifies all of the key model simplifications and assumptions for discussion with stakeholders, ideally during a second workshop. This can help to identify the most appropriate evidence for the model and also improve model validity and credibility. Writing down all of the key simplifications and assumptions and their justification provides a mechanism for systematically questioning them within project team discussions and with the stakeholders; thus enhancing the appropriateness of the model simplifications and assumptions.

Expressing structural uncertainty

It may be that where there is more than one plausible assumption it is appropriate to develop model structures for each assumption in order to undertake posterior analysis of structural uncertainty, for example model averaging. This would be undertaken by creating a parameter to be included within the probabilistic sensitivity analysis to represent the probability of each structure being appropriate. This parameter and its distribution could then be estimated by elicitation with experts.[35]

The level of detail will be affected by the model type chosen, and hence it will be an iterative process between identifying an appropriate level of detail and choosing the model type.

xi) Choosing the model type

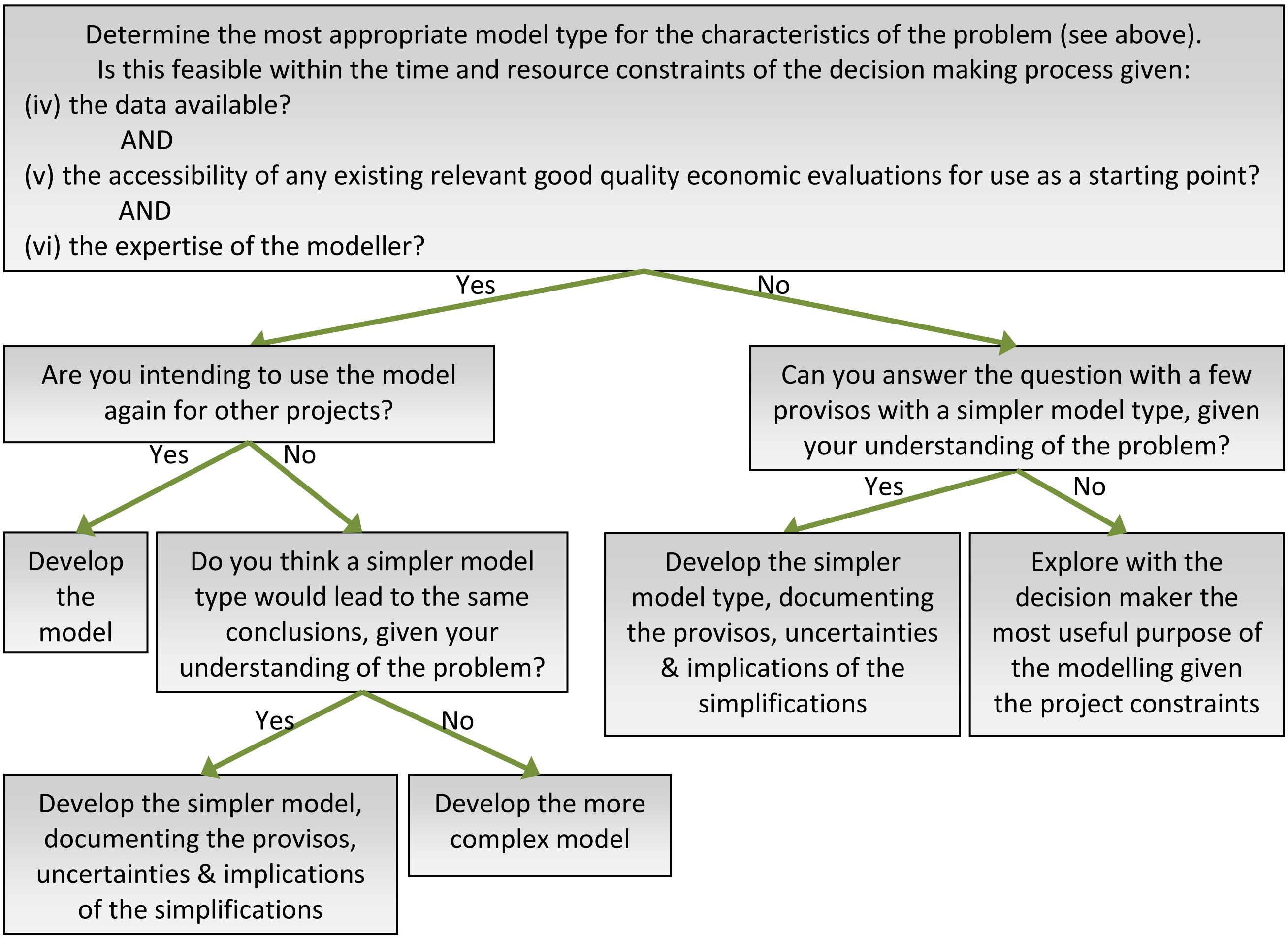
<u>Most appropriate model type given the characteristics of the problem</u>

It is important to understand the most appropriate method given the characteristics of the problem, even if it is not practical to develop this model type, so that the modeller can understand the simplifications they are making. A number of existing papers outline taxonomies for deciding upon appropriate model types given the characteristics of the problem for health economic modelling.[36-38] The taxonomy developed by Brennan *et al.* is used here.[36] It can be summarised by asking whether interaction, timing and stochasticity are important, and whether there is sufficient data for an individual level model rather than a cohort model, each of which leads to a preferred model type. Whilst decision trees and Markov models are most often employed within Health Technology Assessment,[37] because of the complexity associated with Public Health systems it is likely that alternative model types may be more appropriate. Agent-based simulation (ABS) is not included within the taxonomy by Brennan *et al.*; however it may be useful for modelling dynamically complex Public Health systems. ABS is a bottom-up approach where the behaviour of the system is a result of the defined behaviour (based upon a set of rules) of individual agents and their interactions within the system.[39] Thus, ABS may be preferable when the interactions between heterogeneous agents and their environment are important. ABS more easily allows the analyst to capture spatial aspects in order to model appropriate interactions (eg. family and friend networks for transmission of a contagious disease).[39] Studies have shown social network impacts of behaviours such as dietary habits.[40]

<u>Most appropriate model type based upon broader considerations</u>

It may not always be practical to employ the model type which is most appropriate for the characteristics of the problem. Figure 8 provides an outline of how the modeller might decide on the most appropriate model type according to broader practical issues.

Figure 8: Choosing the model structure



xii)Qualitative description of the quantitative model

A qualitative diagram of the quantitative model alongside the development of the model structure can facilitate clear communication of the final model structure to stakeholders, other members of the team and people who may want to understand the model in the future. This will depend upon the model type developed but may take the forms outlined in Table 2. Whilst the design-oriented conceptual modelling can be described prior to the quantitative model development, it may be iteratively revised according to data availability and/or inconsistencies identified during the development of the quantitative model.[8;12;13;31] These modifications should be documented throughout so that there is transparent justification for the final model developed.

Table 2: Suggested diagrams to represent the implemented model

Model type developed	Suggested diagram
Decision tree	Decision tree diagram
Markov model	State transition diagram
System dynamics	Influence diagram / stock and flow diagram
Individual event history model	State transition diagram
Discrete event simulation	Activity cycle diagram
Agent based model	A flow diagram

4. Discussion

A framework has been developed as a helpful tool for modellers of Public Health economic models. In 2011 Chilcott *et al.* highlighted the lack of formal methods for model development[41] and when this research began, there were no publications associated with conceptual modelling within health economic modelling. Since then the International Society for Pharmacoeconomics and Outcomes Research and the Society for Medical Decision Making (ISPOR-SMDM) Joint Modeling Good Research Practices Task Force have developed guidance around conceptual modelling for health economic modelling and a Technical Support Document has been developed for the National Institute for Health and Care Excellence Decision Support Unit (NICE DSU) around identifying and reviewing evidence to inform the conceptualisation and population of cost-effectiveness models.[8;10] The recent development of these two conceptual modelling frameworks highlights the importance and timely nature of this work. The conceptual modelling framework developed here complements and adds to these existing frameworks by focusing upon Public Health economic modelling. The main contribution of this research is that it provides a systematic approach to developing Public Health model structures, and in particular, systematic consideration of:

a. Dynamic complexity (feedback loops, unintended consequences);
b. The broader determinants of health;
c. How to progress from an understanding of the problem to the model structure;
d. Stakeholder involvement.

Initial evaluation will be via a focus group with modellers. It is offered for further testing within case studies. The conceptual modelling framework that has been developed aims to provide a reference document which can be continually improved following its use within different Public Health economic modelling projects and according to developments within other related research areas (eg. modelling human behaviour, quantifying relevant outcomes). The framework has been developed within a UK context and would benefit from testing within an international arena. For more information about how the conceptual modelling framework was developed and the evaluation of the framework please see the doctoral thesis by Squires (in preparation).[3]

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Appendix F: Critical assessment of the conceptual modelling framework

Appendix F1: Topic guide for the evaluation focus group meeting

Aim: to evaluate the potential of the conceptual modelling framework to improve the quality of Public Health economic model structures

Preliminaries

(7 mins)

1) Introduce Paul and I (and explain that I won't be staying in the room and why)
2) Outline of the research topic, purpose (important for participation), funder
3) Confidentiality (anonymous, but may be identifiable), audio recording, what will happen to the data, dissemination. Consent forms (get everyone to sign if not already).
4) Please could everyone treat what is said as confidential and not repeat it outside of the session without permission from the relevant participant.

I leave.

(8 mins)

5) Indication of expectations – want to have a discussion, participants should not wait to be invited before speaking (although don't talk over each other), everyone's views are of interest, want to hear as many different thoughts as possible, as such if agree or disagree with other participants say so.
6) Ask everyone to introduce themselves – names & brief background focusing upon Public Health modelling.
7) Could highlight the diversity/ similarity of the group as a whole.

Topic guide

Thinking of your **previous experience** (eg. think of previous projects), would **a** conceptual modelling framework have been **helpful and why**? (10 mins)

Can give specific examples.

Might it help with:

- providing a tool for communication with stakeholders?

- aiding the development of modelling objectives?

- guiding model development and experimentation?

- improving model credibility, verification, validation?

-allowing model reuse?

What do you think would be the **key benefits and issues** with using **the conceptual modelling framework presented**? (30 mins – let this keep going longer if covering other topics)

Why?

Might it have helped structure your thinking?

Are there aspects within the framework which you may not have considered? Eg. some of the broader determinants of health, the dynamic complexity with feedback loops etc.

Would it have helped with stakeholder involvement decisions?

Might there be feasibility issues with its use?

Would you/ other modellers think that it does not add anything to what they currently do?

Might it be less appropriate for some Public Health contexts? (relates to below question)

Where there any parts of the framework that were more or less helpful than others and why?

In what circumstances might you use or not use the outlined conceptual modelling framework? (15 mins)

Would the decision to use the framework be affected by project timeframes, resources or the decision making context?

To what extent is it relevant beyond the NICE process?

To what extent do you think it might have international relevance?

Who do you think might benefit from using the framework? (5-10 mins)

Experienced/ inexperienced modellers (in public health?)

In what way do you think the outlined conceptual modelling framework **has the potential to improve the quality** of Public Health economic model structures? (30 mins)

Why?

To what extent do you think it might:

- provide a tool for communication with stakeholders?

- aid the development of modelling objectives?

- guide model development and experimentation?

- improve model credibility, verification, validation?

-allow model reuse?

You have been very quiet; do you have concerns about whether the conceptual modelling framework would have the potential to improve the quality of Public Health economic model structures?

What do you think are the **requirements for successful implementation** of the conceptual modelling framework? (5-10 mins)

What further evaluation might be useful?

What might encourage its use? Eg. Publication, conference presentations, recommendation by a decision-making body such as NICE.

Is there **anything else** you'd like to say around what we've talked about today? (5 mins)

Generic probes

Why do you think that?

What did you do after that?

You talked about… Tell me more about…

It would be useful to explore x further…

What do you mean by…?

Other notes about running the focus group

Pressure on participants to conform: Ask whether anyone has any different views or ask a person who is likely to have a different view

Dominant person: That's really helpful; does anybody else have a view on this?

Quiet person: What do you think? Or you said xxx previously, what…

Recording non-verbal behaviour: 'Everyone's nodding a lot – why is that?'

Appendix F2: Verification of the conceptual modelling framework

Framework aims	How this was incorporated into the conceptual modelling framework
A conceptual modelling framework specifically for Public Health economic modelling has the potential to provide more guidance about the approach than a generic framework.	The entire framework is based upon domain-specific procedures and considerations.
To aid the model development process but not constrain it. It should allow for the variation in requirements of different Public Health economic modelling and be clear that there is scope for further methods development given the early phase of development of a framework within Public Health economic modelling.	Phase A involves the modeller aligning how the framework is used with the decision making process. The general tone of the framework aims to be suggestive rather than restrictive. The HESG paper states within the discussion that there is scope for further methods development; however the document circulated to the focus group participants did not make this clear.
To provide a general outline of the model development process in Public Health economic modelling.	Figure 3 provides this.
To provide a tool for communication with the project team and stakeholders.	The diagrams and tables suggested aim to aid communication.
To help modellers make decisions about what to include and exclude within a model.	Figure 9 is a flow chart which aims to help modellers make judgements about what to include/ exclude from the model based upon the documented understanding of the problem.
To help modellers determine appropriate and inappropriate simplifications of the problem.	Box 3 outlines questions for modellers which aim to help them make judgements about the appropriate level of detail, based upon the understanding of the problem. This seems like the least well developed area of the conceptual modelling framework and this may because it is not possible to produce a simple algorithm to help modellers think about this.
To provide a transparent approach for choosing model interventions.	Section Dii outlines an approach with a flow diagram describing this.
To encourage understanding of the implications of the structural choices that the modellers make.	Documenting the understanding of the problem should help modellers consider the simplifications they are making when developing the model and the implications of these. Figure 10 encourages the modeller to consider the implications of choosing a specific model type.
To help decision makers make decisions, as opposed to trying to represent reality.	There is acknowledgment that time constraints are an important factor throughout, including when considering the most appropriate analytic model type.
To facilitate clear reporting of the model structure and the process by which it was developed.	(1) Documenting the understanding of the problem describing the hypothesised causal relationships; (2) Tabling the perspectives and outcomes and describing the interventions, comparators and populations to assess; (3) Tabling what is included/ excluded within the model and why compared with the understanding of the problem; (4) Recording the key model assumptions/ simplifications and their justification; (5) A diagram of the model structure.
To encourage modellers to question the assumptions of the experts and decision makers.	This is explicitly stated within Phase B of the framework.

Framework aims	How this was incorporated into the conceptual modelling framework
To take into account that modellers have different skill sets and encourage modellers to recognise potential skill set biases and moderate impact.	The general tone of the framework aims to be suggestive rather than restrictive. Figure 10 is a flow chart to help modellers make judgements about the most appropriate analytic model type and it considers the modellers expertise.
To include an example to illustrate the methods.	The methods are illustrated throughout using the diabetes project example.
To be clear about what the framework can and cannot do.	This is specified when describing the aim of the framework; however more detail could be added based upon the analysis of the focus group data and any future evaluation.
To be culturally acceptable and simple to use in practice (use of flow diagrams, tables and boxes rather than large chunks of text).	There is a mixture of text, diagrams, tables and boxes; however the qualitative research suggests that there is currently too much text (see Section 7.3.2).
To clearly and concisely describe why a conceptual modelling framework is beneficial. A discussion about the preconceptions that modellers may have which might be inconsistent with the conceptual modelling framework could also be described. In addition, the key principles and methods within the framework need to be well justified and evidence-based where possible.	Within the introduction Table 1 describes the benefits of a conceptual modelling framework. The key principles and methods are justified and relevant literature is referenced where appropriate.

General principles: How the modeller should approach the problem	How this was incorporated into the conceptual modelling framework
A systems approach is expected to be an appropriate approach for modelling most Public Health systems, taking a holistic view of the system and focusing upon the relationships between components. This involves understanding the complex causal chains, including feedback loops, and the unintended consequences of the comparators and interventions upon other parts of the system.	The method for documenting the understanding of the problem involves the modeller describing the hypothesised causal relationships between factors and the accompanying questions encourage consideration of feedback loops and unintended consequences. It is suggested that relevant stakeholders are identified using some features of soft systems methodology and that these are involved throughout model development.
A systematic consideration of the determinants of health is central to identifying all key impacts of the interventions within Public Health economic modelling.	The questions to help the modeller develop the understanding of the problem focus upon the broader determinants of health. It is also suggested that they are considered when choosing the interventions and subpopulations of interest.
To involve stakeholders within each stage of conceptual model development in order to encourage learning about the problem, develop appropriate model requirements, facilitate model verification and validation, help develop credibility and confidence in the model and its results, guide model development and experimentation, and encourage creativity in finding a solution.	It is suggested that stakeholders are involved during all stages of model development and there is advice for doing this throughout the framework.
To specify modelling objectives and develop a thorough documented understanding of the problem, and subsequently choose model options, determine the model scope and level of detail, and identify structural assumptions and model type, with a different representation for each. This model development process is iterative.	The conceptual modelling framework follows this general approach, an overview of which is provided within Figure 3.

Methodological considerations: Things the modeller should do during conceptual modelling	**How this was incorporated into the conceptual modelling framework**
To consider the use of modelling methods to enable the broader determinants of health to be incorporated such as agent-based simulation and social network analysis.	Different model types, including agent-based simulation, are considered within Phase D.
To be practical within a decision making context by considering the needs of the decision makers, including the time requirements upon the stakeholders.	Phase A involves the modeller aligning how the framework is used with the decision making process. The framework aims to be flexible throughout.
Cognitive mapping, causal diagrams and SSM may be useful for objective setting and developing the understanding of the problem.	An approach is suggested combining cognitive mapping and causal diagrams. Stakeholders are identified using features of SSM.
At an early stage, to develop an understanding of the question and the interventions, the population and subgroups of interest.	These are early stages of the framework as shown within Figure 3.
To consider the most appropriate outcome measure and perspective to report to decision makers.	Figure 8 is a flow diagram showing how these might be chosen.
To consider the choice of experts and the implications of these choices.	Phase B describes how stakeholders might be identified.
To consider any diagrams, such as logic models, developed by decision makers or other parts of the team on the project.	It is suggested that these are considered when developing the understanding of the problem.
To recognise relevant methods guidance (eg. NICE methods guide).	It is suggested that such guidance is considered when developing the understanding of the problem and when specifying the model scope.
To consider the likely cost-effectiveness of the interventions in making decisions about model structure.	This is incorporated into Figure 9 and Box 3 which aim to help the modellers make judgements about the model boundary and level of detail respectively.
To consider the trade off between developing an appropriate structure for the problem versus ability to meet deadlines.	Figure 9, Box 3 and Figure 10, which aim to help the modellers make judgements about the model boundary, level of detail and model type respectively, all include consideration of the time constraints of the project.
To consider the trade-off between providing stakeholders with something to critique and limiting their thinking.	This is considered within Phase C (understanding the problem).
To explore the use of existing models in the same area.	Section Di suggests exploring existing models and how this might be useful.
To consider whether a more exploratory analysis would be useful given time constraints.	This is included within the flow diagram for choosing model type (Figure 10).
To suggest that the model perspectives, outcomes, potential interventions and populations are discussed at an early stage of the project, particularly if the project question and scope have been developed by researchers rather than decision maker.	These are early stages of the framework as shown within Figure 3. It is suggested within the process suggestions that these are discussed within the first workshop with stakeholders if one is held.
To undertake a first step to align the framework with the decision making process and develop a project plan.	Phase A involves the modeller aligning how the framework is used with the decision making process. The framework aims to be flexible throughout.
To describe resource use as a two-stage process in order to increase efficiency of model development; first establishing very generally what sort of resource processes there are for key components of the conceptual model of the problem; and second describing resource use in detail during the justifying and developing the model structure phase.	This has been described within Phase Cii.
For the project team to question each other's assumptions throughout the conceptual modelling process. It is important for the modeller to be ready to acknowledge that the beliefs that they had about the system may not be the most appropriate.	This is stated within Principle 3 of the framework.

Consideration of relevant issues for inclusion in the model	How this was incorporated into the conceptual modelling framework
To consider equity and the social gradient.	Included within Step 2 of Phase Ci, although there is no discussion about why this is important within Public Health.
To consider non-health costs and outcomes and what is a 'good' outcome.	Included as questions in Box 1 to help develop the understanding of the problem.
To consider stakeholders who might act to reduce/ increase the impact of intervention.	Included as a question in Box 1 to help develop the understanding of the problem.
To incorporate outcomes dependent upon the determinants of health and consider step-changes in societal behaviour due to sufficient people adopting a type of behaviour.	Included as a question in Box 1 to help develop the understanding of the problem.
To consider assessing population, community and individual-level interventions.	A consideration when identifying potential intervention types in Phase Ci.
To consider the culture and politics of the system.	Included within the key principles of good practice.
To consider heterogeneity and whether there are any appropriate subgroups, including socioeconomic status.	Questions around the determinants of health (which highlights heterogeneity) are considered within Box 1 and Box 2. Subgroups are considered within Phase Diii.
To highlight the difference between causation and association.	Included within a process suggestions box and as a question within Box 1.
To choose model type according to interactions and heterogeneity.	Use of Brennan’s taxonomy within Phase Dv (choosing the model type).
To consider intergenerational impacts.	Included as a question in Box 1 to help develop the understanding of the problem.
To explore the biases such as trial design associated with the effectiveness studies.	Suggested within Phase Dii (choosing model interventions).
To encourage understanding of the modelling requirements in other sectors when the scope of the model extends beyond health and wellbeing.	Suggested within Phase Diii (determining the model boundary).
To think about the constraints of the project scope.	Included as a question in Box 2 to help incorporate interventions into the understanding of the problem.
To encourage modellers to explore the exact meaning of topic specific terminology that also has a lay meaning.	Considered within Principle 3 of the framework.
To consider whether behaviour is being prevented or delayed.	Included as a question in Box 1 to help develop the understanding of the problem.
To encourage reflection upon whether there are other consequences (positive or negative) not considered by the effectiveness studies.	Included as a question in Box 1 to help develop the understanding of the problem.
To consider classifying and defining population subgroups of interest, defining harms and outcomes and modifiable components of risk, specifying the baseline position on policy variables, estimating the effects of changing the policy variables on the risk factors, risk functions relating to risk factors to harm, and monetary valuation.	Included, although not in the same form, throughout the framework.
To describe how to incorporate the disease natural history within the conceptual model of the problem.	Described within Phase Ci (understanding the problem).
To highlight the importance of depicting time in the conceptual model of the problem.	Described within Phase Ci (understanding the problem).
To consult relevant theory to choose which determinants of health to include.	Considered within Phase Ci (understanding the problem) and described within Phase Diii for judging the model level of detail.
To incorporate additional questions around the determinants of health to accompany the conceptual model of the problem.	Included as questions in Box 1 to help develop the understanding of the problem.
To expand the understanding of the problem if stakeholders broaden the potential interventions being assessed.	Included as a question in Box 2 to help incorporate interventions into the understanding of the problem.

Process: Suggestions about the process the modeller might follow, although there may be alternative processes which would allow the general approach to be taken.	**How this was incorporated into the conceptual modelling framework**
If the term 'conceptual model' is employed within the framework it needs to be defined and which groups of people might be involved in the model development process should be clear.	The stakeholders are clearly defined within Phase B.
To encourage the use of the model for understanding the effectiveness of the interventions as well as the cost-effectiveness.	Included within a process suggestions box.
To align the stakeholders' expectations of the process and their requirements with the modellers' expectations.	Included within a process suggestions box.
To highlight that stakeholder recruitment is not a trivial task and that the project team should reflect upon potential stakeholder worldviews to understand their motivation for involvement in order to raise the efficiency of recruitment.	Included within a process suggestions box.
To choose lay members to represent different types of people within society where those differences are likely to be important to the topic area (eg. ethnic minorities, lower BMI, lower socioeconomic status) where feasible. If this is not possible, modellers could consider whether the assumed chains of behavioural causation developed within the conceptual model of the problem are likely to be violated by a particular subpopulation.	Included within a process suggestions box.
To describe a possible information retrieval approach for developing the understanding of the problem and model structure.	Included within a process suggestions box.
Decision makers should determine which interventions to consider within the model, based upon evidence reviews and input from other stakeholders. Discussions between the project team and the stakeholders may be required to limit the breadth of the search for the effectiveness review.	Included within Phase Dii.
The modeller should revisit the questions within the conceptual modelling framework to facilitate the development of the conceptual model of the problem throughout its development.	Suggested within the understanding of the problem phase, above the questions.
To highlight that within any workshops, stakeholders should be told that the aim is not necessarily to reach consensus; however after sharing divergent views, it is useful for the project team to limit these to a few key concepts and issues. During the understanding of the problem phase, it would be valuable to provide some sort of description of the degree of consensus/ disagreement between stakeholders.	Included within a process suggestions box.
To highlight that there is a need for flexibility with the approach for involving stakeholders within the model development process and several means of communication may be required. It may be appropriate to try and hold workshops or meetings with stakeholders around relevant conferences or meetings. Whilst workshops have the advantage of allowing issues to be discussed and debated, one-to-one meetings or telephone conversations may be employed in addition to, or instead of, workshops.	Included within a process suggestions box.
To highlight that the resource requirements during the workshops are substantial in order to maintain engagement with the stakeholders, record what is said and process and collate information developed during the workshop to share with the group later within the meeting.	Included within a process suggestions box.
Stakeholders could spend 2-3 minutes at the beginning of the first stakeholder workshop (or a paragraph of written text if not within a workshop) describing their perspective, what they think they can give to the project and what they would like out of their involvement.	Included within a process suggestions box.
The diagram developed within the understanding of the problem phase can be described as a 'conceptual model of the problem depicting hypothesised causal relationships'.	This is the terminology used throughout the framework.