A DECISION SUPPORT METHOD FOR SELECTING DESIGN AND MANUFACTURING ALTERNATIVES

by

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

Abstract

One of the most important decisions which should be made at the early stage of the design process is to select one design alternative. Not only should the decision be made by tradeoffs between different conflicting criteria of the single stakeholder but also to aggregate different outcomes obtained by multiple stakeholders. This thesis represents a decision support tool for selecting design alternatives, in which a single choice has to be made between a number of alternatives in the presence of single or multiple stakeholders, multiple conflicting criteria, and resource limitation, based on two routes: using Analytic Hierarchy Process (AHP) alone and the combination of AHP with Zero-One Goal Programming (ZOGP). Using AHP-ZOGP allows the concept-concept and concept-specification approaches to be considered simultaneously in order to improve the process of concept design selections.

Different outcomes obtained by using AHP alone, can be aggregated by two heuristic methods based on distance function, to generate an index for final single selection. The first method uses the final weights obtained by AHP, while the second method uses its detailed weights.

AHP weights are then used to construct the ZOGP's objective function and constraints' parameters of intangible criteria for each individual stakeholder. Another ZOGP model can be constructed to aggregate the different outcomes, obtained by individual ZOGP's models, based on combining their objective functions. The advantages of using aggregated ZOGP models in comparison with heuristic methods are, not only ZOGP aggregated model is able to minimise the undesirable distances between sub-criteria and Product Design Specification (PDS), but also it can take into account the resource limitations explicitly.

The case studies, which involved vehicle manufacturing technology selection, choosing a peristaltic pump, selection of a swivel joint design, and the justification of advanced manufacturing systems, possessed the characteristics of the type of problems this tool is intended to support. The case studies showed how it is possible to consider many criteria from different stakeholders to yield a single outcome that covers the requirements of those stakeholders.

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CHAPTER 1
INTRODUCTION

1.1. Overview

The success of manufacturing companies depends on their ability to identify the needs of customers and to quickly create products that meet these needs and can be produced at low cost (Slack et al., 2004). Achieving these goals is not solely a marketing problem, nor is it solely a design problem or manufacturing problem; it is a concept development problem involving all of these functions (Ulrich and Eppinger, 2000). Concept development process is the set of activities beginning with the perception of a market opportunity and ending in the production and sale of a product (Pugh, 1991). The concept development entire process includes the activities shown in figure 1. It should be noted that rarely does the entire process proceed in purely sequential fashion, as is shown in figure 1, completing each activity before beginning the next. In practice, these activities may be overlapped in time and iteration is often necessary. The dashed arrows in figure 1 reflect the uncertain nature of progress in product development. At almost any stage, new information may become available, so it is necessary to step back to repeat an earlier activity before proceeding. In other words, the iteration is an inevitable part of concept design process. The stages of this process are explained briefly.

Identifying customer needs: The goal of this activity is to understand customers' needs and to effectively communicate them to the development team. The output of this step is a set of carefully constructed customer need statements, organised in a hierarchical list, with importance weightings for each need.

Establishing target specifications: Specifications provide a precise description of what product has to do. They are the translation of the customer needs into technical terms. Targets for the specifications are set early in the process and represent the hopes of the development team. Later these specifications are refined to be consistent with the constraints imposed by the team's choice of a product concept. The output of this stage is a list of target specifications. Each specification consists of a metric, marginal and ideal value for the metric.

Concept generation: The ideas for new product can come from sources outside the organisation, such as customers or competitors, and from sources within the organisation, such as sales staff or from the research and development department. Ideas are not the same as concepts. In fact, ideas need to be transformed into concepts so that they can be evaluated and then operationalised by the organisation. Concepts are different from ideas in that they are clear statements that both encapsulate the idea and indicate the overall form, function, purpose and benefits of the idea. The concept should be simple to communicate so that everyone in the organisation can understand it, make it and sell it. Usually marketing department is responsible for keeping an eye and ear on the marketplace in order to identify new opportunities and possible concepts that might be appropriate.

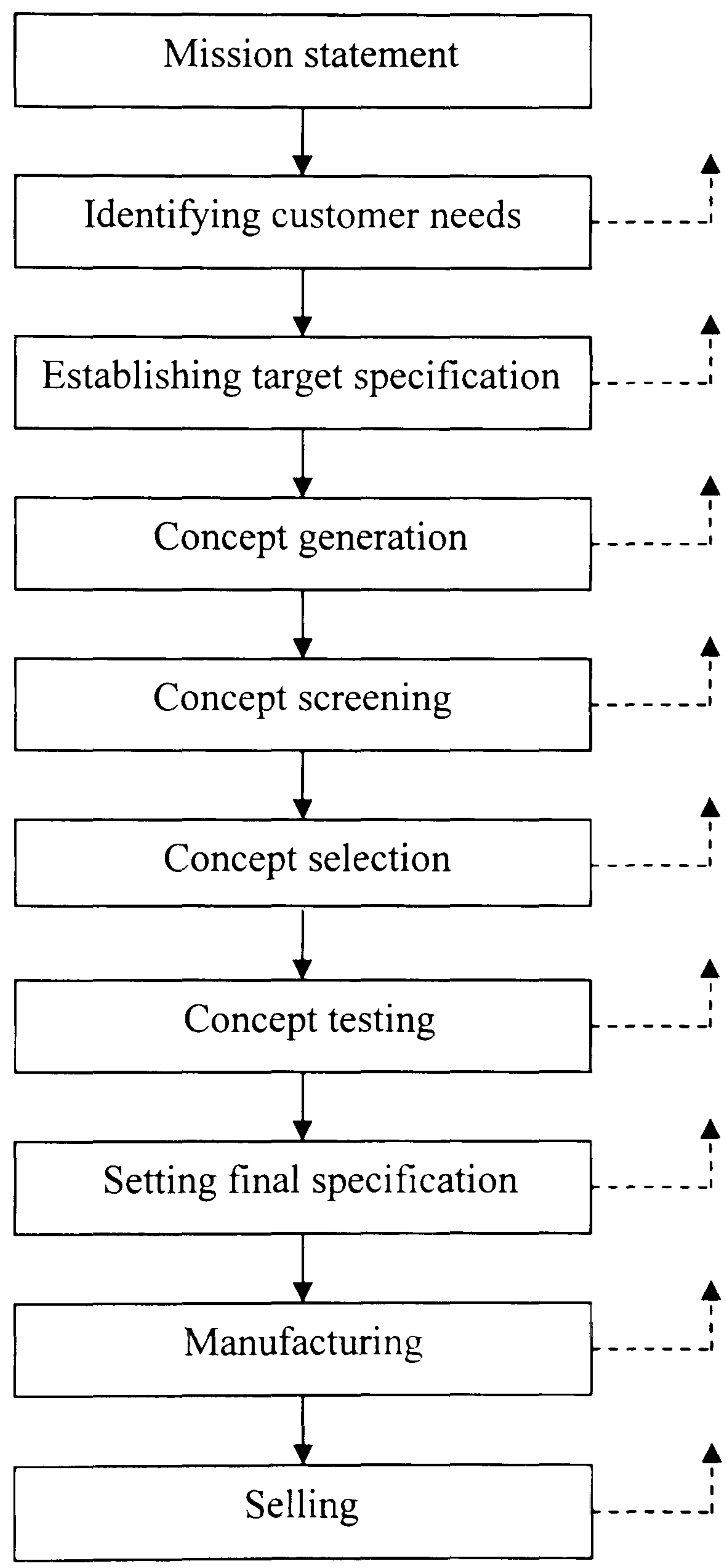

Figure 1 Activities of concept development process

Concept screening: A large set of concepts should be initially screened down to a smaller set because some are clearly not feasible for obvious reasons, such as infeasibility for manufacturing or the cost of producing (Lovatt and Shercliff, 1998).

In other words, not all concepts which are generated will necessarily be capable of further development into products. The purpose of the concept screening stage is to take the flow of concepts emerging from organisation and evaluate them for their feasibility, acceptability, and risk. Concepts may have to pass through many different screens, and several functions might be involved.

Concept selection: Concept selection is defined as the process of evaluation and selection from a range of competing alternatives with respect to customer needs and other criteria, comparing their relative strengths and weaknesses, and selecting one or more concepts for further investigation, testing, or development (Green, 2000). Concept selection is in fact the process of narrowing the set of concept design alternatives under consideration. It should be noted that concept selection is a convergent process; it is frequently iterative and may not produce a dominant concept design immediately (Liu et al., 2003). Using decision making techniques which compare the remaining alternatives, a dominant concept can then be chosen.

Concept testing: One or more concepts are tested to verify that the customer needs have been met, assess the market potential of the product, and identify any shortcomings which must be remedied during further development. If the customer response is poor, the development project may be terminated or some earlier activities may be repeated as necessary.

Setting final specifications: The target specifications set earlier in the process are revisited after a concept has been selected and tested. At this point, the development team must commit to specific values of the metrics reflecting the constraints inherent in the product concept, limitations identified through technical modelling, and tradeoffs between cost and performance.

Manufacturing: Having generated an acceptable product concept with revised target specifications, the next stage is to manufacture the product in a reasonable quantity depends on the nature of the product. Manufacturing comprises of courses and/or programs related to planning, managing and performing the processing of materials into intermediate or final products and related professional and technical support activities such as production planning and control, maintenance and manufacturing/process engineering. In summary, it is the way that products are made in the real world by transformation of .raw materials into finished goods for sale with the use of industrial machines.

Selling: The ultimate aim of concept development process is to sell the products. The selling stage completes the total design activity development.

The problem of choosing the most appropriate concept design alternative after screening phase is a critical step because all subsequent detailed design and process design is based on this decision. Success of the complete design process depends on selecting the right alternative (Green, 2000). Changes made early in the design process are less costly than those made in detail design and later stages (Childs. 2004). Failing to choose the most appropriate concept design alternative may lead to rework, redesign and waste of resources. Although there are a number of techniques that can be employed at this stage to evaluate and improve the concept design selection but they fail to consider all of the stakeholders involving in the process of decision making. The most recent approach is Quality Function Deployment (QFD) which tries to capture what the customer needs and how it might be achieved Hauser and Clausing, 1988). Its major aim is to convert or translate the customers' requirements into corresponding engineering characteristics (Thompson and Fallah, 1989). The problem with QFD is that: 1) designers interpret customer requirements and make tradeoffs that subsequently cannot be traced by other members of the concept development team because information about the customer, as provided by the marketing team, lacks sufficient detail for the entire design process (Bailetti and Litva, 1995); 2) there is a disconnection between the customer requirements gathered through marketing process, and decisions that relate to design (Beiter and Ishii, 1999). In other words, QFD can effectively support the improvement of existing products rather the development of new ones (Dawson and Askin, 1999; Schmidt, 1997); 3) the concern of QFD is given to customers, neglecting other stakeholders which may affect the selection problem; and 4) QFD does not consider other viewpoints that may exist in the process such as limitations of the manufacturing company, and it needs a large amount of subjective data.

1.2. Problem statement

In general, manufacturing companies always deal with selection problems. Choosing materials for making products, selecting the most appropriate manufacturing process, choosing new products to launch and choosing between different design alternatives are some examples of this situation. In these situations, companies need to choose at least one single alternative which best fits to their strategic objectives of the company. Some of these decisions may be strategic decisions because they can affect the company in long period. Therefore, it is necessary to use rational decision making techniques to evaluate the most appropriate alternative which can satisfy the stakeholders' criteria.

Evaluating and selecting the most appropriate concept design alternative is an important task that manufacturing companies should carefully take into consideration (Chen and Lin, 2002; Green, 2000). In the process of designing the concept alternatives, designers should pay attention to the conflicting criteria that exist between different stakeholders inside an organisation and customers involved in the process outside of the organisation (Takai and Ishii, 2001). It is a complex task because of the conflicting tangible and intangible criteria, sub-criteria, different stakeholders, and real constraints. Tangible criteria are those that can be objectively measured and so, they can be compared with each other with a physical scale (such as cost) and intangible criteria are those that cannot (such as flexibility). Different stakeholders may favour different alternatives, but what is important for the company, is to select that alternative which can satisfy the diverse stakeholders' viewpoints as much as possible.

The design alternative which is best from the point of view of, for example, the manufacturing department, may not be the best from another department, for instance, marketing, because each individual department has its own perception, viewpoint and criteria. In addition, there are always customers outside the organisation who may prefer other alternatives to those selected alternatives by the departments. In this situation, decision maker(s)[1] is unable to decide between a number of alternatives not only because of the presence of different stakeholders but also because there are often multiple conflicting criteria within each stakeholder. Usually the decisions are made with multiple individuals inside each department. So in this situation, using group decision making methods will be necessary. In general, this sort of problem should be investigated at the Multiple Criteria Decision Making (MCDM) environment from perspectives of Multiple Stakeholders Decision Making (MSDM). In general term, MCDM-MSDM refers to the solving of decision problems involving multiple (generally conflicting) criteria and multiple stakeholders. Solving means that a reasonable alternative should be chosen from a set of available ones in the presence of multiple criteria and multiple stakeholders. Therefore, in the process of solving MCDM-MSDM problems, the interventions of stakeholders are necessary.

Selection of the most appropriate concept design alternative that can best satisfy the diverse conflicting criteria is a MCDM problem (Khatami Firouzabadi and Henson, 2004). However, in the presence of multiple stakeholders, the problem is converted to a MCDM-MSDM problem. Among several created concepts, the company should decide which of them goes through the detailed design in order to finally make the product. Each individual stakeholder can choose the best alternative from his viewpoint with tradeoffs between conflicting criteria. The problem will be more complicated if the stakeholders' viewpoints conflict with each other.

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[1] Decision maker is the person who has legitimate and adequate power to implement the decision. He may be a main stakeholder.

The available methods for concept design selection problems are categorised within two general approaches as concept-specification and concept-concept (Green, 2000). Concept-specification comparison involves direct comparison between the concept alternative and the Product Design Specification (PDS), while concept-concept approach involves direct comparison between two competing concepts. Although both approaches to design evaluation are well known to designers and form the basis for many methods of evaluation, individual application of these two approaches are insufficient because they cannot consider the PDS and comparing the alternatives with each other simultaneously. In one hand, comparing the alternatives with each other is important because insignificant differences between alternatives can be detected (Malhotra and Birks, 1999). On the other hand, PDS should be considered because it reflects how much an alternative has fulfilled its requirements. To overcome this problem, this thesis suggests combining these two approaches by using Analytical Hierarchy Process (AHP) and Zero-One Goal Programming (ZOGP) simultaneously; AHP from concept-concept approach and ZOGP from concept-specification approach.

Finding the most appropriate alternative which can satisfy all stakeholders' points of view may be impossible because of the different conflicting interests they may have. It is no longer possible to ignore the fact that each real decision is the result of a compromise, if it is possible, between multiple stakeholders which all have their advantages and disadvantages, depending on their point of views. Therefore, to choose an alternative, it is necessary to aggregate the outcomes (ranking) obtained by the methods such as weighted objectives method (Cross, 2000) and controlled convergence method (Pugh, 1991). In other words, what is important is to choose the most appropriate concept design that can best satisfy all stakeholders involved in the decision as much as possible. In fact, in the MCDM-MSDM context, a crucial matter lies in addressing the problem of how to aggregate the numerical preferences (weights) of individual stakeholders which may have different criteria and hierarchies, in order to make a single decision. Normally, preferences (weights) of alternatives are elicited through a process such as AHP from each stakeholder's viewpoints. It is necessary then to aggregate the obtained outcomes to reach a single decision.

Although there are several methods for aggregating the numerical preferences within a hierarchy with multiple stakeholders which have common decomposition of elements, such as direct interaction with the members of the group to reach a consensus outcome, voting, taking the arithmetic mean, taking the geometric mean, or using goal programming (Linares and Romero, 2002; Pachon and Romero, 1999), but the problem is how to aggregate the numerical preferences between the hierarchies created by multiple stakeholders with different criteria and different hierarchies.

Distance functions are used to aggregate the different outcomes obtained by different stakeholders by generating an index for each alternative. The index measures the distance between an alternative's point and ideal line and between an alternative's point and origin of coordinate system. The questions of how to determine the alternatives' points and how to generate the index will be explained in chapter 4 in detail.

Figure 2 represents the different sense of "aggregation within" and "aggregation between" the stakeholders. It is assumed that there are two stakeholders and each stakeholder has a hierarchy for himself, some special criteria and some common criteria. In this figure w_i^j represent the weight of criterion i within the stakeholder's hierarchy j. $w_C^{1,2}$ represent the common criterion that may exist in both stakeholders' hierarchies. Vector w_j represents the final weight of the alternatives for stakeholder j within a hierarchy; "aggregation within" a hierarchy. Vector W is the aggregated weight of the alternatives for both stakeholders' hierarchies that it should be identified with aggregation method between both stakeholders; "aggregation between" the hierarchies. Available methods represent the vectors w_1, and w_2, not W which is the vector of aggregated weight between the hierarchies.

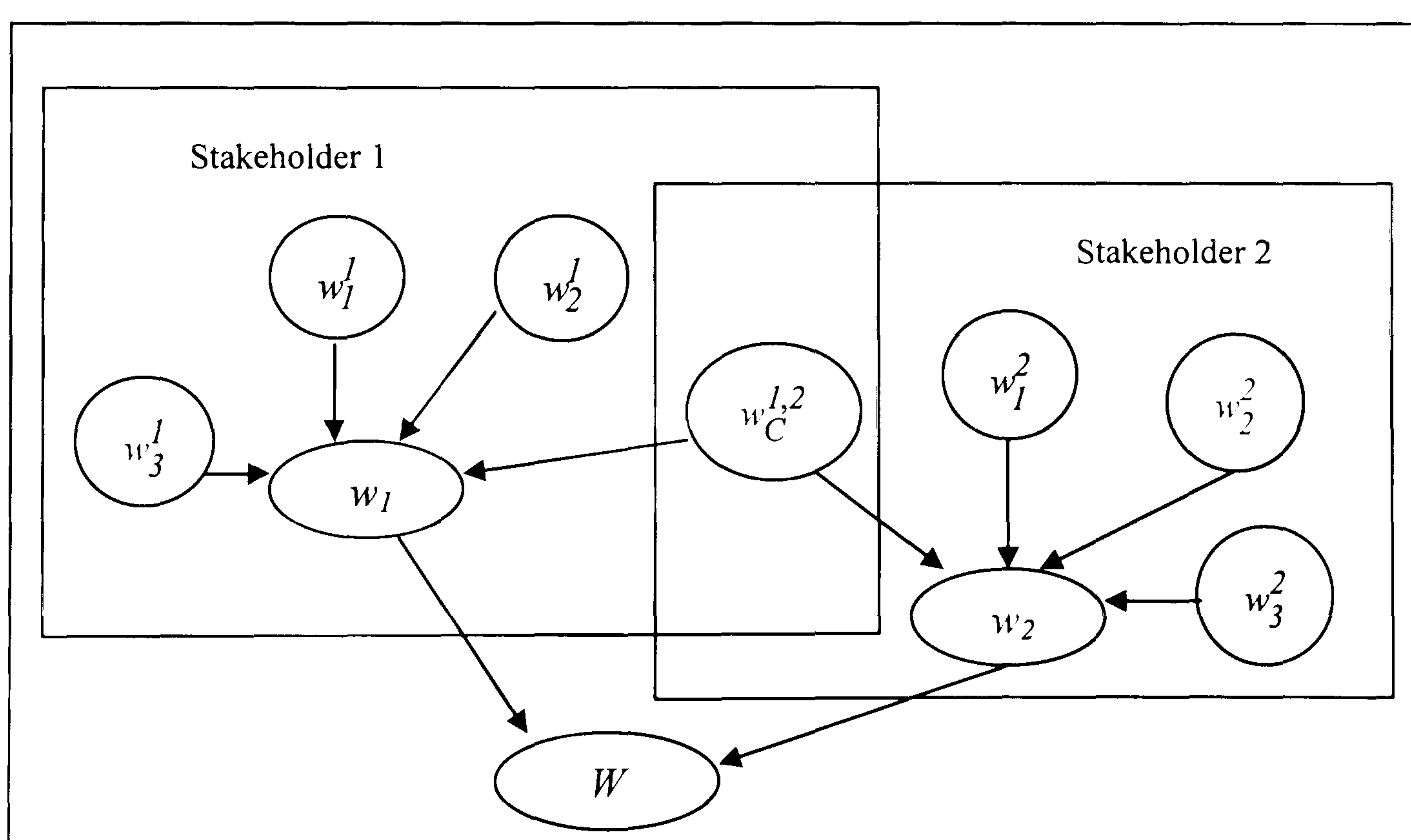

Figure 2 Difference between the aggregation within and between the hierarchies

In summary, the first problem is how to evaluate the reduced competing set of concept design alternatives after screening phase of concept development process, considering not only their PDS's but also comparing them with each other simultaneously from the point of view of each individual stakeholder. The second problem is how to aggregate the different outcomes (obtained within a hierarchy) between multiple stakeholders.

1.3. Definition of concepts

There are four components that must be explained in more detail. They are:

1- What is decision making, group decision making, and what is a rational decision?

2- What is a strategic decision and what are its characteristics?

3- What are stakeholders?

4- What is MCDM- MSDM and what are its characteristics?

1.3.1. Decision making and rational decision making

1.3.1.1. Decision making

Decision making refers to the mental activities that take place in choosing among alternatives (Galotti, 2002). Decision makers often have many goals and many conflicting criteria in choosing the most appropriate alternative. Decision makers may have to prioritise the goals and criteria in order to select one alternative. In this situation, decision makers should decide which criteria have most effect in the decision. Different people will attach different priorities to different criteria at different times and that is why there is never an absolute correct choice.

1.3.1.2. Group decision making

Group decision making is the process of arriving at a judgment based upon the feedback of multiple individuals involved in the decision. Such decision making is a key component to the functioning of an organization, because organizational performance involves more than just individual action. Due to the importance of the group decision making process, decision making models can be used to establish a systematic means of developing effective group decision making.

1.3.1.3. Rational decision making

Rational decision making refers to selecting ways of thinking and acting to serve one's goals as well as the environment permits (von Winterfeldt and Edwards, 1986). If a decision maker wants to choose an alternative rationally from a set of available ones, he needs to make sure that he takes into consideration all the relevant goals, objectives and criteria, not just the ones he thinks about at first glance.

Rational decision making also requires that the decision maker gather information about the decision as carefully as possible under the circumstances. Rational decision making requires in particular that the decision maker look not only at evidence that supports his initial conclusions but also at evidence that does not (Galotti, 2002).

1.3.2. Strategic decisions and its characteristics

1.3.2.1. Strategic decisions

Strategic decisions are decisions whose implementation has a long term effect on an organisation (Ordoobadi and Mulvaney, 2001). Strategic benefits are often intangible (such as improving flexibility and improving the standards) and cannot be realised in a short term period, especially in the early stage of implementing the decision (MacDougall and Pike, 2003). In addition, strategic decisions require the intervention of multiple stakeholders within an organisation and customers outside the organisation because of their different viewpoints (Nagalingam and Lin, 1998). For example, decision making for transferring and choosing a vehicle manufacturing technology which should be imported by a government is a strategic decision. On the one hand, the benefits associated with implementing the decision is intangible and cannot be obtained in short terms, and on the other hand, the government cannot make a decision without considering the vehicle companies managers' viewpoints, customers' viewpoints, and the viewpoints of the staff that will be working with that technology, each having their own criteria for evaluating the alternatives. In this case, each stakeholder will select an alternative which best fits his objectives. It is obvious that, for example, if a manager selects a technology that cannot satisfy the customers' needs, then that decision has been worthless.

Choosing a concept design alternative is another example. A company should pay attention not only to its manufacturing process from the point of view of relevant criteria such as ease of production, ease of assembly and so on, but it must also take into account the criteria of potential customers.

1.3.2.2. Strategic decisions characteristics

The characteristics of strategic decisions are as follow:

- They have a long term effects on the success of the company.
- They are non-repetitive.

- Conflicting views may exist between different stakeholders. For example, customers might like to purchase a particular product, but managers might find its manufacture difficult.
- Even within an individual stakeholder or stakeholder group, criteria may conflict. For example, customers want quality but also want something inexpensive.
- There are a large number of intangible and tangible criteria (Ordoobadi and Mulvaney 2001).
- Retaining the status quo may not be considered as an alternative because in the increasingly competitive world, companies in international markets must continuously improve their products and productivity to survive. Choosing to do nothing may market share to decrease (Noble, 1990).

1.3.3. Stakeholder's definition

The definition of a stakeholder comes in various forms, some narrow, others deliberately maintaining the broadest possible scope. The classical broad definition is Freeman's. A stakeholder in an organisation is any group or individual who can affect or is affected by the achievement of the organisation's objectives (Freeman, 1984). However, a narrow definition of stakeholder refers to those groups that have interests in the survival of an organisation (Alkhafaji, 1989). The second definition is accepted because this thesis deals with the stakeholders who affect an organisation with legitimate claims, regardless of their power to influence the organisation.

1.3.4. MCDM-MSDM and its characteristics

To define MCDM-MSDM, it is necessary to define each part of it separately and then present the concept of MCDM-MSDM.

1.3.4.1. MCDM definition

MCDM is defined as the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the decision making process (Zeleny, 1982). In both everyday life and in organisations, difficult choices are made by decision maker(s) in MCDM environment. To make a decision, decision maker(s) should make tradeoffs between the conflicting criteria in order to select the most appropriate alternative.

1.3.4.2. MSDM definition

MSDM can be defined as the methods and procedures that can be used to incorporate different stakeholders' viewpoints in the decision making process.

Therefore, aggregation of viewpoints is an inevitable part of MSDM. In organisations, it will become harder and harder to disregard the complexity of points of view, motivations and objectives. The wishes of all those involved in all their diversity must be taken into account (Steuer and Na, 2003). In other words, to make a decision, views of different stakeholders should be considered. These stakeholders may have different views of a problem based on their perception of the problem, criteria and so forth. If the problem is to rank the alternative options, they may rank them differently because each individual stakeholder can create his own hierarchy, criteria, and weighs these criteria based on his own beliefs.

1.3.4.3. MCDM-MSDM definition

MCDM-MSDM is defined as the methods and procedures for solving the decision making problems involving multiple conflicting criteria and multiple stakeholders inherent in the decision for assessing and choosing an alternative among a set of available ones.

In MCDM-MSDM, a stakeholder can be:

1- A single person or an individual entity, whose interests should be considered in the decision making process. This person or entity evaluates the decision alternatives based on his perception and the defined criteria identified by himself. For example, to choose a concept design, the decision maker should pay attention to manufacturing department's interests.

2- A group of persons or a group of entities whose interests should be taken into consideration. They assess the decision alternatives based on the group's perception to construct the problem and to determine the criteria by voting, consensus or compromise, whichever is possible. For example, to select a concept design alternative, the decision maker should pay attention to the manufacturing departments' viewpoints as well as marketing department's views.

1.3.4.4. MCDM-MSDM characteristics

The characteristics of MCDM-MSDM are summarised as:

1- The stakeholders are faced with selection at least one alternative among several ones.

2- The stakeholders have several criteria or sub-criteria, including tangible and intangible, often contradictory, for evaluating the alternatives. These criteria or sub-criteria are at least partially contradictory in that, if one stakeholder adopts one of the criteria, he will not choose the same alternative as he would from the standpoint of another criterion.

3- Different stakeholders can choose different alternatives.

4- In the context of MCDM and MSDM, choosing the optimum alternatives which can fulfil all of the criteria from point of view of all stakeholders involved in the decision making process is impossible because of presence of different interests between stakeholders and existence of conflicting criteria. So, the notion of "optimisation" does not really have a sense in MCDM-MSDM. Instead, a satisficing outcome which is not necessarily completely optimal is considered (Dym et al. 2002).

5- The outcomes of individual stakeholder should be aggregated in order to attain a single decision.

1.4. Research questions

There are several questions which should be answered in order to evaluate the concept design alternatives. The most important questions for this research are as follows:

1- How can intangible criteria be quantified?

2- How can both tangible and intangible criteria be taken into account?

3- How can alternatives be weighted (ranked) by each individual stakeholder?

4- How can the preferences of multiple stakeholders be aggregated?

5- How can the most appropriate alternative be selected according to each stakeholder's viewpoint considering intangible constraints, limitations on non-obligatory resources and their target values for each individual stakeholder?

6- How can the outcomes obtained by different stakeholders' viewpoints be aggregated in the presence of constraints?

The first question refers to any decision making problem. In most decision, there are a significant number of intangible criteria which should be measured quantifiably because it is generally recognised that a good principle is to quantify whenever possible (Edwards, 2002), in order to facilitate the process of evaluation and selection. The second question concerns the consideration of both tangible and intangible criteria simultaneously in order to make tradeoffs between them. The method of weighting (ranking) the alternatives from each stakeholder viewpoint is the concern of the third question because the value assigned to the criteria may be different for each individual stakeholder. The method should be able to take into account intangible criteria alongside tangible criteria. To make a decision in a multiple stakeholders' environment, it is necessary to aggregate the individual outcomes obtained by individual stakeholders if the outcomes are not the same. Therefore, finding approaches to aggregate the weights of alternatives are a crucial matter which is the concern of the fourth question.

In the real world, limitations or constraints will also affect the decision. If the limitations are obligatory, the screening process can quickly remove alternatives that violate them. In the most cases, the limitations are non-obligatory, that means the decision maker prefers not to exceed or make less than these limitations. For example assume a decision maker has a limit on his budget to make a product. In this case, he prefers to choose a manufacturing process that its cost does not exceed from the available budget, because although achieving more funds is possible, it is not an easy process. In addition, how to define intangible constraints and determine their target values are the concerns of fifth question. However, the target value for tangible constraints can be the available resource for those constraints. Finally, the sixth question is related to find approaches for aggregating the weights obtained by individual stakeholders in the presence of tangible and intangible constraints which may exist for stakeholders.

1.5. Problem importance

The problem of choosing the most appropriate concept design alternative after screening phase is very important because it represents the beginning steps of a product. Success of the complete design process depends on selecting the right alternative (Green, 2000). Changes made early in the design process are less costly than those made in detail design and later stages (Childs, 2004). Failing to choose the most appropriate concept design alternative may lead to rework, redesign and waste of resources.

In the presence of multiple stakeholders, each individual stakeholder may choose a different set of alternatives when they are performing the screening phase, depending on their perception, criteria, limitations and so forth. In addition, each individual stakeholder may choose a different final concept design after evaluating the remaining alternatives. So it is important to choose a single concept design alternative which can best correspond to the stakeholders involved in the decision making process.

1.6. Domain of research

Concept design selection is often performed in two stages as a way to manage the complexity of evaluating of product concepts (Liu et al. 2003). The first phase is the screening phase. Screening is a quick and its aim is to remove infeasible alternatives from viewpoint of stakeholders. The second phase, concept selection, is a more careful evaluation of the remaining concept designs in order to choose the concept design most likely to lead to product success.

The domain of research is limited to the second phase: concept selection box in the figure 1. In fact, the research focus is to develop an approach for the selection of most appropriate concept design alternative after completing the screening phase considering multiple stakeholders' viewpoints.

1.7. Aims and objectives

The aim of this research is to develop a decision making method for concept design selection which can take into account multiple stakeholders' viewpoints with consideration of tangible and intangible constraints. The approach also should be able to aggregate the outcomes obtained by different stakeholders.

The objectives of the research are to:

1- Make comparisons between the available methods; discuss the strength and weaknesses of them and identify their drawbacks.

2- Develop a method or combination of methods which can remove the drawbacks of available methods.

3- Develop a method or methods for aggregating the outcomes obtained by different stakeholders.

4- Verify the implementation of the approach using case studies, analysing the obtained results and comparing them with other available methods.

1.8. Thesis structure

Chapter two of this thesis is assigned to the literature review of MCDM-MSDM methods, especially those for evaluating concept design alternatives. In the concept design selection literature, the desired characteristics for concept design selection problems will be described. The chapter will also discuss previous research relate them to this thesis. Chapter three discusses the AHP and ZOGP, their characteristics, and the reasons for using their combination. Chapter four explains the approach in detail and discusses its pros and cons. In addition, an illustrative case study is used to clarify the steps of the approach in this chapter. Case studies and their results will be discussed in chapter five. Chapter six discusses some issues related to the approach such as Arrow's impossibility theorem[2], game theory[3], approach evaluation, and so forth. Finally chapter seven discusses the conclusion of the research and related future researches.

1.9. Concluding remarks

In product design, concept selection is a critical step because all subsequent detailed design and process design is based on this decision. The selection problem is a MCDM-MSDM problem because of multiple conflicting criteria and multiple stakeholders inherent in the decision. The presence of multiple stakeholders, multiple criteria, and real constraints demands new methods that can aggregate the weights of individual stakeholders.

This thesis describes an approach for modelling and aggregating stakeholders' viewpoints for selecting design alternatives, using: 1) AHP as a stand-alone methodology for comparing the design alternatives with each other, and 2) the combination of AHP and ZOGP to take into account both concept-concept and concept-specification approaches (which compares each alternative with its PDS) simultaneously, in order to include the PDS's information for making decision. Using PDS's information can be used as the target value of each single criterion which stakeholders intended to attain. AHP alongside with ZOGP has been proposed not only to resolve conflicting criteria and conflicting stakeholders but also for considering real non-obligatory constraints that can affect the outcome from each stakeholder's viewpoint. Although real tangible constraints can be included in the ZOGP models, there are no suggestions to include intangible constraints for making the decision.

The proposed approach also offers two heuristic methods for aggregating the outcomes of different stakeholders based on a distance function when the AHP is

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[2] Arrow's theorem states that there can be no consistent, equitable aggregation method for social choice.

[3] Game theory deals with decision situations in which two or more intelligent opponents have conflicting objectives.

used as a stand-alone approach. While the first method uses the final weights[4] of alternatives, the second method applies its detailed weights. In addition, it also offers using ZOGP models to aggregate the outcomes by two different aspects using: 1) linear additive of individual objective functions, and 2) minimum of maximum (MINIMAX) summation of individual objective functions of ZOGP models.

The novelty of the proposed approach is that it can simultaneously account for: minimisation of additive undesirable intangible and tangible criteria; resource limitations and goal constraints; taking into account the difference between the target goal of a criterion and relative importance of selected alternative related to that criterion, and it can suggest a single, aggregated, go or no-go decision when the combination of AHP and ZOGP is used. Moreover, aggregation of outcomes based on distance functions using the final and detailed weights of AHP when AHP is used as a stand-alone methodology is another novelty.

To test the proposed approach, four case studies have been applied in order to illustrate that the approach is able to handle the decisions which it is intended to support. Vehicle manufacturing technology selection is used to demonstrate the approach in chapter 4 when the approach is explained, while other case studies will be discussed at chapter 5.

The results of applying the case studies demonstrate that the proposed approach is able to handle selecting design alternatives in the presence of multiple criteria and multiple stakeholders with tangible and intangible constraints. The AHP-ZOGP approach provides more information for decision makers, facilitating the process of decision making, especially when a careful sensitivity analysis is applied to the problem. The information which can be obtained for both individual ZOGP models and aggregated models, includes: 1) the underachievement or overachievement of the criteria compared to their target values, 2) the range of target values of each criterion which preserve the obtained outcome, and 3) the acceptable range of relative importance of each criterion which preserve the obtained outcome. In addition, the range of relative importance of each individual stakeholder that can preserve the outcome of the aggregated ZOGP model is also can be obtained.

[4] Final weights are the weights of alternatives after completing all the steps of AHP.

CHAPTER 2
LITERATURE REVIEW OF DESIGN EVALUATION METHODS

2.1. Overview

In the process of designing many decisions should be made in the multiple criteria multiple stakeholders environment. After screening phase which reduces the number of concept designs alternatives, an important decision is to evaluate the remaining alternatives in order to choose the most promising one. For this reason, the evaluation of design concepts has always been an interest of researchers in the field of the design process because design decision making is a complex problem (Edwards, 2002).

This chapter focuses firstly on how concept design is chosen in reality. Secondly, the existing methods for concept design evaluation will be briefly explained. After that, the existing methods for dealing with multiple criteria and available methods to evaluate the weights of criteria and synthesising procedures will be discussed. Then the available mathematical programming methods will be explained. Finally in the conclusion, a summary will emerge to clarify why it is necessary to develop other methodologies for choosing the concept designs.

2.2. Making concept design decisions in reality

Concept design decisions are made in companies in different ways. These decisions are usually made based on the group's perception within any individual stakeholder. The methods vary in their effectiveness and include the following (Ulrich and Eppinger, 2000):

- **External decision:** concepts are submitted to the customers, clients, or some other external entities for selection. External people do not have sufficient information about the next stages of manufacturing process, so the decision made by them may not be the most appropriate one.
- **Product champion:** an influential member of the product development team chooses a concept based on his personal preference. Because this person neglects other stakeholders' viewpoints, the decision may not be a good one.

- **Intuition:** the concept is chosen by its feel. Explicit criteria or tradeoffs are not used. The concept just seems better. This approach is not rational because the concept is not measured by its criteria.
- **Voting:** each member of the team makes his choice intuitively and the final concept then is chosen by voting. The concept with the most votes is selected. The problem of this method is that it is not rational because each member of team considers the final concept neglecting the importance of each part of it.
- **Pros and cons:** the team lists the strengths and weaknesses of each concept and make a choice based on group opinion. This method neglects the relative importance of these strengths and weaknesses.
- **Prototype and test:** the organisation builds and tests prototypes of each concept, making a selection based on test data. The cost of applying this method is significant.
- **Decision matrices:** the team rates each concept against pre-specified selection criteria, which may be weighted. The method of rating and aggregating different viewpoints is questionable.

2.3. Theoretical methods for concept design evaluation

Methods of concept design are developed based on decomposition assumption. This means that designs are usually evaluated against a set of apparently separate, although inevitably interrelated, design criteria or sub-criteria and then synthesised, via the evaluation model, to achieve a total evaluation of the proposed design (Cziulik and Driscoll, 1997; Goker, 1997). The most obvious source of data that can be used for evaluation is the experience base of human judgements (Green, 2000) because of the presence of many intangible criteria involved in such decisions. Concept-specification and concept-concept comparisons are two general methodologies which designers use them in practice (Green, 2000). The available methods are attempted to be placed into one of these methodologies.

2.3.1. Concept-specification comparison

Concept-specification comparison involves direct comparison between the concept alternative and the PDS. This approach reveals the degree to which a concept is likely to meet the demands of the PDS (Green, 2000). The result of applying this approach is a weight for each potential alternative which measures the degree of meeting the PDS. This approach is usually used when designers have a special attention to PDS's. The methods of this approach are explained in the following section.

2.3.1.1. Weighted objective method

Weighted objective method is a form of value analysis based on the systems approach and the combined technical-economic evaluation. This method has been claimed the most useful for assessing concept designs (Pahl and Beitz, 1984). The philosophy of the weighted objective method is decomposition of the overall objective into sub-objectives in terms of a tree diagram. Some features of a specification are usually more important than others, so to identify the importance of each element in the tree diagram, weights are allocated to each element (Cross, 2000). Assigning weights gives a greater discrimination for selection of the most appropriate concept. Weightings, based on a 1-5 scale or other scales, which are then normalised, are applied on a top-down basis usually starting from 1 which is allocated to the first level of the tree diagram. The PDS is used as a guide for assigning the weights.

In this method, a weight (w_i) is allocated to criterion i ($i \in n$) to indicate its relative importance in comparison with the other criteria. Then a numerical value (v_{ij}) is assigned to design alternative j associated to each criterion i in order to show how much alternative j can satisfy the criterion i. The utility of criterion i can be obtained by multiplying the weight of the criterion and its numerical value which can be as a different scale. The overall utility of the design alternative j is determined by a linear summation of individual parameter values and their related weights.

$$U_j = \sum_{i=1}^{n} w_i v_{ij}$$

The most appropriate concept design is that which has a greatest overall utility.

The problems associated with this method are:

1- The method of weightings to the criteria (w_i) and assigning the values for determining how much an alternative can satisfy a criterion (v_{ij}) is based on assigning the numbers directly within a determined scale. Only an individual person who has long familiarity with physical objects that have measurement on some existing scale can accurately assign numbers directly from that scale (Saaty, 1997). In other words, the method of assigning numbers to represent the weights of criteria, especially intangible ones, is unreliable.

2- This method uses a tree diagram to show the importance of each criterion or sub-criterion. Although different stakeholders can construct different tree diagrams to use them to choose different alternatives, there is no guarantee that different stakeholders generate the same decision.

3- The target value[5] of a criterion, upper limit, and lower limit of criterion is not considered.

4- Concept designs and criteria are not compared with each other. They are evaluated individually based on the overall utility and assigned numbers, respectively.

5- The method is not able to take into account the effect of real non-obligatory constraints such as budgetary limitation.

6- Although this method can consider multiple stakeholders within the stakeholders via agreement on a tree diagram or agreement on assigned numbers, it does not support aggregation between multiple stakeholders because of lack of any device to aggregate different outcomes obtained by different stakeholders.

2.3.1.2. Design compatibility analysis

Design compatibility analysis, which is almost completely identical to weighted objective method, focuses on the compatibility between the PDS and the proposed design based on consistency knowledge of experts (Green, 2000). This method uses fuzzy numbers to quantify the compatibility evaluation of the design with the requirements within the PDS (Green, 2000). The problems associated with this method are almost completely identical to weighted objective method.

2.3.1.3. Design margin method

This method uses a number of statistical methods and approaches taken from the probability, reliability and quality domains. This method assumes that designers use decomposition of a design to undertake evaluation at design characteristic level, and thus achieve comparison between concept criteria and specification. The method uses the mean and standard deviation from the probability distribution to obtain a measure of the overlap between the target values and the design characteristics (Green, 1997). The greater the overlap, the greater the probability that the proposed concept will meet the target value of a particular characteristic.

The problems associated with this method are:

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[5] Target value is defined as a determined level that its achievement is most likely desirable for decision maker. For example, reducing the 20% of production cost can be a target value for manufacturing company. However, it can have a minimum and maximum level, such as 10% and 40%.

1- The alternatives are individually compared with the PDS. They are not compared with each other. Comparison between alternatives may distinguish small differences which a comparison with PDS cannot discover them.

2- The tradeoffs between different criteria are not made.

3- Estimation of accurate relevant probability distribution function is time-consuming.

4- There has not been any suggestion on how to take multiple stakeholders into account.

2.3.2. Concept-concept comparison

Concept-concept comparison involves direct comparison between two competing concepts. The result of applying this approach is a list of alternative rankings. Although this approach identifies the most appropriate concept design alternatives, it will not reveal whether the selected concept satisfy the demands of the PDS (Green, 2000). This approach to design evaluation is well known to designers and forms the basis for many models of evaluation.

2.3.2.1. Controlled convergence method

The controlled convergence method has been claimed that can select actual concepts in practice with greater certainty of success (Pugh, 1991). This method uses a matrix to express the criteria for selection and the concepts including the datum concept. The datum concept is an existing concept (for example, the old version of a product), or the first concept that the designers think is the most appropriate concept, against which the developed concepts are to be compared. Each concept design is compared with the datum concept with regard to a criterion. Using a 3 point scale, three situations may occur; the developed concept acts better, worse or the same when it is compared with the chosen datum. In these situations, the legends "+", "-", and "S" or "0" have been placed in relevant cell in the matrix, respectively. It is possible to use a 5 point scale instead of 3 point scale for more discrimination between the criteria. For example, when an alternative has a significant superiority (minority) to datum alternative with regard to a sub-criterion, then "++" ("--") is assigned to that alternative. Each individual concept then has a score pattern in terms of the number of "+'s", "-'s", and "S's". The designers try to remove the weaknesses via redesigning or combining the developed concepts. The steps of this method repeat until the decision maker will be satisfied. Selection can be made by summation of "+'s", "-'s" and "S's" when 3 point scale is used. The best choice is the one with (1) highest "+'s", (2) lowest "-'s", and (3) highest "S's". The more the number of "+'s" and the less the number of "-'s", the relevant concept is better.

The problems associated with this method are:

1- Each design concept is compared with a datum concept not with each other. This procedure is not able to identify the relative little superiority of a design concept against other competing concepts. In other words, when two competing concepts are compared with each other, the difference with them can be more separable.

2- When a design concept is compared with a datum in a pairwise fashion, just the ordinal preference is taken into account which may not be reliable (Saari and Sieberg, 2004).

3- The degree of importance for all criteria or sub-criteria is assumed to be equal.

4- If a concept alternative is absolutely better (worse) than the datum concept with regard to a criterion which has a large number of sub-criteria, and so it is better (worse) than majority of its sub-criteria, the number of "+'s" ("-'s") will abnormally increase. In other words, in this situation, the number of "+'s" or "-'s" cannot carry the real information.

5- The rule of selecting the most appropriate concept is ambiguous. Assume the following table indicates the information of applying this method for two competitive alternatives (*A* and *B*) with 10 criteria.

Sum of: / Alternatives	"+'s"	"-'s"	"S's"
A	7	1	2
B	6	-	4

Although the rule of this method selects alternative *A*, but actually it can be criticised because alternative *A* has a weakness when it is compared with alternative *B*.

5- The target value, lower limit and upper limit of a criterion cannot be considered.

6- This method can treat the aggregation within the stakeholders not between the stakeholders.

2.3.2.2. Multi-attribute utility theory

In Multi-Attribute Utility Theory (MAUT), a utility function[6] is specified for each criterion. MAUT considers the utility of each criterion compare with other criteria and allocate the utility for each criterion. The worst alternative for each criterion should be assigned a utility of "0", and the best alternative for each criterion should be assigned a utility of "1". The shape of each utility function depends on the decision maker's subjective judgement (Keeny and Raiffa, 1976). To construct a utility function, a series of lottery-type questions[7] can be asked in order to obtain the data points in a two dimensional space, in which the horizontal axis represents the value of an attribute and the vertical axis represents the utility of the corresponding value on the horizontal axis. These points are then considered to approximate the shape of a utility function. To evaluate each alternative, the individual attribute value is mapped to the utility value through the utility function of the attribute. The utility values of all attributes are aggregated to obtain the overall utility of an alternative. It should be noted that in this theory, rank reversal[8] on alternatives is not allowed to happen when a new non-optimal alternative is added or removed from the set of alternatives (Forman and Gass, 2001). This method has been reported to have been applied to many design problems (Chen and Lin, 2002).

The problems associated with MAUT method are:

1- Estimation of utility functions which should be specified for each criterion is not an easy task. The process of estimating the fitted curves to utilities is time-consuming.

2- Lottery-type questions are usually not meaningful for the persons involved in the decision making process.

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[6] The utility function represents the aspirations of the evaluator with respect to a certain criterion, or, in other words, his ideas about the level of achievement that is desirable with respect to that criterion. The utility function specifies for each criterion whether it has been served badly or satisfactory or well.

[7] An example:

Question: which of the following would you prefer:

A: £30 million for certain; or

B: A lottery ticket which will give you a %70 chance of £60 million and a %30 chance of -£10 million?

[8] If an alternative is non-optimal, it cannot be made optimal by adding new alternatives to the problem.

3- MAUT implicitly assumes that the decision maker will never be inconsistent. This is a very strong assumption which can also make the elicitation of preferences highly biased (Golden et al, 1989).

4- Intransitive relationships[9] are not admissible in MAUT (Forman and Gass, 2001).

5- The hierarchical decomposition of the problem is often only a structuring phase and preference tradeoffs are only evaluated at the lowest level (Golden et al, 1989). In other words, the effects of upper levels' criteria with their relative importance are not considered explicitly.

6- Redundant judgments[10] are not allowed in order to increase accuracy (Forman, 1990).

2.3.2.3. Fuzzy method

Another concept-concept comparison approach is the fuzzy method. This method seeks to identify the preference structure between competitive design concepts based on imprecise information. In the design stage, the results of evaluation may be described in an imprecise way or by linguistic terms, such as "good", "low", and "high". This method employs fuzzy set theory to address the imprecise preference structure inherent in conceptual design (Wang, 1997). A finite set of fuzzy numbers represents weights of the attributes and rating of alternatives with respect to the attributes. Each fuzzy number has a corresponding membership function ranging from "0" to "1". To rank the competitive alternatives, the method uses a linear summation index.

$$P(a,b) = \sum_{i=1}^{n} w_i P[g_i(a), g_i(b)]$$

w_i is the weighting assigned to criterion i and $P[g_i(a), g_i(b)]$ is the degree of preference [0,1] of concept a over concept b in relation to criterion i.

The result of applying this method is a preference ranking of all competitive concept design.

The problems of using this method are:

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[9] If A is three times as preferable as B and B is twice as preferable as C, then A must be six times as preferable as C. Otherwise, there is an intransitive relationship.

[10] If one compare A to B and then B to C, then it is not necessary to compare A to C. Comparing A to C is a redundant judgement.

1- The method of weightings to the criteria is based on assigning the numbers directly within a determined scale.

2- Estimation of fuzzy numbers and membership functions are not easy tasks.

3- The target value, upper limit and lower limit of a criterion in both types, tangible and intangible, are not taken into account.

2.3.2.4. AHP method

The AHP is a technique for considering data or information about a decision in a systematic manner. The AHP is a highly flexible decision method that can be applied in a wide variety of situations because it is able to incorporate judgements on intangible criteria alongside tangible criteria (Saaty, 1980). It is usually used in decision situations which involve selecting one (or more) decision alternatives from several candidate decision alternatives on the basis of multiple decision criteria of a competing or conflicting nature (Schniederjans and Garvin, 1997). AHP has been proposed to deal with problems whose criteria and sub-criteria have a hierarchical structure (Saaty, 1980) so it can be a useful tool for design selection problems. However it does not satisfy certain theoretical conditions such as the axiom of irrelevant alternatives. AHP has been claimed to be an applicable method because of its simplicity, for addressing and analysing discrete alternatives decision problems with multiple conflicting criteria (Steuer and Na, 2003).

AHP starts by sub-dividing a problem into a hierarchy of an overall objective, criteria, sub-criteria, sub-sub-criteria, etc., until it reaches the decision alternatives. Then pairwise comparisons are made between the elements immediately below each other element. Since the comparisons are performed in a pairwise fashion, it can lead to inconsistency. Therefore, the result of each comparison matrix has to be checked for consistency. If all comparisons fulfil the consistency ratio suggested by Saaty (1980), then the relative importance between criteria and the relative importance between alternatives are obtained. Completing each level and then synthesising the relative weights obtained by pairwise comparisons, a priority ranking for each alternative taking all criteria concerns into account can be established (Saaty, 1980). The disadvantages of AHP are:

1- Pairwise comparison will be a tedious task when there is multi-level hierarchy with a number of criteria and sub-criteria.

2- The method is not able to include target value, upper limit and lower limit of criteria.

3- Constraints cannot be taken into account directly.

4- AHP is not able to include the difference[11] between the final selected alternative and what is selected when alternatives are compared with a specific criterion.

5- Rank reversal can occur, especially when a close alternative is added or removed from a set of alternatives.

2.4. Comparison of theoretical methods

Both concept-specification and concept-concept methods are useful methods for choosing the most appropriate concept design after the screening phase. These methods view choosing the concept design differently. While the concept-specification method considers a single concept and evaluates against its PDS explicitly, concept-concept methods compare the concepts against the PDS or other criteria implicitly. When two different alternatives are considered to be analysed based on concept-specification approach, the approach may assign the same weight to a common criterion for both alternatives, however they may be slightly different. When concept-concept approach is used, this problem can be solved because these alternatives are directly compared with each other with regard to that criterion. So, when one compares these alternatives with regard to that criterion, he can express his judgement more accurately. In other words, differences for a common criterion can be denoted more obviously. On the other hand, when two alternatives are compared based on concept-concept approach, there is no guarantee the alternatives fulfil the PDS's. Therefore, when these methods are applied individually, they cannot consider simultaneously the PDS data and comparisons of concepts based on criteria. In general, decisions are made better when explicit comparisons can be made or when there is information about the ranges and effects of relevant criteria (Baron, 2000). Combining of these methods is suggested in order to overcome the problem of not considering PDS data and comparisons of concepts with each other.

In addition, the presence of multiple criteria and multiple stakeholders make it necessary to discuss: 1) the methods for determining weights of criteria; 2) the methods for aggregating the decomposed elements in order to reach a single

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[11] It is obvious that a final selected alternative cannot be the best from point of view of all criteria or sub-criteria. Therefore, there is a distance between final selected alternative and a criterion which final selected alternative has not been the first choice regard to that criterion.

outcome; and 3) the mathematical programming[12] methods that can consider MCDM and MSDM.

2.5. Methods for determining weights

In MCDM-MSDM, a decision maker or a stakeholder may declare that one criterion is either more or less important than another. This may be for various reasons including personal preferences which may be reasonably objective or completely subjective. The measure of relative importance of criteria as seen by the decision maker is called the weight. It is necessary to estimate the weights of criteria as accurately as possible because weights can reflect the preferences of stakeholders.

To estimate the weights, it is necessary to determine which scales should be used to satisfy our requirements. There are generally four scales of measurements: nominal, ordinal, interval and ratio. Among them, the ratio scale possesses all the properties of the other scales (Malhotra and Birks, 1999). In the ratio scale, classification, ranking and comparing differences between objects is possible. It is also meaningful to compute ratios of scales values. Ratio scales can be added or multiplied with each other that is necessary for aggregation of individual stakeholders' outcomes. Therefore, ratio scale is focused in this research.

The method of evaluating weights has been proven to have an effect on the final outcome (Schoemaker and Waid, 1982). So it is necessary to find which method should be chosen in order to evaluate weights. These methods divide into two general subdivisions: indirect and direct evaluation methods. In this section, the most applicable methods for determining weights are discussed briefly. Then, the advantages and disadvantages related to these methods are discussed. Finally the reasons for selecting a weighting method will be explained.

2.5.1. Indirect evaluation methods

In these methods, the values of the weights are determined without the direct involvement of the stakeholders. Therefore, for identical situations but different stakeholders, the outcome of using these methods is the same. This procedure seems not to be rational because different persons have their own perception of the criteria in a problem.

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12 A mathematical representation of a problem with an objective function(s) and constraints is referred as mathematical programming.

2.5.1.1. The entropy[13] method

In this method, the essential idea is that the importance of a criterion, is a direct function of the information conveyed by the criterion relative to the whole set of alternatives. This means that the greater the dispersion[14] in the evaluations of alternatives, the more important that criterion (Pomerol and Romero, 2000). In other words, the most important criteria are those which have the greatest discriminating power between alternatives.

The entropy of a criterion j (E_j) is calculated as follow:

$$E_j = -k \sum_i a_{ij} \log(a_{ij})$$

In above statement, k is a constant which should be adjusted so that for all j, $0 \le E_j \le 1$. a_{ij} is the normalised value of criterion j with regard to alternative i. It should be noted that the closer together the values of a_{ij}, the higher the entropy E_j of a criterion. This is exactly the opposite of what the method needs to discriminating power. Therefore the opposite of this measure will be "measure of dispersion" (D_j).

$$D_j = 1 - E_j$$

Finally with normalising the D_j's, the weights of criteria will be found.

$$w_j = \frac{D_j}{\sum_j D_j}$$

The main advantage of this method is decision maker's objectivity relative to the data of the problem (a_{ij}). In other words, this method does not include any subjective judgement on the part of decision maker in determining the weights. This idea is interesting in cases of conflict where the stakeholders involved are arguing over the values of the weights.

2.5.1.2. The modified entropy method

The problem of decision maker's non-intervention in the entropy method for determining the weights can be resolved if the decision maker is allowed to interfere in the process. In this case, the obtained weights (w_j) of entropy method can be multiplied by the preferences of criteria which are represented by decision maker

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[13] Entropy is a concept that adopted from information theory, represents the amount of lack of reliability from a received message.

[14] Dispersion can be defined here as the numerical difference between alternatives regard to a criterion. The greater the range after normalisation of data, there are more dispersion.

(p_j). The final result $r_j = w_j p_j$, once normalised, will be the weights (Pomerol and Romero, 2000). In this way, objectivity of decision maker is removed.

2.5.1.3. The correlation method

Another indirect evaluation method of determining weights is the correlation method. This method is based on how great the correlation is between the columns of the decision matrix[15] (Pomerol and Romero, 2000). If r_{jk} is the coefficient of correlation between column j and column k, the weight of criterion j is then defined as:

$$w_j = \sigma_j \sum_k (1 - r_{jk})$$

In above statement, σ_j is the standard deviation of column j.

Thus, the more the information provided by a criterion j differs from that provided by the other criteria, the greater the weight of criterion j, which will have a high variance.

If a decision maker wishes to interfere in the process, the same procedure used for the entropy method, can be applied.

2.5.2. Direct evaluation methods

A large range of methods can be placed under this heading. The term indicates that the decision maker assigns weight values directly to the elements involved in the problem. In other words, to determine the weights, decision maker may be asked to answer some questions to determine the weights.

2.5.2.1. Simple ranking method

In this method, the only information asked of the decision makers is his order of preference for ranking the criteria. The value of 1 is given to the least important criterion, 2 to the next most important and so on up to reach to the final criterion. The values obtained then are normalised. These normalised values reflect the weights of criteria. Although this method has the advantage of simplicity, with the decision maker only having to provide ordinal information, but there is serious

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[15] A decision matrix is a chart that allows one to systematically identify, analyse, and rate the strength of relationships between sets of information. The matrix is especially useful for looking at large numbers of decision factors and assessing each factor's relative importance. The rows and columns of the matrix usually include the competing alternatives and the criteria or sub-criteria for evaluating those alternatives, respectively.

disadvantage. This method prevents the possibility of weights taking all possible values between 0 and 1. For example if there are 5 criteria, no weight can be greater than 0.333 or smaller than 0.067 (Pomerol and Romero, 2000). For this reason, the method does not appear to be very realistic.

2.5.2.2. Probabilistic method of evaluation

This method uses the same information as the simple ranking method. The method assumes a uniform distribution of the probability of the vector w lying anywhere in the set of w subject to the summation of w_j's equal to one and $w_1 > \cdots w_j > \cdots > w_n$ with an upper bound assigned to each w_j. In this method, the intervals between the values of w_j decrease as the criteria become less and less important. For example, if there are three criteria, then the weights can be calculated as: $w_1 = \frac{1}{3}(\frac{1}{3} + \frac{1}{2} + \frac{1}{1}) = \frac{11}{18}; w_2 = \frac{1}{3}(\frac{1}{3} + \frac{1}{2}) = \frac{5}{18}; w_3 = \frac{1}{3}(\frac{1}{3}) = \frac{1}{9} = \frac{2}{18}$. Determination of upper bounds to each criterion weight is a disadvantage of this method.

2.5.2.3. Simple cardinal evaluation

In this method, the decision maker evaluates each criterion according to a pre-defined scale of measurement (e.g. from 0 to 5, from 0 to 100, etc.) and ranks the criteria based on a simple ranking method. In this method and other modified methods which apply the concept of cardinal evaluation, the psychological problem of the decision maker can bias the process and results inconsistencies which are hard to eliminate even to make the information asked of the decision maker more intuitive (Pomerol and Romero, 2000).

2.5.2.4. Eigenvalue method

The eigenvalue method is the method which AHP uses for determination of the weights of criteria. The core of this method is pairwise comparisons which compare criterion i with criterion j. Pairwise comparisons between criteria have been proven to be the easier way rather than assigning a score against an individual criterion in a straightforward way, as is implicitly necessary in direct evaluation methods (Pomerol and Romero, 2000). This comparison yields values a_{ij} which will be placed in a $n \times n$ matrix (matrix A). It is well known that the brain is unable to handle more than 7 ± 2 items in the short term memory (Saaty, 1980), so more than 9 criteria should not be compared with each other at once. 1 to 9 numbers are given to the pairwise comparisons to form matrix A. The practical reasons for choosing this scale of values and this method of proceeding include:

- Twenty eight other ways are examined with different numbers and the experiments have shown that the 1 to 9 scale is the best (Pomerol and Romero, 2000).
- There is a wide range of possibilities which do not exceed the capacity of the short term memory.
- Integral values are used and values are increased when the difference between two compared criteria are observed.

After constructing the comparison matrix A, the largest eigenvalue of matrix A is computed by $Aw = \lambda_{max}\, w$, which λ_{max} is the largest eigenvalue of that matrix and w is its related eigenvector.

2.5.3. Comparison between weighting methods

Direct evaluation methods are preferred because they have the ability to include the multiple stakeholders' viewpoints for determining the weights. Between the methods of direct evaluation, the eigenvalue method is selected because this method has an averaging effect (Saaty, 1980) and it can provide the true or approximate weights of the items being compared when there is enough redundancy for pairwise comparisons (Forman and Gass, 2001).

2.6. Synthesising methods

Synthesis is the opposite of decomposition. While decomposition means an entity separates to its constituent elements, in contrast, synthesis involves putting together or combining parts into a whole (Forman and Gass, 2001). After identifying the weights of criteria, it is necessary to synthesise the weights in order to obtain a final outcome. There are two well-known and applicable synthesising methods that will be explained briefly.

2.6.1. Weighted linear sum

This method is simple, so it secures the confidence of the decision maker (Pomerol and Romero, 2000). The main advantages of this method are that it is intuitive and simple to apply. The normalisation procedure which is necessary for this method is the main disadvantage of applying it. In fact, using different normalisation procedure may create different final outcomes.

For each alternative a_i evaluate:

$$R(a_i) = \sum_j w_j a_{ij} \qquad (i = 1,2,\ldots,m)$$

In the above statement, w_j is the weight of criterion j, and a_{ij} is the normalised value of ith alternative with regard to jth criterion. The chosen alternative a_i will be the one which gets the highest value of $R(a_i)$. Since the values $R(a_i)$ are real numbers, they are naturally ranked and can be classified according to the obtained values of $R(a_i)$.

This method is based on an assumption that there exists a decision maker's utility function which is additive over the criteria. So, to use this method, it is supposed that the criteria are independent (Pomerol and Romero, 2000).

2.6.2. The weighted product

One way to avoid the influence of the normalisation procedure on the final result is to use the weighted product method, whose principle is close to that of the weighted linear sum. Values are multiplied instead of added, and each alternative is evaluated as follows:

$$P(a_i) = \left(a_{i1}^{w_1}\right) \times \left(a_{i2}^{w_2}\right) \times \cdots \times \left(a_{in}^{w_n}\right) = \Pi_j \left(a_{ij}^{w_j}\right)$$

Synthesising by weighted product has been proven to be much less prone to influence from normalisation procedures than the weighted linear sum (Pomerol and Romero, 2000). When the weighted product is used, each criterion can be expressed in any desired unit, without any need for normalisation. A drawback of the method is over-values extremes[16], leading to undesirable results (Pomerol and Romero, 2000). This occurs because a weighted product is in fact nothing more than a weighted linear sum when logarithms have been taken.

2.7. Mathematical programming methods

This section explains the mathematical programming methods which are applied to MCDM problems and expresses their advantages and disadvantages. The aim of this section is to show that these sorts of models can be used for selecting the most appropriate design alternative among many when the assessment criteria are tangible. However, these methods can be used to include intangible criteria with some modifications. In addition, these models are able to make tradeoffs between the criteria and stakeholders' viewpoints.

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[16] When normalised value of an alternative with regard to a criterion is very much larger than other normalised values in the same column of decision matrix, it is called over-values extremes.

2.7.1. Goal programming

Goal Programming (GP) is a procedure for compensation tradeoffs between goals within the general framework of linear programming (Steuer and Na, 2003). The GP models are based on the assumption that for each criterion, a goal target is chosen by decision maker or by the results of other methods, such as AHP, to penalise positive or negative (or both) achievements (deviations) from this target. Deviations are penalised using a direct linear relationship between the penalty and distance from the goal. The gradient in this relationship is the weighting coefficient of the deviation in the objective function. In GP, instead of attempting to maximise or minimise the objective function directly, as in linear programming, the deviations between goals and what can be achieved within the given set of constraints are minimised. Obviously, it is not possible to achieve every goal to the extent desired, because of presence of conflicting goals or criteria. Then, given the usual resource limitations or constraints, such as budgetary limitations or limited hours of labour, and other selection limitations, the decision maker attempts to develop decisions that provide "good enough" outcome in terms of coming as close as possible to reaching all goals, based on Simons' "satisficing" philosophy, which implies that decision makers are interested usually only in minimising the non-achievement (undesirable variables) of several goals (Romero, 2001). Therefore, in GP, the most satisficing outcome is sought, which in general, will not be optimum from all of the criteria.

Although this method should be generally placed under the concept-specification approach for concept designs selection, because it can take into account the tangible specification of alternatives as constraints, it is generally a type of mathematical programming models. For this reason this method has been mentioned under mathematical programming section.

GP is a useful method in concept design decision making because tangible criteria can be expressed in terms of goals. In this case, the criteria are added to the constraint set with their associated deviational variables.

A general format for a GP is:

$$
\begin{aligned}
& Min \quad P_i f_i (d_i^-, d_i^+) && (i = 1,2,\ldots, m) \\
& subject \quad to: \\
& f_i(X) + d_i^- - d_i^+ = b_i && (i = 1,2,\ldots, m) \\
& X \in S \\
& X, d_i^-, d_i^+ \geq 0
\end{aligned}
$$

P_i is the priority of the ith criterion, $f_i(X)$ is the mathematical linear representation of ith goal criterion, the b_i are the target values (aspiration or acceptable level) of the m goal criteria, and S is feasible region. The d_i^- and d_i^+, deviational variables, are the underachieved or overachieved amounts of criterion i, respectively. $f_i(d_i^-, d_i^-)$ is the deviational variables' objective function which can have any linear function and may be expressed as the weighted sum of the undesirable deviation variables. In weighted sum method solution of GP, the objective function is expressed as $\sum_{i=1}^{m} w_i^- d_i^- + w_i^+ d_i^+$. In this statement, w_i^- and w_i^+ are relative importance weights attached to the underachievement and overachievement deviational variables. If the importance of a criterion is assumed to have a direct relationship with its priority, then p_i can be removed from the mathematical statement. The weights reflect differing levels of importance of criteria when they are expressed in comparable units. When criteria cannot be stated in comparable units, then it is necessary to un-scale them.

Three possible situations regarding criteria or constraints may exist when generally using mathematical models. They are:

1- $f_i(X) \geq b_i$

2- $f_i(X) \leq b_i$

3- $f_i(X) = b_i$

Using the concept of deviational variables, the transformations of the above mathematical statements into a GP model are as follows:

1- $f_i(X) + d_i^- - d_i^+ = b_i$ $\quad$ $Min \quad d_i^-$

2- $f_i(X) + d_i^- - d_i^+ = b_i$ $\quad$ $Min \quad d_i^+$

3- $f_i(X) + d_i^- - d_i^+ = b_i$ $\quad$ $Min \quad (d_i^- + d_i^+)$

Some of the criteria may need to have a minimum level of aspiration such as minimum level of flexibility which is necessary in a production line (case 1). In this situation, minimisation of d_i^- prevents having less than the target value as far as possible (Romero, 2001). For some criteria such as the available budget to implement a project, the nature of the constraint is like case 2, because there is a limitation with regard to budget. In this situation, minimisation of d_i^+ prevents exceeding target value, if it is possible (Romero, 2001). The remaining case is the situation that a criterion should be attained no less and no more than its target value as much as possible (case 3). Spending the government budget allocated to a project is an example of this situation. In this case, minimisation of the sum of associated deviation variables means that the target value is satisfied as much as possible (Romero, 2001).

The advantages of using GP for concept design selection problems are that: 1) it permits resource limitations to be taken into account, 2) the underachievement or overachievement (difference) between target value and what has been chosen can be considered, and 3) multiple tangible criteria can be incorporated into a model. GP's disadvantages are that formation of the decision maker's preferences is required a priori in the form of priority levels in its objective function when it is applied in its general form, it disregards intangible criteria, and the type of variables is continuous, which are not suitable for selection problems.

2.7.2. ZOGP

GP can be used to solve MCDM problems with some modification, not only to include the tangible criteria, but can also incorporate the binary nature of selection problems, with each criterion viewed as a "goal". ZOGP can be used to take into account selecting the alternatives because of the binary nature of the selection variables, and the multiple conflicting criteria involved. It should be noted that the combination of ZOGP is not able to consider the intangible criteria. The general format of ZOGP is similar to GP with one exception; the main variables are binary, i.e., if a main variable takes a value of 1, that means the related alternative has been selected and if it takes 0, that means it has not.

2.7.3. Multiple objective programming

In contrast to GP, a Multiple Objective Program (MOP) does not require a priori information. During the search process to find the most preferred outcome, the role of constraints and objective functions may be changed depending on how well the decision maker has been satisfied with the current outcome. MOP seeks outcomes that are consistent with multiple competing objectives. In MOP, the efficient set[17] of outcomes is computed and the results, in whole or in part, are presented to a decision maker for the ultimate selection of a final outcome (Steuer and Na, 2003).

The general mathematical framework of MOP is as follow:

$$\begin{aligned} &Max \ \{ f_1(x) = z_1 \} \\ &Max \ \{ f_2(x) = z_2 \} \\ &\quad \vdots \\ &Max \ \{ f_m(x) = z_m \} \\ &subject \ to \\ &x \in S \end{aligned}$$

The key assumption in MOP is that the decision maker's value function is implicit (assumed to exist but it is unknown). MOP does not need any priori

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[17] Efficient set of outcomes refer to those which can be the outcomes of an objective functions within the feasible region.

information from the decision maker to declare his preferences about objectives because all of the objectives are considered simultaneously. Using the result of the problem, the decision maker may declare his preferences about some objectives and he may also change the availability of resources to achieve a better outcome. The disadvantages of this method are: 1) the feasible region is continuous, and 2) as GP it cannot take into account intangible criteria. The first disadvantage can be resolved by introducing integer variables into the problem, but the other remains.

2.8. Concluding remarks

There are different approaches with different views that can be used for choosing a concept design alternative. Decision techniques employed for selecting concepts range from intuitive to structured methods. Successful design is facilitated by structured concept selection. Individual application of the available methods cannot guarantee the characteristics of concept design selection fully satisfied. The presence of tangible and intangible criteria as well as resource limitations and how to aggregate different stakeholders' viewpoints, requires a systematic approach. A combination of techniques is suggested to solve the problems associated with them when they are used individually.

CHAPTER 3
COMBINATION OF AHP AND ZOGP

3.1. Overview

Designers and in general, organisations are confronted with decisions, which should be made in a multiple stakeholders' viewpoints environment. In chapter two, it was mentioned that it is necessary to develop a systematic approach for facilitating the concept design selection. A combination of the techniques from concept-specification and concept-concept approaches can solve the problems of the available methods when they are used individually. They are:

1- Not considering constraints associated not only with tangible but also intangible criteria.
2- Not considering the distance between the final selected alternative (from the viewpoint of all criteria or sub-criteria) and the selected alternative when an individual criterion is taken into account.
3- Multiple stakeholders' viewpoints between stakeholders are not taken into account.
4- A need for understandable and easy to use aggregation methods.

Although one can say that the first case is considered during the screening phase and if an alternative is not feasible, then it will automatically be removed from the set of alternatives. There are some constraints which can be eliminated with additional effort and cost. For example, the budget constraint can be removed if additional funds are accessible through borrowing money. Thus, when constraints are taken into account, the decision maker should carefully notice these limitations. On the other hand, using AHP as a stand-alone approach for selecting a set of alternatives among available ones with the highest weighted alternatives has been shown to be not the best set in the presence of real constraints (Badri, 2001; Schniederjans and Garvin, 1997; Schniederjans and Wilson, 1991).

The distance between an ideal alternative from the point of view of a criterion and the final chosen alternative (which considers all of the criteria and sub-criteria together) is important because the distance reflects how far a final chosen alternative is from the ideal alternative from the point of view of that criterion. In addition, each single criterion or sub-criterion has a relative preference which should be considered. The more the relative preference of a criterion, the more important the role its distance play. When the number of criteria and sub-criteria for evaluating the alternatives are increased, the distances become more important because it can reflect more distinction between alternatives. In this case, there is a need to construct a tool that can consider these distances with their related relative preference of criteria.

The following example (table 1) can clarify the distance issue. Assume that there are three criteria (C_1, C_2, and C_3) for choosing between two alternatives (X and Y). Assume this table represents the weights of alternatives when they are compared with criteria.

Table 1 An example to clarify the disadvantages of AHP

Criteria / Alternatives	C_1	C_2	C_3
X	0.60	0.30	0.50
Y	0.40	0.70	0.50

Therefore, from the view of criterion C_1, the best alternative is X, while from the view of criterion C_2, the best alternative is Y. From the view of C_1, the goal target can be 0.60, the relative importance of selected alternative's weight, because when alternative X is chosen, there is no discrepancy between the relative weights of selected alternative and the goal target. When the view of C_2 is considered, then the goal target of that criterion should be 0.70 with the same reason. Now, assume that finally the best alternative from all of the views is Y. In this case, there is some discrepancy from goal target of criterion C_1, because the weight of that criterion regard to alternative Y was 0.40, not 0.60, the relative importance of alternative X. Thus, the 0.20 (0.60 – 0.40 = 0.20) discrepancy yielded from choosing alternative Y instead of X should be taken into account somewhere in the process. AHP just combine these relative weights in the synthesising process to establish the final weights of alternatives.

The third and fourth cases will be important when there are multiple stakeholders with different objectives. Not only should the different views be considered but it is also important to develop easy to use and understandable methods for aggregation of multiple stakeholders' viewpoints. Although there are methodologies such as the soft systems methodology (Checkland, 1999), which can be used to resolve the problem of considering multiple stakeholders between stakeholders (with different objectives), but it:

1- is suitable for ill-defined problem situations,

2- emphasises the improvement of a system,

3- focuses on a desirable system and the ways to reach it.

4- is a useful method when objectives need to be clarified.

5- is quite concerned with existing systems because the process explicitly requires a current system to be taken into account,

6- hopes for convergence in term of the ideas of stakeholders,

7- focuses on human communication,

8- is a heavy time-consuming process,

9- does not require mathematical analyses,

10- is an open-ended process.

The characteristics of concept design selection do not correspond to the soft system approach. Multiple stakeholders' viewpoints can be handled but other characteristics of this method do not make it to be a suitable approach for design selection problems. Therefore, it is necessary to construct a tool that can take into account these issues together. This chapter focuses on combining AHP and ZOGP as a tool to overcome these problems as shown in figure 3.

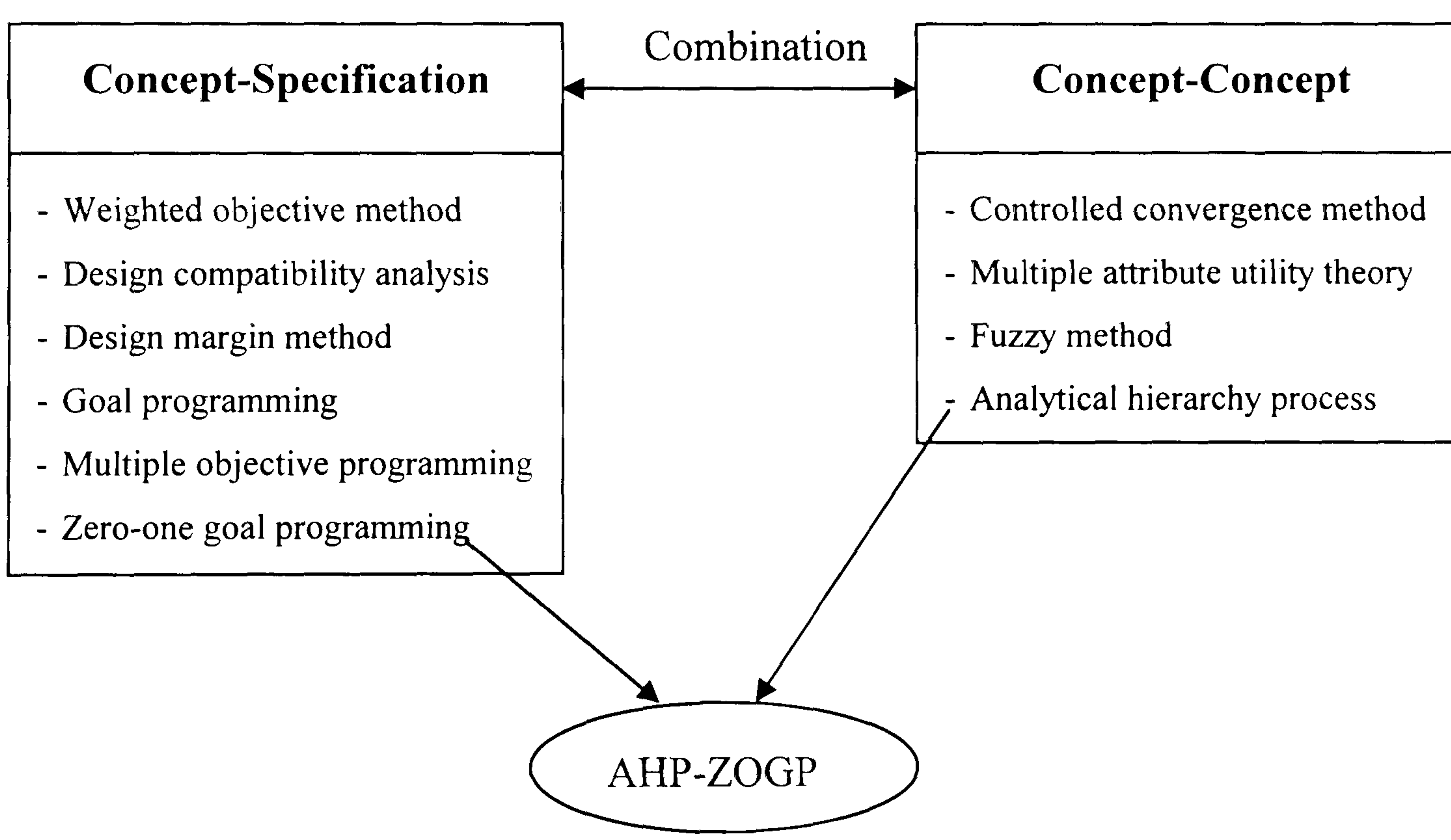

Figure 3 Combination of AHP and ZOGP

This chapter starts with an explanation of AHP and ZOGP characteristics and then the reasons for using AHP and ZOGP are discussed. A review of combining these two methods in previous research in different areas is made and then a linkage between the new research and previous ones is constructed. Finally a conclusion will be given.

3.2. The reasons of using AHP and ZOGP

Concept design selection is a problem that requires decomposition of elements (structuring), estimation of relative importance of elements (measurement of many tangible and intangible elements), and combining them (synthesising) in order to choose the most suitable concept design alternative. These characteristics of concept design selection, which are consistent with the applicability of AHP, allow us to use this method.

The AHP is chosen as a part of this approach because:

- AHP is systematic,
- Intangible criteria can be handled,
- Group decision-making is facilitated,
- The process is flexible and allows for updates,
- It is able to generate true or approximate weights through pairwise comparisons,
- It can formally deal with inconsistencies which may appear when using pairwise comparisons,
- The judgement of the importance of one element over another can be made subjectively (Lai et al, 2002).

Using AHP and ZOGP as stand-alone methodologies have some problems which were discussed earlier in chapter 2. Although ZOGP models have been designed to include tangible constraints, they are able to include intangible constraints which exist in the concept design selection problem, with some modifications. Tangible constraints are real constraints that may exist in every decision making problem. This type of constraints has a determined scale for exploring such as hours or dollars. The allocated fund to each new design product, available budget for designing new products, the selling price of each product or upper limit of selling price for a product are some examples. The data for this type of constraint are usually available or can be estimated. On the other hand, intangible constraints are those which do not really exist but should be considered because they can reflect the amount of accessibility of intangible criteria. This type of constraint is applied to the ZOGP model in order to include the importance of distance between the chosen alternative with regard to a criterion and the final selected alternative. When the final selected alternative is the same as the alternative which is the best from point of view of a criterion, this distance is zero. Achievements to a minimum flexibility of a technology or a minimum quality of a product are some examples of these types of constraints.

ZOGP's objective function is usually the minimisation of a weighted sum of undesirable variables which are related to tangible criteria. The weights of variables in the objective function are coefficients, which should reflect the relative importance of the criteria. They can be obtained by direct involvement of the decision maker to guess based on his perception, or better, can be elicited by other methods, such as AHP because of its ability to generate true or approximate weights through pairwise comparisons (Saaty, 1980; Golden et al, 1989; Forman and Gass, 2001).

The final element in ZOGP models are variables. The variables should reflect which alternative is selected or not selected. In addition, there are other variables which in the literature of GP models are called deviation variables which reflect the underachievement or overachievement of a criterion with regard to its target value. The deviation variables play roles for the distance between an ideal alternative when it is compared to a criterion and the final selected alternative.

The superiority of using the combination of AHP and ZOGP, instead of using either method separately, lies in the strength and weaknesses of both methods when they are applied alone. If only the AHP method is used to make the final ranking of alternatives, the outcome may not be feasible, because of real constraints. In addition, as was discussed earlier, the difference between the target value of each criterion and the relative importance of selected alternative associated with that criterion cannot be taken into account. If a ZOGP model is tried without the AHP weightings, only pure chance could generate the same outcome that the combined AHP and ZOGP method derived. That is, no preferential ranking of the alternatives is possible without a weighting system which recognizes alternative relative importance as with the AHP (Schniederjans and Wilson, 1991). In addition, using a ZOGP model allows for additional tradeoffs information that permits decision makers to see these tradeoffs in terms of all criteria (Badri, 2001). Therefore, the combined AHP and ZOGP method offers a systematic, easy-to-use approach to a selection decision problem because:

- It can consider several criteria (goals);
- The relative importance of criteria and sub-criteria can be identified;
- It can minimise the undesirable variables or maximize the desirable variables;
- The difference between the target value of each constraint and the value of the selected alternative in the same constraint can be considered. These

differences measure the total distance between an ideal alternative when it is compared to a criterion and final selected alternative;

- It is able to take into account the nature of the go/no go decision;
- Not only can it consider the real constraints, but it is also able to take into account intangible constraints; and
- It can aggregate different stakeholders' viewpoints.

Therefore it is necessary to review the literature of combining these two methods in order to find whether it is possible to use this combination for concept design selection. The next section of this chapter is assigned to discuss the state-of-the-art of this issue.

3.3. Review of combining AHP and ZOGP

There are a huge number of papers which used the AHP or ZOGP individually but a few studies have been done to combine these two decision making techniques. Although there are some papers that use the AHP with other mathematical programming methods such as linear programming, they are not discussed here because the nature of concept design selection requires using binary variables not continuous variables which are normally used in other mathematical programming models. This section reviews previous works which have used the combination of AHP and ZOGP and to make a link with new research. The drawbacks of those models will be explained and then a link between the research and previous works will be made.

3.3.1. Combination of AHP and ZOGP in previous researches

A combination of AHP and ZOGP has been applied to several areas of research. Four different applications of combining these techniques were found in the literature which will be discussed briefly.

3.3.1.1. Information system project selection

One of the basic management activities in information system planning deals with the selection of information system projects and the allocation of resources to complete these projects. A combination of AHP and ZOGP has been applied for this selection problem involving a single decision maker (the organisation manager), three intangible criteria (increasing accuracy in clerical operations, information processing efficiency, and promotion of organisational learning), one tangible criterion (cost of implementing), four tangible constraints (programmer hours, analyst hours, clerical hours, and budget), and six alternatives (Schniederjans and

Wilson, 1991). The AHP was first used to prioritise the set of information system projects under consideration on the basis of the pertinent criteria of the organisation. The alternatives were evaluated by each criterion and the criteria were compared against each other by pairwise comparisons fashion. The resulting prioritisation information was then used as a ranking scheme within the framework of a ZOGP model. The alternatives' final weights of using AHP were applied to establish a part of the ZOGP's objective function to allow selecting highest AHP weights of the alternatives depends on the resource limitations. The ZOGP model explicitly has considered not only the relative importance of the information system projects but also has considered important resource availability constraints faced by the organisation when determining the proper selection of the projects which should be implemented.

To justify the outcome of the AHP-ZOGP, the authors (Schniederjans and Wilson, 1991) solved the selection problem with using AHP alone. The outcome was a ranking system. To decide which set of the projects should be selected to satisfy the constraints, they started from the highest ranking project, coming to the second one, and so on, until using the resources as much as possible without exceeding the availability of them. Then the same problem was solved with the AHP-ZOGP methodology. The outcome of the methodology was different. The outcome of AHP-ZOGP used the resources in an efficient way. When using AHP alone, some resources were unused, while using the outcome of AHP-ZOGP, the amount of unused resources was decreased. In other words, the utilisations of resources are increased.

There are some drawbacks of using the combined model as follows:

1- The method of assigning numbers to priority levels of goals in the objective function is not straightforward.

2- Intangible constraints associated with intangible criteria have been neglected in the model. Having a preferred minimum level of acceptance for an intangible criterion, such as flexibility, is not included in the model.

3- The deviation variables have different scales such as U.S dollars and hours and therefore they cannot be added in an objective function unless they have become un-scaled. In the current model the different scales of deviation variables have appeared in additive fashion in the objective function.

4- The problem was solved with normalised data with two different methods: lexicographic[18] and weighted method[19]. The outcomes indicated that different outcomes emerged when lexicographic and weighted methods with variable coefficients were used.

5- The focus of the model was to select a set of alternatives between a number of them not to select a single alternative. In fact, the problem is which set of alternatives should be selected in order to satisfy the tangible constraints as much as possible.

6- The problem has been sought from a single decision maker and therefore there was no need to aggregate the outcome.

3.3.1.2. Selection of cost drivers in activity-based costing

The selection of cost drivers in activity-based costing is a highly judgemental multi-criteria decision making problem (Schniederjans and Garvin, 1997). Current rule-based suggestions on how cost drivers should be selected have lack of consistency. Although using AHP approach can help bring consistency to the cost driver selection process but selecting the alternatives with highest AHP weightings may not utilise the resources efficiently (Schniederjans and Wilson, 1991). This problem has been solved by combining the AHP and ZOGP (Schniederjans and Garvin, 1997). The problem was decomposed to a hierarchy with four criteria (correlation with cost, reduction of drivers, performance, and cost of measure), three tangible constraints (budget, analyst hours, and auditing hours) and three alternatives. AHP was applied to obtain the final weights of alternatives and then they were used as the coefficients to establish a constraint in the ZOGP model. The right hand side of this constraint was set up at 1, which allows the model to select more than one alternative. The AHP-ZOGP allows selecting the best set of multiple cost drivers to use resource limitations efficiently and to avoid exceeding the resource limitations if possible. The ability of AHP-ZOGP to select a feasible set of multiple cost drivers is an important feature which has been neglected in the literature of this selection problem.

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[18] Lexicographic method uses a rank order of each goal. The problem is individually solved by first ranked goals in objective function. Then the problem is solved again with second ranked order. If its outcome causes to decrease the index improvement of first ranked order, the outcome is not accepted and the first obtained outcome is accepted. Otherwise this procedure continues in the same manner.

[19] Weighted method assigns a weight to each goal and then the problem is solved by linear addition of their individual components.

For justifying the AHP-ZOGP methodology, the same procedure of information system project selection was applied to this problem. AHP was used alone and then the combination approach was used. When using AHP, there are some unused resources, while using AHP-ZOGP approach, the amount of unused resources has been decreased.

The drawbacks of using the combined model are as follows:

1- The method of ranking resource priorities was not identified. Authors assumed a special ranking for the resources.

2- The problem involved selecting a set of alternatives not just a single alternative.

3- Normalisation of data has not been made. An experiment was made with its un-scaled data. The result showed that the parameters in the model should be normalised because they produced different outcomes.

4- The model did not include intangible constraints.

5- A single decision maker is assumed to make a final decision.

3.3.1.3. International location-allocation problem

International location-allocation decisions involve a substantial capital investment and result in long-term constraints on production and distribution of goods. The problem is complex due to highly judgmental and sensitive criteria such as the political situation, global competition and survival, foreign government regulations, and economic factors related to the host country. The complexity stems from a multitude of tangible and intangible criteria influencing location choices as well as the intrinsic difficulty of making numerous tradeoffs among these criteria. In addition, there are always real resource limitations that should be taken into account. The selection of location alternatives via the AHP alone has not taken into consideration all the facets of the problem. First, the decision makers are faced with a multiple location problem; second sufficient resources do not exist to support the selected location(s); and third, extending the AHP method to selecting multiple locations at a time can result in an infeasible selection since possible limiting or constraining resources are not directly considered in the selection process.

A combination of AHP and ZOGP has been used to tackle the problem (Badri, 1999). The problem has six potential plant location sites (alternatives) in Middle Eastern countries, including Saudi Arabia, the United Arab Emirates, Bahrain, Kuwait, Qatar, and Oman, with four criteria (political situation of foreign country, global competition and survival, government regulations, and economic related factors) and a three-level hierarchy. The weights of using AHP alone were used as the coefficients to establish an equation (constraint) goal of ZOGP model with 1 in its right hand side. This constraint with its associated deviation variables and with its preference system in the ZOGP's objective function allows selecting more than one alternative.

A comparison of the AHP alone and the combined AHP-ZOGP outcomes reveals the potential superiority of the combined methodology when making the decisions. The AHP alone outcome of selecting the four highest weightings constitutes an infeasible outcome since insufficient resources exist to support that selection. In other words, there are many problems associated with opportunity losses and infeasibility when AHP was used alone. Using AHP-ZOGP approach not only will select those four alternatives that are feasible due to resource limitations but also the opportunity losses are minimised.

The suggested model has the same drawbacks of the two previous models. The model is different from the two previous models, as it involves group decision making. The elicitation of judgements for identification of goals' priority has been made through a group of decision makers.

3.3.1.4. Selection of quality control systems

A combined AHP and ZOGP model was developed for selection of quality control systems (Badri, 2001). Seven alternatives with five criteria were considered in a three-level hierarchy. In this application, it had been assumed that three instruments needed to select. In the combined model, the objective function sought to minimise deviation from the desired goals constraints (tangible and intangible constraints) with the AHP ranking of the quality control instruments. In addition of normal constraints, an equation associated with the AHP weights for the quality control instruments was added to reflect the preferences for the different instruments. This constraint attempts to maximise the weights by selecting the quality control instruments with the highest priorities. To determine the ability of the instruments to measure each of the five criteria, the AHP weights for each quality control instrument by each quality measure had been used. The right hand side values for each goal constraint sought to pressure a selection of service quality control instruments with the highest scores (the most useful collection of instruments to measure quality). In other words, the best set of three quality instruments was chosen for each of the five criteria. The right hand side of these constraints was derived by summing the best three of AHP weightings for each of the five quality measures. The suggested combined model used group decision making, tangible and intangible constraints using final weights of AHP and their partial weights[20] and global weights[21] for determining the coefficients of objective function. The method of prioritising the goals in the objective function has not been identified and the author just used a ranking of goals based on his perception. Moreover, the model used a single stakeholder. The other drawbacks of previous models remain.

To justify the methodology, the same procedure for the other three recent implementations was used. Using the AHP alone with the first three selected alternatives was not feasible and there were some underachievement for some goal constraints. Using the combined approach solved this non-utilisation of resources and minimised the non-efficiency of the resources.

3.3.2. Linking between the new research and previous models

This section illustrates how the new research relates to previous works. A summary of related previous works are shown in figure 4. The lines between each element in that figure illustrate how previous works have used each part of AHP and ZOGP.

New research will be shown to:

1- Include multiple stakeholders;

2- Use invaluable weights obtained by AHP;

3- Include intangible constraints relate to intangible criteria;

4- Use normalised data or parameters;

5- Aggregate the outcomes by AHP's final weights;

6- Aggregate the outcomes by AHP's partial and global weights;

7- Aggregate the outcomes by ZOGP model; and

8- Include the difference between final chosen alternative and best selected alternative when alternatives are compared to a criterion.

3.4. Concluding remarks

The provided models showed they had some shortcomings which can be removed by careful consideration of weights obtained by AHP and including

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20 The weights of alternatives when alternatives are compared to a criterion are called partial weights.

21 The weights of criteria when they are compared with each other, through the pairwise comparison are called global weights.

tangible and intangible constraints in a rational way. Furthermore, the suggested models did not provide any means to aggregate the outcomes obtained by individual stakeholders in order to reach a single decision. The new research attempts to take into account the neglected parts of previous works.

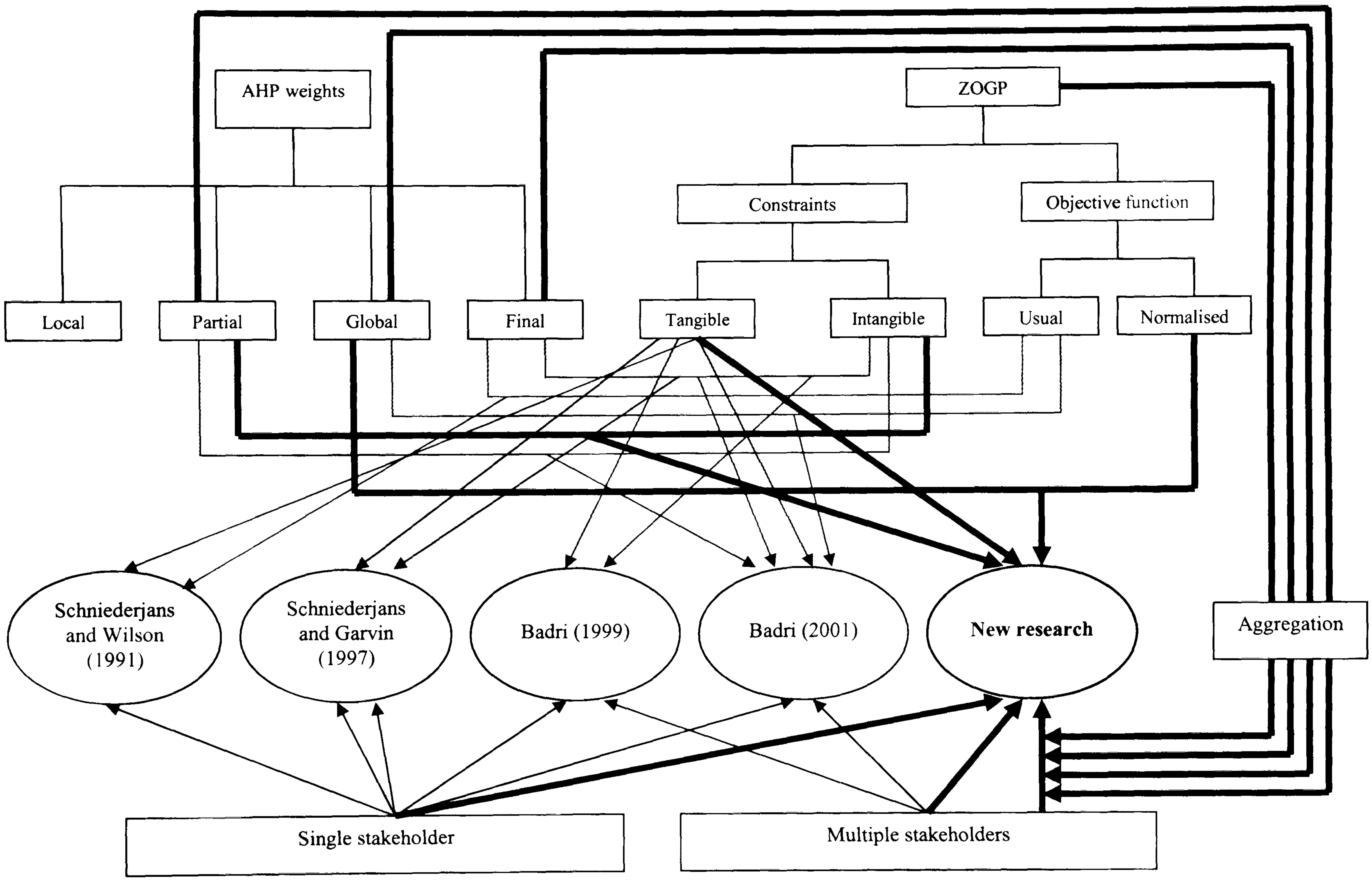

Figure 4 Links between previous researches and new research

CHAPTER 4
PROPOSED APPROACH

4.1. Overview

In view of the multiplicity of stakeholders' viewpoints and criteria, tangible and intangible, inherent in decision making situations, the approach of MCDM-MSDM is used as the general framework of analysis. A decision making problem with more than one stakeholder, can be constructed as more than one hierarchy with different criteria. Saaty (1980) has used this concept to solve a problem involving profits and costs criteria. He constructed profits and costs hierarchies and then each hierarchy was solved individually. For aggregating the preferences, the ratio between the weights of the benefits' hierarchy and weights of the costs' hierarchy was obtained. The best alternative then was chosen by the maximum ratio. A problem can also be sought from different stakeholders, with their special criteria or sub-criteria, and some common criteria but having identical alternatives. For example, when a vehicle manufacturing factory is going to decide to transfer a technology, they may consider two stakeholders as managers and customers. Managers' look at the problem as macro economic, affecting not only the country, such as increasing the job opportunities, increasing international market share, but also increasing national market share, while customers look at the problem as micro economic, wanting to be satisfied with buying a car. In this case, the hierarchies and criteria for stakeholders are different, because managers have their own criteria such as flexibility of production lines, process quality of production lines, and etc. while the customers also have their own criteria such as the price of product, the durability of the car, safety and so forth. In this case, it is almost impossible to make a single hierarchy that covers these different criteria and hierarchies.

The general framework of the approach has been depicted in figure 5. The basic idea in this framework is to use problem decomposition and explicit value or preference tradeoffs from each stakeholder's viewpoint to improve the understanding of a complex problem. This framework allows each individual stakeholder, to focus on their own hierarchy and different criteria separately. The outcome weights from each stakeholder's viewpoint can be obtained by any evaluation methods. It is then necessary to aggregate the different outcomes, arising for individual stakeholders, in order to derive a single decision from all of the stakeholders' viewpoints.

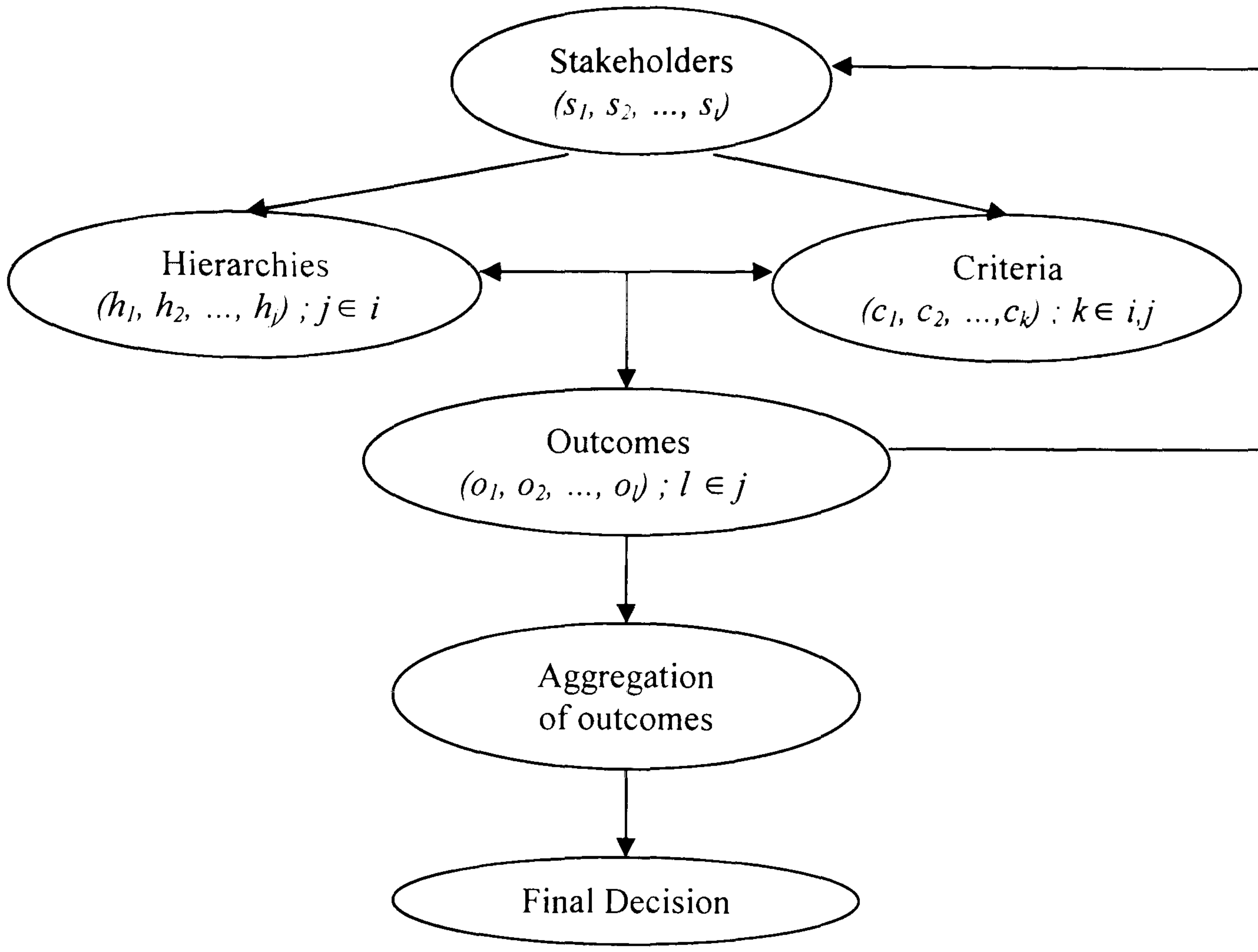

Figure 5 General framework of MCDM-MSDM problems

In figure 5, *i* stakeholders, *j* hierarchies, *k* criteria, and *l* outcomes are assumed to exist with regard to choosing an alternative. In fact, each individual stakeholder can create a general hierarchy and then identify the relevant criteria or sub-criteria, or one can identify the criteria and sub-criteria and then put them into a hierarchy. An outcome (weights of the alternatives) can then be made by using an evaluation method from each hierarchy with its relevant criteria. Finally, the individual outcomes are aggregated to reach a final single decision.

The aims of developing the approach are: (1) to make a decision making method to facilitate the MCDM-MSDM process for design and manufacturing selection problems, (2) to use both tangible and intangible criteria, and (3) to aggregate the different stakeholders' viewpoints. The approach includes four general stages:

1- Using the AHP alone in order to weight the alternatives from the viewpoint of each stakeholder. The result of this stage is the alternatives' final weights from the point of view of each individual stakeholder.

2- Aggregation of different outcomes, obtained by AHP, by heuristic methods based on a distance function in order to find a single outcome. The result of this stage is a single aggregated outcome.

3- Constructing a ZOGP model for each stakeholder's viewpoint, using the detailed information (global and partial weights) derived by the AHP, and data from real situation, in order to find the most appropriate alternative from the viewpoint of each stakeholder.

4- Aggregation of the ZOGP models by another ZOGP model with i) combining their objective functions by summation of individual objective functions; and ii) MINIMAX concept, minimisation of maximum weighted undesirable deviation variables. The constraints in the new ZOGP model are all constraints in the individual models. A single outcome will emerge by using this ZOGP model.

4.2. The proposed approach

The overall picture of the approach is shown in figure 6. The main idea is to decompose a problem into its elements and sub-elements as a hierarchy as shown in figure 5. In figure 6, each box is identified by a number for detailed explanation of the approach. Box 1 is assigned to identify stakeholders, criteria, and constructing the hierarchy for each individual stakeholder. Boxes 2 to 6 are related to using AHP as a stand-alone methodology as well as heuristics methods for aggregating different outcomes obtained by individual stakeholders while other boxes are related to using a combination of AHP and ZOGP, for choosing an alternative and for aggregating the outcomes obtained by the individual models.

In this chapter, the methodology is explained in detail. To make it more concrete, results of an initial case study undertaken by the author are used throughout for illustration. This case study, in the area of manufacturing investment decision taking, is concerned with relative merits of purchasing complete automotive plant from Fiat, Honda, Hyundai, Toyota, and Volks Wagen. Background ideas are described next.

4.2.1. Illustrative Case Study (ICS)

Growing competition, increasing demands from customers and scarce resources are forcing Iranian vehicle manufacturing companies to consider investment in new technologies, adopting manufacturing technology from a well-known international company. A new technology is any type of technology that, when incorporated into a manufacturing operation, has a significant impact on the product, process, and informational viewpoints of the system (Ordoobadi and Mulvaney 2001).

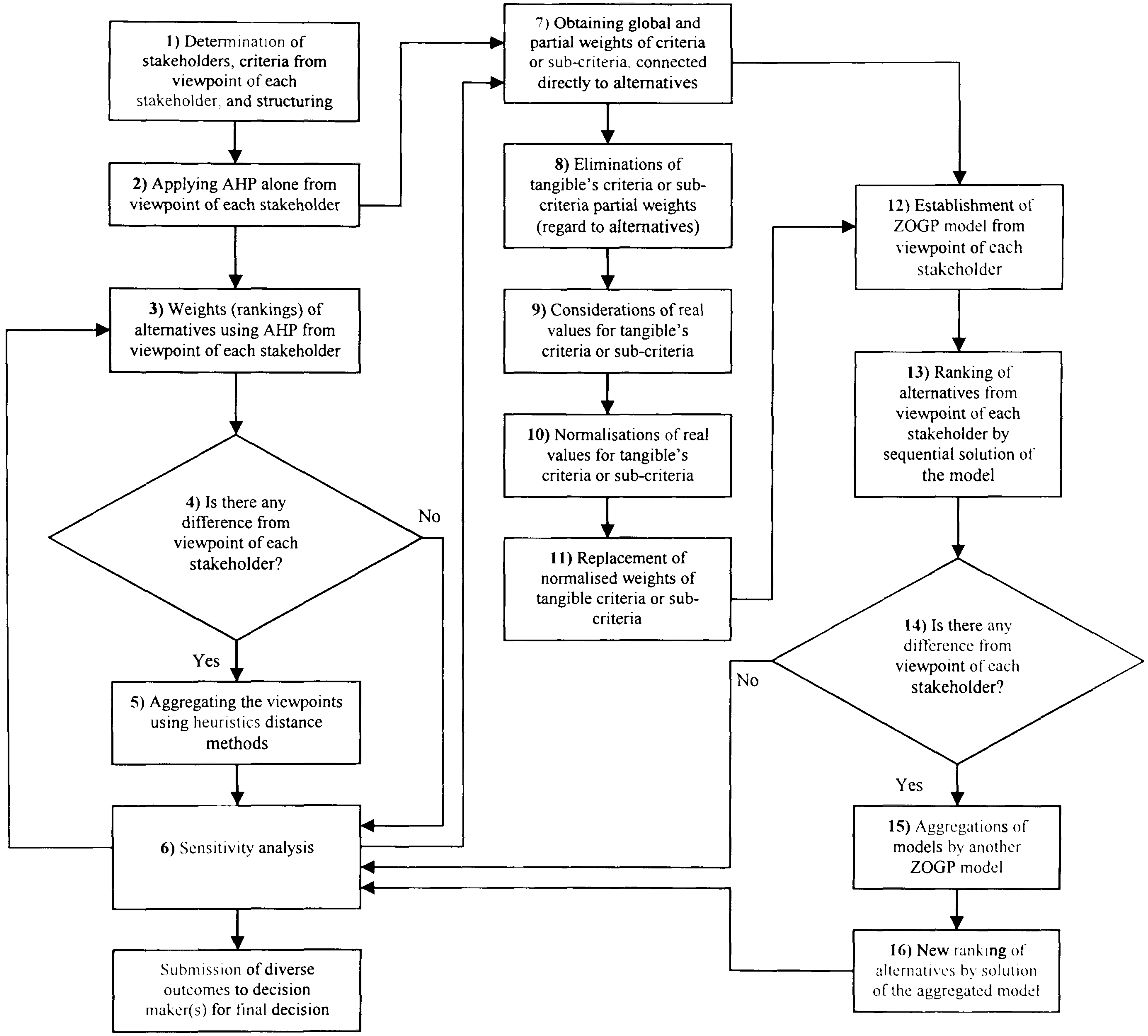

Figure 6 Proposed approach

The case study envisages a situation in which a company purchases an entire vehicle manufacturing technology, when the technology has come to the end of its market life in its country of origin, to manufacture the vehicle under license. Adoption of a technology implies transferring all of the hardware including machines, equipment, tools and production lines. It includes transferring all the accompanying software, documents, technical diagrams, standards, methods and systems including training from a country that has the technology to another country under a contract.

Evaluating and justifying new technologies is a very challenging and complex task because of its long-term benefits; the social, economical, and political criteria; the existence of intangible and tangible criteria; the existence of conflicting criteria; and the presence of multiple stakeholders. In addition, they have a long life with high capital investment which is expected to be returned over several years (Troxler and Blank, 1989). Large investments are often associated with the selection of new technologies and companies make such decisions relatively infrequently. Consequently, the nature of the problem is that of a binary decision; selection or non-selection. The selection of a new technology affects many stakeholders such as managers, customers and perhaps governments. This problem is characterised by the difficulties associated with strategic selection decisions which were discussed in section 1.3.2.2.

Selection of a new technology such as a vehicle manufacturing system is not trivial, and the decision is only explored at a general level. Nevertheless, the case study is offered for illustrative purposes. The data for this case study is gathered through questionnaires which represent the stalkeholders' viewpoints. Every element in this case study is obtained from real persons who are involved in the decision or obtained from real documents which are available to decision maker(s).

4.2.1.1. Literature review of the ICS

The traditional way of justifying strategic selection decisions is financial assessment. In traditional methods, the future benefits of an investment are converted to monetary values, ignoring most of the intangible benefits because of inadequate means for quantifying them. Traditional methods usually justify decisions using low-level capital budgeting, which works well for investments with benefits clearly defined as monetary values, but does not work well for longer term strategic investments (Parsaei and Wilhelm, 1989). This is because some selection criteria, such as flexibility and quality, cannot be converted into monetary values exactly. Thus traditional methods ignore intangible benefits and long-term perspectives. For a more detailed assessment of traditional financial methods for evaluating new technologies, one is referred to Canada and Sullivan (1990), and Ordoobadi and Mulvaney (2001). Their assessment suggests that companies should not rely on traditional economic methods alone for the selection of a technology.

Another way of justifying strategic selection decisions is to perform a strategic/economic analysis, making a list of all potential benefits, and performing a traditional economic analysis on the quantifiable benefits. Then, if the project is not justified through these procedures, expected value analysis is used to estimate any remaining non-quantifiable benefits (Noble, 1990; Pant and Ruff, 1995). However, this method does not take into account the views of multiple stakeholders and the assignment of probabilities to calculate the expected value is subjective.

4.2.2. Identifying stakeholders, criteria, and constructing the hierarchies

The first step in the approach is to determine the stakeholders, criteria, and constructing hierarchies from each stakeholder's viewpoint (box No.1 in figure 6). This section discusses these issues.

4.2.2.1. Identifying the stakeholders

The first major task in any choice problems in the MCDM-MSDM environment is to identify the stakeholders whose interests will affect the selection procedure. Stakeholders may have different interest when they are looking at the problem. For example, to choose the most appropriate technology, the employees' interests not only differ from the organisation manager's interests, but also these interests may conflict with each other. The stakeholders may not be weighted on some occasions. For example, it is hard to say whether the manufacturers' issues are more important than customers' interests when a new product is supposed to be designed.

4.2.2.1.1. Identifying the stakeholders for the ICS

The stakeholders for the selection might include managers, customers, government and employees. Although the approach is not restricted to the consideration of just two viewpoints, for the sake of clarity only two stakeholders, managers and customers, are considered.

4.2.2.2. Identifying the criteria

The quality of a decision depends on selected criteria because decisions are made by evaluating each alternative against a common set of decision criteria and assigning values that represents how well each alternative satisfies each criterion. So determination of criteria or sub-criteria is an extraordinary task because in almost every stage of the approach, the criteria and sub-criteria play important roles. So it is necessary to be careful about the qualities of a good system of criteria which affect the problem.

When there are multiple stakeholders with different hierarchies and different sets of criteria for evaluating the alternatives, the stakeholders may choose different alternatives. A criterion which is important from the point of view of a stakeholder and therefore should be included in the set of criteria may be worthless from the viewpoint of another stakeholder and thus, should not be considered. Therefore, the second major task in design and manufacturing selection problem is to identify the criteria that affect the problem from each stakeholder's viewpoint. One major problem is how to determine the criteria and what characteristics they should have. In this regard three general properties (exhaustiveness, consistency and non-redundancy) have been proposed for determining the criteria (Roy, 1986).

The exhaustiveness property says that none of the criteria used to discriminate between alternatives should be forgotten. In other words, all relevant criteria of the problem from point of view of individual stakeholders should be covered. This property is important at the time of modelling the problem because it is vital to see whether the selected criteria express all of the attributes actually considered in the decision.

The consistency property concerns the decision maker's global preferences. Global preferences should be coherent with the preferences according to each criterion. For example, if there are two alternatives which the decision maker is indifferent between, then the improvement of one criterion for the first alternative should imply that the first alternative now is preferred to second one. The property of consistency is generally satisfied with a rational decision maker because it is assumed that decision maker has a good knowledge of the global preferences.

Non-redundancy property says a family of criteria that satisfies the properties of exhaustiveness and consistency will be non-redundant if removing one single criterion leads to the rest of the family no longer satisfying the requirements of exhaustiveness and consistency.

In addition to the above properties, the criteria should be decomposable, operational, and minimal for practical applications (Golden et al, 1989). They can be broken down into parts for detailed analysis. The lowest level of criteria should be meaningful and assessable, and finally they should not be too many because of the limited ability of the human brain to consider them simultaneously (Saaty, 1994).

4.2.2.2.1. Identifying the criteria for the ICS

To determine the criteria for selection of vehicle manufacturing technology for both stakeholders' viewpoints, the idea of hierarchical structure by dividing the criteria into sub-criteria was used.

The criteria for customers were obtained by interviewing experts in three large car agencies, five mechanics in the garages and 20 persons who had a car for more than ten years. The criteria for managers were obtained by interview of more than ten managers and experts who were working at three large vehicle manufacturing companies in Iran. The process of interview for determining the criteria from the viewpoints of managers and customers were repeated three times in order to refine the criteria which were determined previously. In this regard, there are two points which must be explained.

1- Less important sub-criteria were eliminated from further consideration and some cognate criteria were considered together.
2- Just general criteria which were common between the respondents were taken into account. In other words, the special criteria or sub-criteria were eliminated.

The criteria and sub-criteria for both stakeholders' viewpoints are shown in figures 7 and 8. Definition of all criteria and sub-criteria are given in the questionnaires in Appendix A.

4.2.2.3. Constructing the hierarchies

Establishing the hierarchy which represent the decision making process well is crucial to accurate decision making (Hanratty and Joseph, 1992). The stakeholders' task is to break down the decision problem into the hierarchies of related decision elements (criteria and sub-criteria) based on their different viewpoints. The task also involves compromising on a hierarchy when different viewpoints may exist within the stakeholders. In this case, it is necessary to discuss everything that affects the problem with the members of the group. The decision hierarchy can be viewed as a type of tree diagram. At the top of the hierarchy is the objective of the decision making process, choosing the most appropriate alternative. The level below the top level contains the criteria upon which the top level decision is based. The levels below this add details to the decision elements in level above, we can say it as sub-criteria, followed by sub-sub-criteria. The final level contains the decision alternatives. The complexity of the problem domain and the detail of the problem modelling will dictate the number of levels in the hierarchy and the number of decision elements per level.

The hierarchy should not be so complex and it should be understandable for everyone involved in the decision. Because there is generally more than one stakeholder, the hierarchies and levels of it, may be different, or may not. It depends on whether the criteria and their subsets are common from each stakeholder. For example, managers of a company agree on a hierarchy with compromising between themselves, while customers' hierarchy may be different.

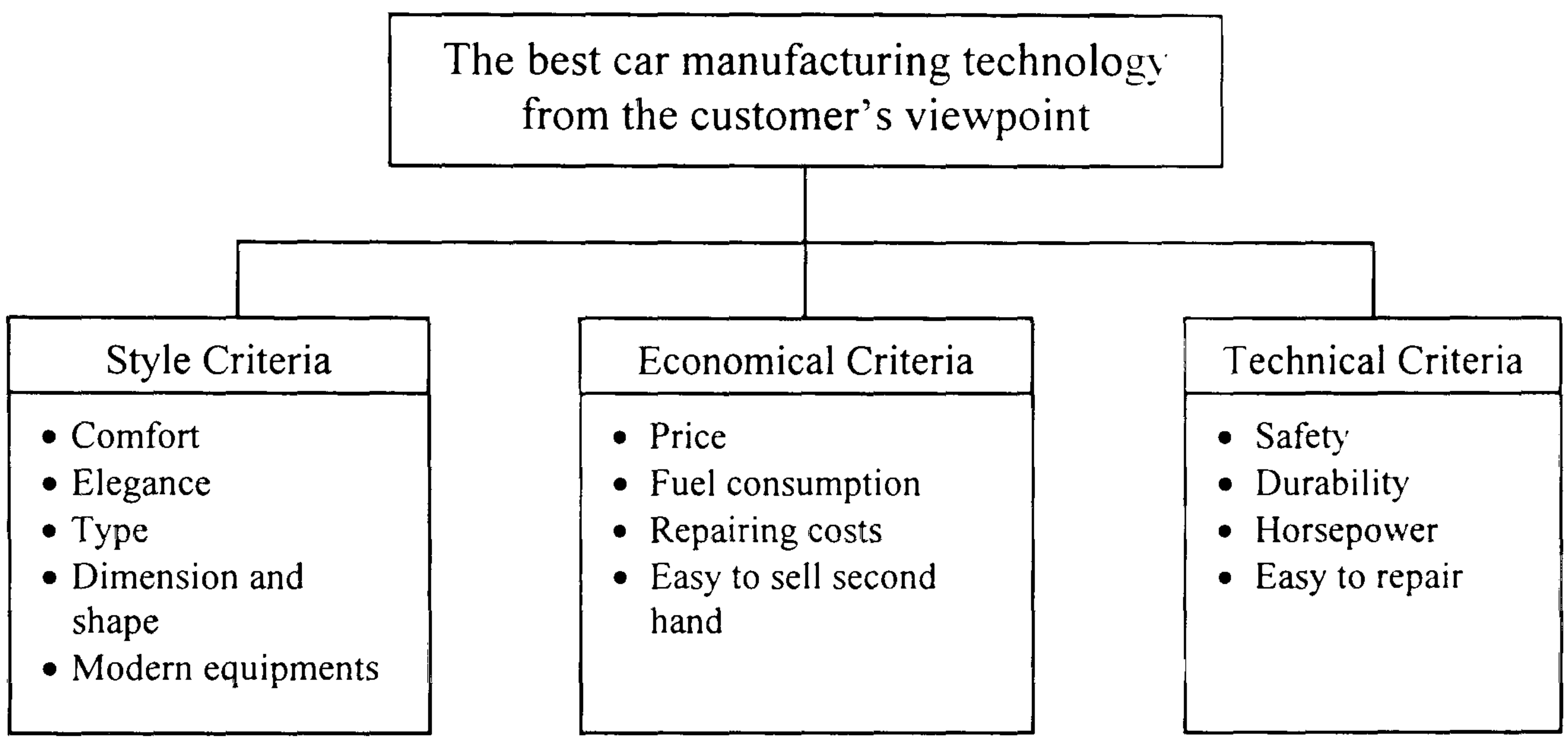

Figure 7 The hierarchy, criteria and sub-criteria from viewpoint of customers

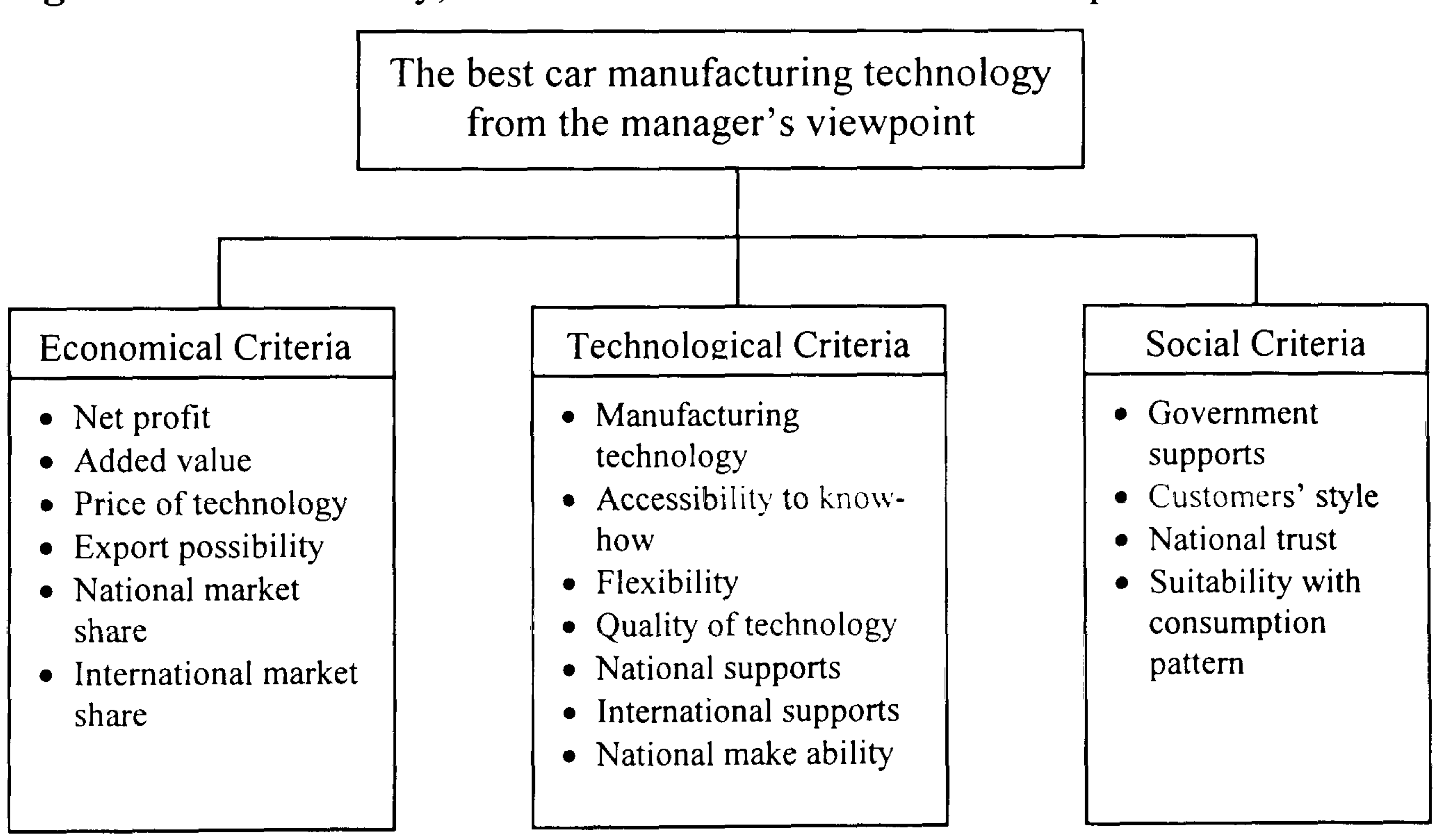

Figure 8 The hierarchy, criteria and sub-criteria from viewpoint of managers

4.2.2.3.1. Constructing the hierarchies for the ICS

Before constructing the hierarchies, it is necessary to determine the alternatives which the stakeholders want to choose. To do this, an initial list was considered including the vehicle companies' name all around the world. The initial list of alternatives was more than 30 famous companies. The list of possible alternatives was decreased to limit the choice to a small number of alternatives that could be examined in detail based on some reasonable factors (Pomerol and Romero, 2000). That list of alternatives was then decreased based on the following factors:

- Government support;
- Limitation of political issues;
- Export possibility of products;
- Availability of data;
- Interests of vehicle manufacturing managers and interest of customers;
- Usability for middle class people; and
- Reasonable selling price of products.

These factors reduced the number of alternatives sharply. For example, limitation of political issues prevented consideration of American companies, while usability for middle class people prevented consideration of companies such as B.M.W or Mercedes-Benz. After full consideration of alternatives from the viewpoints of the listed factors, Fiat, Honda, Hyundai, Toyota and Volks Wagen were chosen for further consideration. In addition, in order to avoid rank reversal of alternatives when similar alternatives exists (Golden et al, 1989), from each company a model was selected which was compatible with interests of customers, had medium size and was suitable for a family with an average size of 4. They were: Punto (Fiat), Civic (Honda), Elantra (Hyundai), Celica (Toyota), and GTI VR6 (Volks Wagen).

Based on the above description of alternatives, criteria and sub-criteria, two hierarchies were built to express the stakeholders' viewpoints. These hierarchies have been shown in figure 7 and 8. Alternatives will be laid on the bottom of these hierarchies. For chosen alternatives, real data regarding to tangible customers' criteria were elicited from www.kbb.com and regarding to tangible managers' criteria were obtained from related proposal which were available for vehicle manufacturing companies in Iran. These data are depicted in tables 2 and 3.

Table 2 Tangible data for alternatives (customers)

Model	Price		Fuel Consumption			Power @1000 rpm	
	($)	Normal	(MPG)	(LPM)	Normal	(H)	Normal
Punto (Fiat)	15000	0.181	37	0.123	0.141	11.8	0.102
Civic (Honda)	18000	0.217	26	0.175	0.201	24.6	0.213
Elantra (Hyundai)	14000	0.168	24	0.189	0.217	22.5	0.195
Celica (Toyota)	16000	0.193	27	0.168	0.193	21.9	0.190
GTI VR6 (Volks Wagen)	20000	0.241	21	0.216	0.248	34.5	0.300

$: U.S. Dollars; **MPG**: Mile Per Gallon; **LPM**: Liter Per Mile;
HP: Horsepower; **rpm**: revolutions per minute

Table 3 Tangible data for alternatives (managers)

Technology	Price of Technology		Net Profit		Added Value	
	Presented	Normal	Presented	Normal	Presented	Normal
Fiat	700	0.250	25	0.085	3	0.059
Honda	500	0.179	40	0.136	6	0.118
Hyundai	200	0.071	100	0.339	20	0.392
Toyota	400	0.143	50	0.169	12	0.235
Volks Wagen	1000	0.357	80	0.271	10	0.196

The alternatives from the viewpoints of managers were the technologies of producing the products such as Toyota technology, while the alternatives from viewpoints of customers were the products of technologies such as the Punto model from Fiat technology.

There are two points which must be explained:

1- The data for technology which was obtained from managers of vehicle manufacturing companies was scaled by a constant coefficient from the original data. The companies tended not to present the real data because of security purposes. There was no difference between using the real data or its transformation, because the approach uses the data as normal values.

2- Net profits for technologies will have been predicted by 100% utilisation for a 5-year period after the whole technology would set up.

To construct the hierarchies, all criteria for both viewpoints were grouped to relevant upper level criteria. The upper level criteria for managers' viewpoints were established as economical, technological, and social criteria. The upper level criteria for customers' viewpoints were as style, economical, and technical criteria. Then each individual criterion such as flexibility or price (now is a sub-criterion) is placed under one of these upper level criteria from its relevant stakeholder's viewpoint. Theses categorisations were then submitted to the managers and some of customers. Both stakeholders were agreed to these hierarchies for further consideration.

4.2.3. Using AHP as a stand-alone methodology

The second step of the methodology is to apply the AHP, from each stakeholder viewpoint, for determining the final weights of alternatives through detailed weights, obtained by pairwise comparisons, using the synthesising procedure (box No.2 in figure 6).

The original AHP involves a five step procedure as follow:

1- Set up a decision hierarchy by breaking down the decision problem into a hierarchy of interrelated elements.

2- Collect the input data of pairwise comparisons of the decision elements.

3- Evaluate the consistency ratio based on what has suggested by Saaty (1980).

4- Use the eigenvalue method to estimate the relative weights of the decision elements (Golden et al, 1989).

5- Synthesise the relative weights of the decision elements to arrive at a set of ratings for the decision alternatives.

4.2.3.1. Constructing the hierarchy

The first step in AHP is to develop a graphical representation of the problem in terms of the overall goal, criteria, and decision alternatives as a hierarchy. The first level of the hierarchy is the overall goal of a problem. For selection problem, this goal is indicated by selection of the most preferred alternative. At the second level to penultimate level, all the criteria and their sub-criteria which will contribute to the achievement of the overall goal are considered. Finally, at the end level, alternatives are placed.

4.2.3.2. Elicitation of judgements

In step 2 of the AHP process, the pairwise judgement comparisons of the decision elements are established to elicit the judgements for how "good" the alternatives perform under each criterion, sub-criterion, or sub-sub-criterion which it depends on whether criterion, sub-criterion, or sub-sub-criterion has been connected to the alternatives directly. Figure 9 explains this situation. In this figure, criterion *C* has been connected directly to the alternatives, while other criteria (*A* and *B*) have not because they have some sub-criteria, so their sub-criteria are directly connected to the alternatives. It is necessary also to compare the criteria (sub-criteria) against other criteria (sub-criteria) in order to identify how important the various criteria (sub-criteria) are to the decision because the criteria (sub-criteria) are not equally weighted. This process is made as the same as comparing the alternatives regard to a criteria or its subsets (Golden et al, 1989).

The pairwise comparison procedure is equivalent to assigning numbers to criteria which sum to one under its parent node. In every comparison just two alternatives or criteria or sub-criteria are compared. The AHP requires answers (either numerical or verbal) to a sequence of questions that compare two elements. The pairwise comparison question is something like "Is element *A* more important than (or preferred to) element *B* and by how much?" In essence, when answering a pairwise comparison question, the decision maker(s) estimates the true but unknown weights based on insight and experience relative to the multi-criteria decision problem (Bodin and Gass, 2003). When the pairwise comparisons are made, the weights of each criterion or sub-criterion can be determined. For example, in the figure 9, assume the weights of criterion *C* regard to options are 0.20, 050, and 0.30, respectively. These values have been derived by asking the pairwised questions such as "which of alternatives (1, 2, or 3) do you prefer regard to criterion *C* and by how much?" After completing the pairwise comparisons, AHP can calculate the weight of each alternative regard to that criterion. These weights show that from viewpoint of criterion *C*, the best alternative is option 2 because it has largest weights among others. The same procedure can be applied to determine the weights or relative importance of each criterion (sub-criterion) in comparison with other criteria (sub-criteria) by asking the pairwise questions such as "Which of the criteria *A* and *B* is more important than another one and by how much?" After that AHP can calculate the relative importance of each criterion. The same procedure can be applied to determine the relative importance of sub-criteria regard to each other.

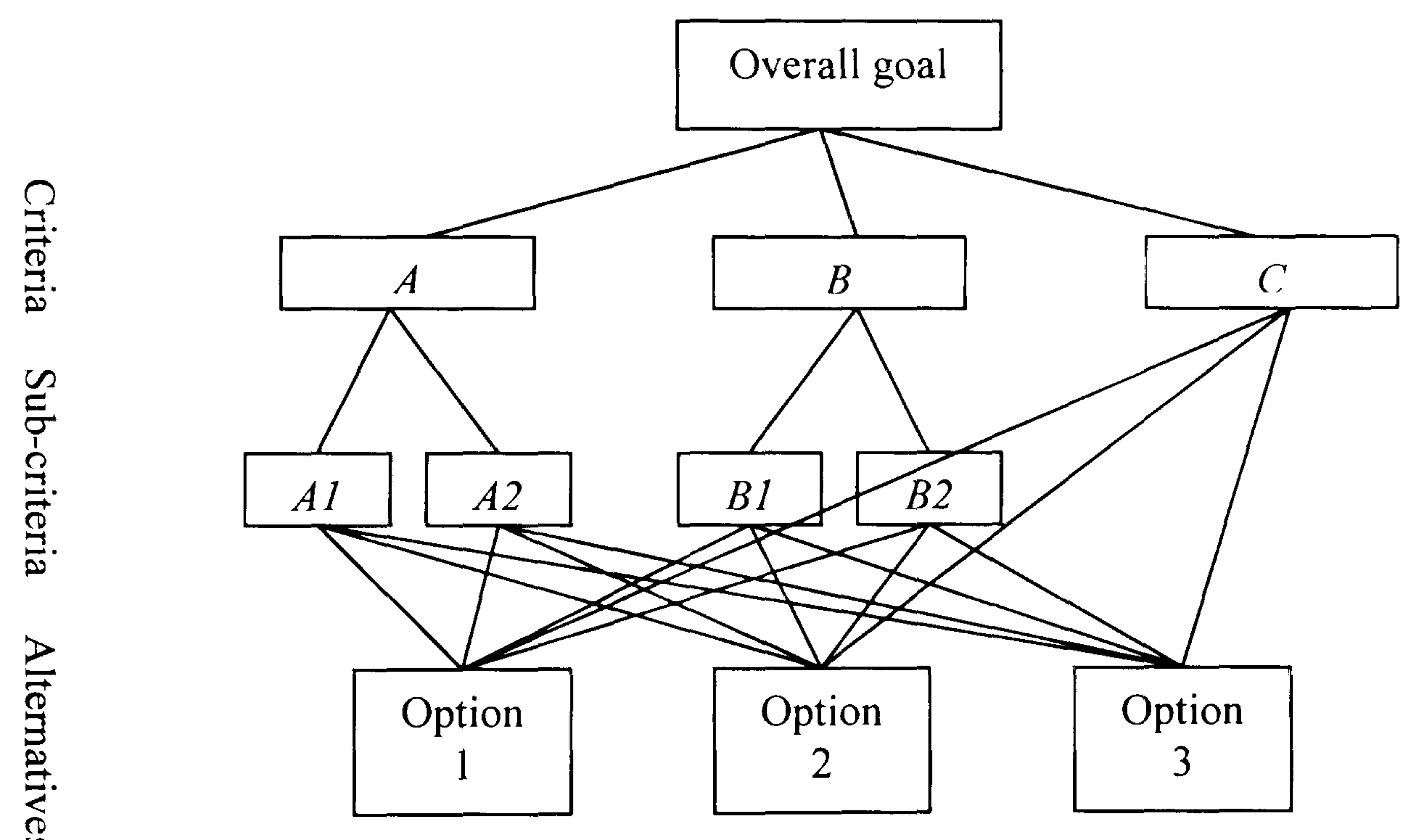

Figure 9 Connection between criteria or sub-criteria directly to alternatives

Pairwise comparisons are not always necessary for tangible criterion or its subsets, because they have already the available measurements like as distance and purchasing cost of products, unless the criterion or its subsets involves a degree of utility of that measurement (different people assign different values for something tangibles like as money), so it is usually essential to consider the pairwised comparisons subjectively rather than objectively when using the AHP. In this case, the value judgements must be made on the relative "goodness" of each alternative respect to that criterion or its subsets (Golden et al, 1989).

The use of such comparisons to collect data from the decision maker offers significant advantages. It allows the decision maker to focus on the comparison of just two objects, making the observations as free as possible from extraneous influences. Additionally, pairwise comparisons generate meaningful information about the decision problem, improving consistency in the decision making process (Schniederjans and Wilson, 1991). Whatever the complexity of hierarchy is less, the number of judgements is decreased and they can be made in a timely manner (Golden et al, 1989).

The numerical answers are given using a fundamental 1-9 scale, while the verbal answers are converted to their equivalent numeric values on that 1-9 scale. Large numerical values in the comparison between two elements indicate a greater degree of preference of one element over another in the given comparison. In fact "1" denotes equal importance and "9" denotes the highest degree of importance (Lai et al, 2002). The 1-9 scale has proven to be a most adequate measurement scale that enables a decision maker to approximate the unknown weights for a wide and important class of multi-criteria problems. It is possible to assign any numbers that can reflect the preferences of decision maker, if decision maker to be satisfied with those numbers. The 1-9 fundamental scale works exceptionally well in its ability to take into account a problem's tangible and intangible information as required by the pairwise comparison mode of the AHP (Bodin and Gass, 2003).

To create the pairwise comparison matrix for n decision elements at least $n - 1$ and at most $n(n-1)/2$ pairwise comparisons need to be made among the elements because (1) there is a minimal spanning tree relationship between elements which relates all of the elements, and (2) there is a reciprocal relationship[22] between element i and element j in the AHP (Saaty, 1980). $n - 1$comparison can be used based on minimum spanning tree. In this case, all of the alternatives (nodes) are connected by a line which indicates that all the alternatives can be compared regard to a criterion or sub-criterion. The following example shows how this procedure can be used to decrease the pairwised comparisons. There are 7 alternatives and 6 lines (figure 10). Six lines indicate that it is necessary to judge six pairs of alternatives in order to compare all of the alternatives. If, for example, alternative 1 compares with alternative 4, and alternative 4 compares with alternative 2, then it is not necessary to compare alternatives 1 and 2 directly, because they have already indirectly compared with each other through alternative 4.

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[22] If element i is "n-times" more important than element j, then necessarily element j is "$1/n$-times" more important, or equally "n-times" less important than element i.

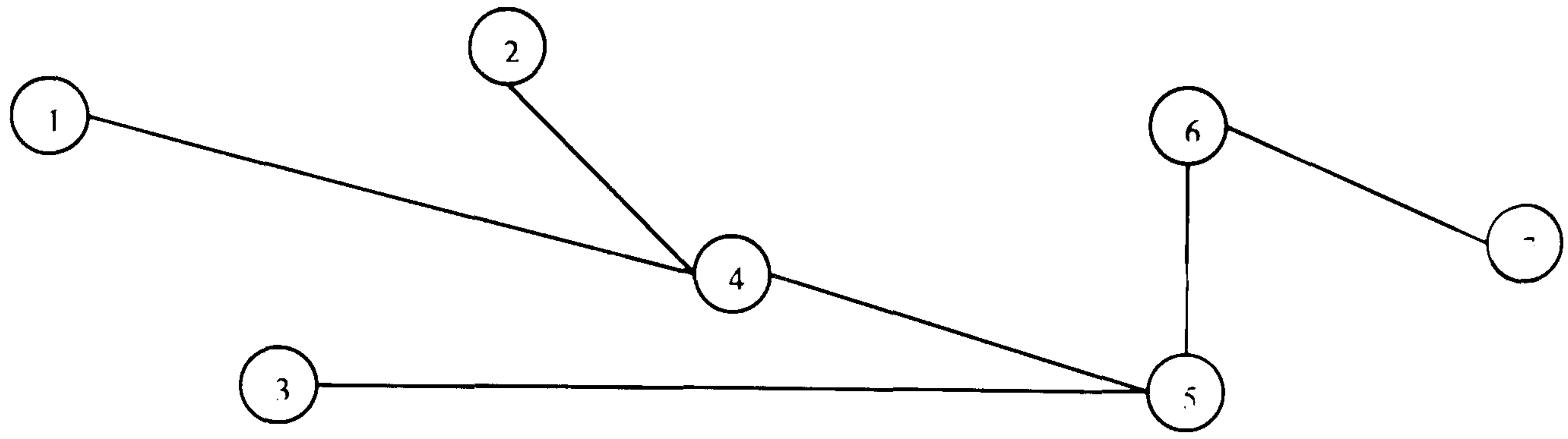

Figure 10 An example of using *(n-1)* comparisons

Another way of comparing alternatives is to compare each alternative with alternative 1. In this case, *n - 1*comparisons should be made again. These procedures although avoid inconsistencies in the AHP, but they have a problem. The question may be arisen in the minimum spanning tree method is that why firstly alternative 1 compared with alternative 4 and then why alternative 4 was compared with alternative 2. This process could be done by firstly comparing alternatives 1 and 2, and then between alternatives 1 and 4, and then alternatives 2 and 4 could be compared indirectly. The same question can be asked for latter method. Why all of the comparisons are made regard to alternative 1, and why not 2, 3, and etc. Avoiding inconsistencies implies that we must make a priori and ad hoc assumption on which alternative we shall treat as the base for comparison. The AHP, through the requirement of asking *n(n-1)/2* questions, avoids this problem. Inconsistencies will always occur in judgement. We can either assume them away or deal formally with them when they occur; the latter is the philosophy underlying the AHP (Golden et al, 1989).

Making pairwise comparison by asking *n(n-1)/2* questions, becomes a tedious task when the levels of the hierarchy, number of criteria and sub-criteria, and the alternatives are relatively excessive, because at each level of the hierarchy, decision maker should answer *n(n-1)/2* questions. On the other hand, *n - 1* comparison is not adequate because redundancy comparisons in questioning are an inherent part of the AHP which is essential if reasonable estimates of priorities are to be obtained (Golden et al, 1989). To decrease the number of pairwise comparisons, Harker suggested the incomplete pairwise comparison method based on estimating the incomplete elements of pairwise judgement matrix (Golden et al, 1989). In this method, the number of questions will be reduced between *n-1* and *n(n-1)/2*. Later in this section, this method will be explained very briefly.

4.2.3.2.1. The methods for eliciting judgements inside groups

In the group decision making, it is possible that different members of the group do not develop the same judgement of an element because the comparisons that generate the weights at the various levels of the hierarchy are made independently. In this case, confliction has been emerged and it is necessary to find compromise judgements. There are three methods for eliciting the judgements inside groups in order to accommodate the views and judgements of group participants in the priority setting process when a common objective context, sharing the same objective is existed: consensus, vote or compromise, and geometric mean of the individuals' judgements (Dyer and Forman, 1992).

- **Consensus concept**

Consensus refers to the achievement of a consensus of group participants in making pairwise judgements. A considerable amount of discussion among the participants might be required to produce an entry for a comparison matrix. Additionally, if the hierarchy is large, this step could require a significant number of comparisons that are usually tedious and time-consuming (Golden et al, 1989). A group may not reach consensus for its judgements because some of participants believe their ideas are more important than others. For example, a top executive management view a problem from a higher level abstraction than would an operational manager because he has a much wider choice space from which to draw controllable alternative courses of actions (Srisoepardani, 1996).

- **Vote or compromise concept**

When a consensus cannot be reached, the group may then choose to vote or compromise on a judgement. When vote for a particular judgement is chosen, we should be careful to minimise the effect of voting because voting increase the possibility of group inconsistency and the individual's incompatibility with the group, so it must be minimised, especially when a vote should be done at the higher level in the hierarchy (Srisoepardani, 1996).

- **Using geometric mean**

If a consensus cannot be achieved and the group is unwilling to vote or to compromise, then a geometric mean (average) of the individuals' judgement can be calculated. This method allows each individual specifies a value and then the combined judgement for group is obtained by taking the geometric mean (Golden et al, 1989). In the context of the AHP, geometric mean has proven to be unique way for aggregating the preferences inside a group because the individual judgements are measured on ratio scale and the group choice is required to satisfy reciprocity property (Aczel and Roberts, 1989), two axioms of AHP.

4.2.3.2.2. The relationship between different methods for eliciting the groups' judgements

The relationship between the methods for eliciting the judgements inside groups and how to choose one of them in order to overcome a disagreement inside a group is shown in the figure 11.

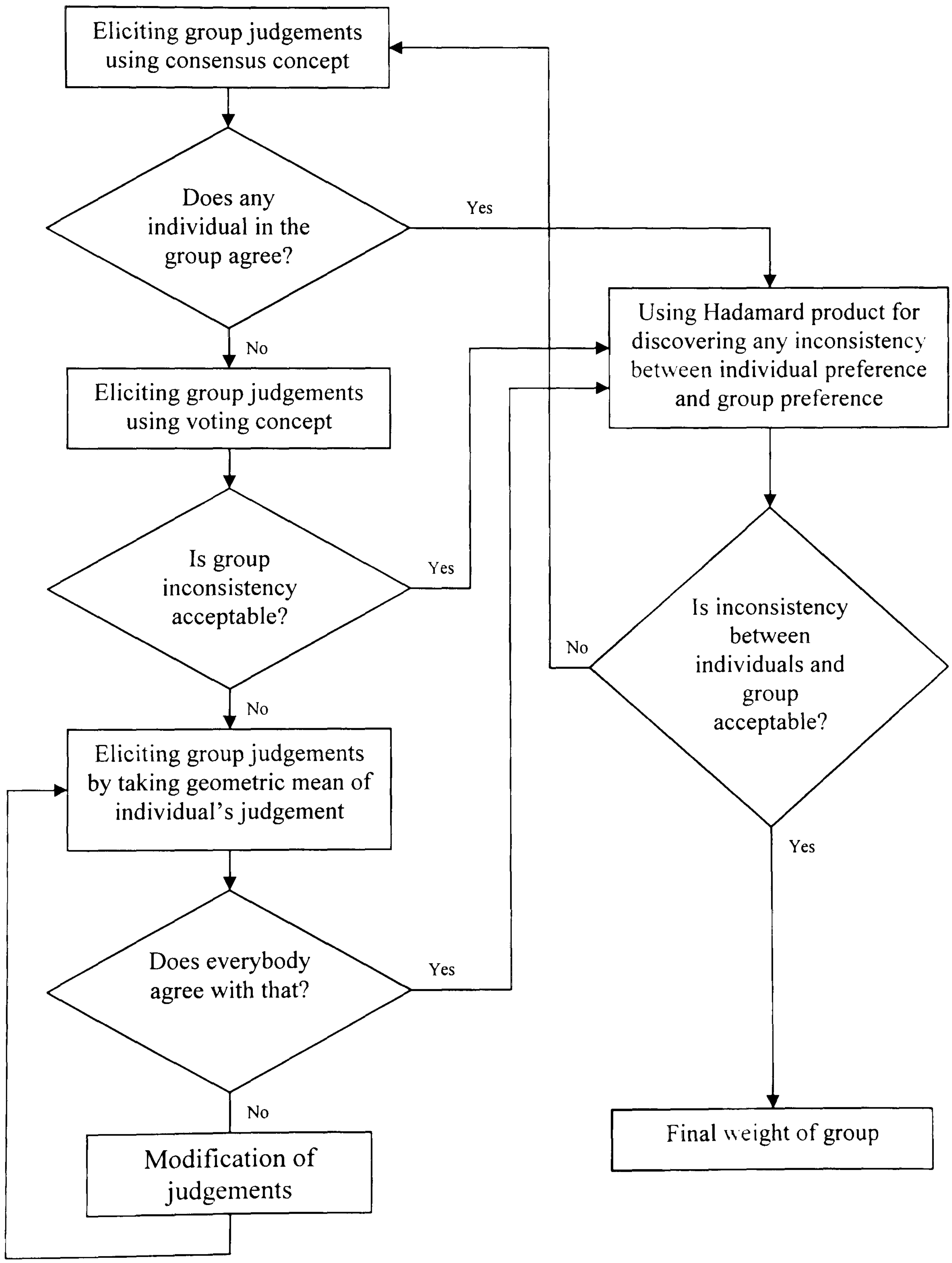

Figure 11 The relationship between the methods of eliciting group judgements

The result of applying the above methods for eliciting the group judgements may cause some differences between the group preference and each individual preference matrix. If it is important to discover which individual has created the most difference against the group preference, then the Hadamard product can be used to identify which judgement is the most incompatible between the individual and the group.

4.2.3.2.3. Hadamard Product

Making a decision in the group decision making environment may create the inconsistencies between the group preference and each member of group preferences. When AHP is used as a group decision making, these inconsistencies exist between the group preference matrix, when the matrix is obtained not by negotiation between the member of groups (for example, taking the geometric mean of entries) and each individual matrix. The Hadamard product between an individual's matrix of ratios and the transpose of the group matrix is useful for identifying which judgement is the most incompatible between the individual and the group. If W_k is the matrix of ratios of an individual group member k and W_g is the matrix of ratios of the group, then Hadamard product $W_k \times W_g(T)$ is a matrix as W_{kg} whose elements are the multiplication between the individual's relative preference for a given pair of alternatives and the reciprocal of the group's preference for the same alternatives (T means the transpose of that matrix).

$$C_{ij}(k) = W_{ij}(k) \times W_{ji}(g) = [W_i(k) / W_j(k)] \times [W_j(g) / W_i(g)]$$

Whatever C_{ij} (k) is greater than one, it shows that the individual and group are incompatible and whatever that is close to one, it means that the judgements of individual is compatible with group judgement.

By locating the largest C_{ij} (k) in the Hadamard product of each individual's matrix of ratios with that of the group, one can identify which individuals whose judgements are the most incompatible with the group, and for which judgements. Then that judgement can be amended to make consistency between the group and individuals (Srisoepardani, 1996).

4.2.3.2.4. Effectiveness of group decision making

Using the described methods to elicit a representative judgement from different judgements obtained by each member of a group may create inconsistencies not only for representative judgement but also for each individual judgement. In this case what is important of the methods is their effectiveness. The effectiveness of a group decision making process can be defined satisfactory if (Srisoepardani, 1996):

- The inconsistency of each of the individual judgements is acceptable,
- The inconsistency of the group (representative) judgements is acceptable,
- Each of the individual's preferences is compatible with the representative.

However, in practice it is not necessary that all of the conditions are satisfied. The most important requirement would be that the inconsistency of the representative outcome is acceptable, although some individual preferences may not be compatible with that (Srisoepardani, 1996). In other words, there is no need to reach consensus in every part of the problem. Because the approach uses AHP for the problems where the individuals do not know their own outcome in advance, incompatibility does not necessarily mean that they do not accept the ultimate outcome. Knowing that their answers to the questions for pairwise comparisons are included in the process in an integrated manner helps the individuals to accept the outcome (Srisoepardani, 1996).

An effective method to identify the inconsistencies between the group preference and each member of a group is Hadamard method which was introduced in section 4.2.3.2.3.

4.2.3.2.5. Harker method

In order to decrease the number of pairwise comparisons, incomplete pairwise comparison method is available based on estimating the incomplete elements of pairwise judgement matrix (Golden et al, 1989). This method is useful when the levels of the hierarchy and the alternatives are relatively excessive. At each level of the hierarchy, decision maker should answer $n(n-1)/2$ questions. For a large hierarchy, the number of questions to be answered grows rapidly. For example, compare the case of having a 3 level hierarchy with 6 alternatives and having a 5 level hierarchy with the same alternatives. The former case needs [(3 × 5 × 6) / 2 =] 45 questions to be answered, while in the latter case the number increased to [(5 × 5 × 6) / 2 =] 75. Decision maker can answer just $n-1$ questions based on minimum spanning tree without any inconsistency. However, it may be possible to reduce the number of questions between $n-1$ and $n(n-1)/2$. An example has been used in order to explain this method briefly.

Assume that the following pairwise comparison matrix completed by a decision maker with an incomplete element (a_{13}) for a given criterion (note that a_{31} element cannot be completed but its value is reciprocal with a_{13} because of reciprocal axiom).

$$A = \begin{bmatrix} 1 & 2 & w_1 / w_3 \\ 1/2 & 1 & 2 \\ w_3 / w_1 & 1/2 & 1 \end{bmatrix}$$

w_1/w_3 is the relative importance of alternative 1 against alternative 3. Applying the equation $AW = \lambda_{max} W$ we will have:

$$\begin{bmatrix} 1 & 2 & w_1/w_3 \\ 1/2 & 1 & 2 \\ w_3/w_1 & 1/2 & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix} = \lambda_{\max} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix}$$

Then, the following result appears:

$$\begin{bmatrix} 2w_1 + 2w_2 \\ 1/2w_1 + w_2 + 2w_3 \\ 1/2w_2 + 2w_3 \end{bmatrix} = \begin{bmatrix} \lambda_{\max} w_1 \\ \lambda_{\max} w_2 \\ \lambda_{\max} w_3 \end{bmatrix}$$

Note that the left hand side vector in above equation can be obtained by the multiplication of following matrix by *W*.

$$\begin{bmatrix} 2 & 2 & 0 \\ 1/2 & 1 & 2 \\ 0 & 1/2 & 2 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix}$$

If the above left hand side matrix is compared with matrix *A*, then we will see that a zero has been placed in the *A* matrix instead of elements that have not been answered, and has been added value of one to the diagonal for each missing entry in a row. It has been shown that the same theory and computational procedure holds for positive and reciprocal matrices (Golden et al, 1989). Now the above left hand side vector can be used for subsequent computation in order to obtain the weights.

In summary, the incomplete comparison method allows one to reduce the effort involved in the elicitation of pairwise comparisons which at the same time allowing for the redundancy which is an important component of the AHP.

4.2.3.3. Checking the inconsistencies

In previous step of AHP, one may ask why $n(n-1)/2$ comparisons should be made while it is possible to make $n - 1$ judgements. The answer to this question is because $n - 1$ judgements includes no inconsistency, while in the real world it is impossible to be fully consistent when comparing elements subjectively. Decision maker can answer just $n-1$ questions without any inconsistency, but redundancy in questioning is an inherent part of the AHP which is essential if reasonable estimates of priorities are to be obtained. Therefore, the pairwised matrix judgements have usually some inconsistencies because of making some redundant comparisons. A matrix is said to be consistent if $a_{ij}.a_{jk} = a_{ik}$, which the element of ij in the pairwise matrix represents the relative importance of element i compared against element j (w_i/w_j). The AHP deals formally with the inconsistencies by using all of the information contained in the pairwised matrix (Golden et al, 1989). The AHP provides a decision maker with a way of examining the consistency of entries in a pairwise comparison matrix and the hierarchy as a whole through the Consistency

Ratio (*CR*) measure (Saaty, 1994). *CR* provides a measure of how inconsistent would be a judgement pairwised matrix. In other words, the *CR* provides a way of measuring how many "errors" were created when providing the judgements. A rule of thumb is that if the *CR* is below 0.1, then the errors are fairly small and thus, the final estimates can be accepted. The number *0.1* which is the accepted upper limit for *CR* says that there is a 10% chance that the decision maker answered the questions in a purely random manner. Larger values require the decision maker to reduce the inconsistencies by revising judgements (Golden et al, 1989).

In this step, the *CR* for each comparison matrix is calculated. If *CR* cannot satisfy the rule, individual's judgement should be amended by reviewing the questions and the value which allocated to those questions (Saaty, 1980). This procedure repeats until to fulfil the cut of rule 10%.

4.2.3.4. Estimation of relative weights

In this step, the weights of the decision elements, when errors in judgement exist, are estimated from the pairwise comparison matrices. Each entry in the decision matrix can be thought of as the estimate of the relative importance of weight w_i of one element to another. There are four kinds of weights when the AHP is used: final, global, local, and partial weights. Final weights are the weights of alternatives which will be derived after all of the steps of AHP are completed. With obtaining the final weights, the alternatives can be prioritised. When the AHP is used alone, the final weights of alternatives are important because choosing an alternative with highest weight is what we are looking for. Global weights refer to the weights which indicate the relative importance of each criterion or sub-criterion against other criteria or sub-criteria that are connected directly to the alternatives (the sum of all global weights regard to objective of the hierarchy should be equal to 1). Local weights are the weights of criteria or sub-criteria under a parent node in the hierarchy (the sum of local weights under a parent node should be equal to 1). Partial weights are those weights that will be obtained when alternatives are compared against a criterion or a sub-criterion (the sum of partial weights should be equal to 1 when an alternative is compared with all criteria or sub-criteria).

Eigenvector method has an approach to estimate the weights from a matrix of pairwise comparisons A, which is positive and reciprocal. In this case the vector of weights or priorities as $W = (w_1, w_2, \ldots, w_n)$ are calculated. Note that by using ratio scales, the weights are unique up to multiplication by a positive constant; i.e., W is equivalent to cW where $c > 0$. W will be normalised for convenience (Golden et al, 1989). This method computes W as the principal right eigenvector of the matrix A:

$$AW = \lambda_{max} W,$$

Where λ_{max} is the maximum eigenvalue of the matrix, or

$$w_i = \frac{\sum_{j=1}^{n} a_{ij} w_j}{\lambda_{\max}} \quad for\ all\ i = 1,2,\ldots,n.$$

The eigenvector method has the interpretation of being a simple averaging process by which the final weights W are taken to be the average of all possible ways of comparing the alternatives, i.e., this method provides an intuitive interpretation in that it is an averaging of all possible ways of thinking about a set of alternatives. Thus, the eigenvector is a "natural" method for computing the weights. The eigenvector method is a theoretically and practically proven method for estimating the weights (Golden et al, 1989). This method is the best at uncovering the true rank-order of a set of alternatives. The estimation of the weights of a given set of alternatives through the eigenvector method is a well understood and easily implemented procedure.

4.2.3.5. Obtaining final weights by synthesising the relative weights

The final step of applying the AHP alone, is to synthesise the derived priorities that were based on the decision-makers' judgements. Synthesis means adding up the global weights of the common nodes at the bottom level of the hierarchy so as to generate a composite priority for an alternative across all criteria. In fact, the relative importance of the alternatives for each criterion and the relative importance of the criteria themselves are used to determine the overall ranking of the alternatives. If w_i represent the relative importance of criterion i and w_{ij} represent the relative importance of alternative j with respect to criterion i, then the overall relative importance of alternative j (w_j) is determined as:

$$w_j = \sum_i w_i w_{ij}$$

The larger the value of w_j is, the higher the relative importance of alternative j. Thus, the composite values of w_j represent the relative ranking of the alternatives under evaluation (Schniederjans and Wilson, 1991).

4.2.3.6. Computer support for AHP

There are a number of very effective packages available to support AHP. Expert Choice is a well established package making it very easy and natural to go through the entire AHP process, including building the hierarchy (www.Expertchoice.com). Criterium is a newer product, allows users to use a more spreadsheet oriented approach, which can be effective as well. Both of these packages have been noted to be quite easy to use, even for large AHP models (Buede, 1992).

HIPRE 3 is another package with different aspects of pairwise comparisons. HIPRE 3 incorporates the idea of interval pairwise comparisons. With this approach, decision makers are not asked for a precise ratio of the relative value of one element over another, but rather are asked for a range of relative advantage. If the system is able to prove that the final score of the leading alternative could be no worse than the best all other alternatives could be, it concludes with a recommendation. The benefit of this approach is that ranges of preference might be more accurate representations of decision maker preferences than some precise value. The problem is that the analysis may take considerable time if the first two alternatives are very close in worth (Olson, 1996).

REMBRANDT is a software which uses geometric means rather than eigenvalues to calculate weights, uses a logarithmic scale rather than 1-9 verbal scale used in AHP, and aggregates scores by weighted products rather than by arithmetic means. REMBRANDT also provides the option of assessing relative advantage by standardised scoring rather than by pairwise comparisons. This package provides computer support to those who have questioned some of the approaches incorporated into AHP (Olson, 1996).

Among the available packages to solve the AHP problems, the Expert Choice is used in this thesis because it is accessible through Internet and can be easily downloaded, this software is user friendly, all the weights including local, global, partial, and final can be shown in a hierarchy manner, and its sensitivity analysis is powerful with graphical modes.

4.2.3.7. The modified AHP as a stand-alone methodology

The overall view of applying the AHP alone in the proposed approach is depicted in figure 12. Although AHP main procedure includes five stages which discussed earlier, this approach has added a new step: "elimination of insignificant criteria". This step removes those criteria, sub-criteria or their subsets which have insignificant weights in comparison with others in order to eliminate the effect of irrelevant criteria or sub-criteria. This procedure will cause the weights of eliminated criteria or sub-criteria to be redistributed over the remaining criteria or sub-criteria and may change their relative importance. A numeric index is defined for this procedure as follows. Given two criteria, C_1 and C_2, which are consecutive when the criteria are ordered by weight, then given that w_1 and w_2 are the weights of C_1 and C_2 as the more important $(w_1 > w_2)$, then the index is as:

$$I_{12} = \frac{w_1 - w_2}{w_1}$$

If, for any given pair C_1 and C_2, $I_{12} > 0.90$, C_2 can then be removed from the list of criteria. In other words, when the weights of two criteria are close to each other, they are important and should remain in the list of criteria. For example assume the weights of three criteria are 0.50, 0.46, and 0.04. Using the index shows that the third criterion should not be considered because its index is more than $90\% (I_{23} = \frac{0.46 - 0.04}{0.46} = 0.913)$. In other words, 0.04 is insignificant when compared with 0.46. The other two criteria are important because its index is $0.08 (I_{12} = \frac{0.50 - 0.46}{0.50} = 8.0\%)$.

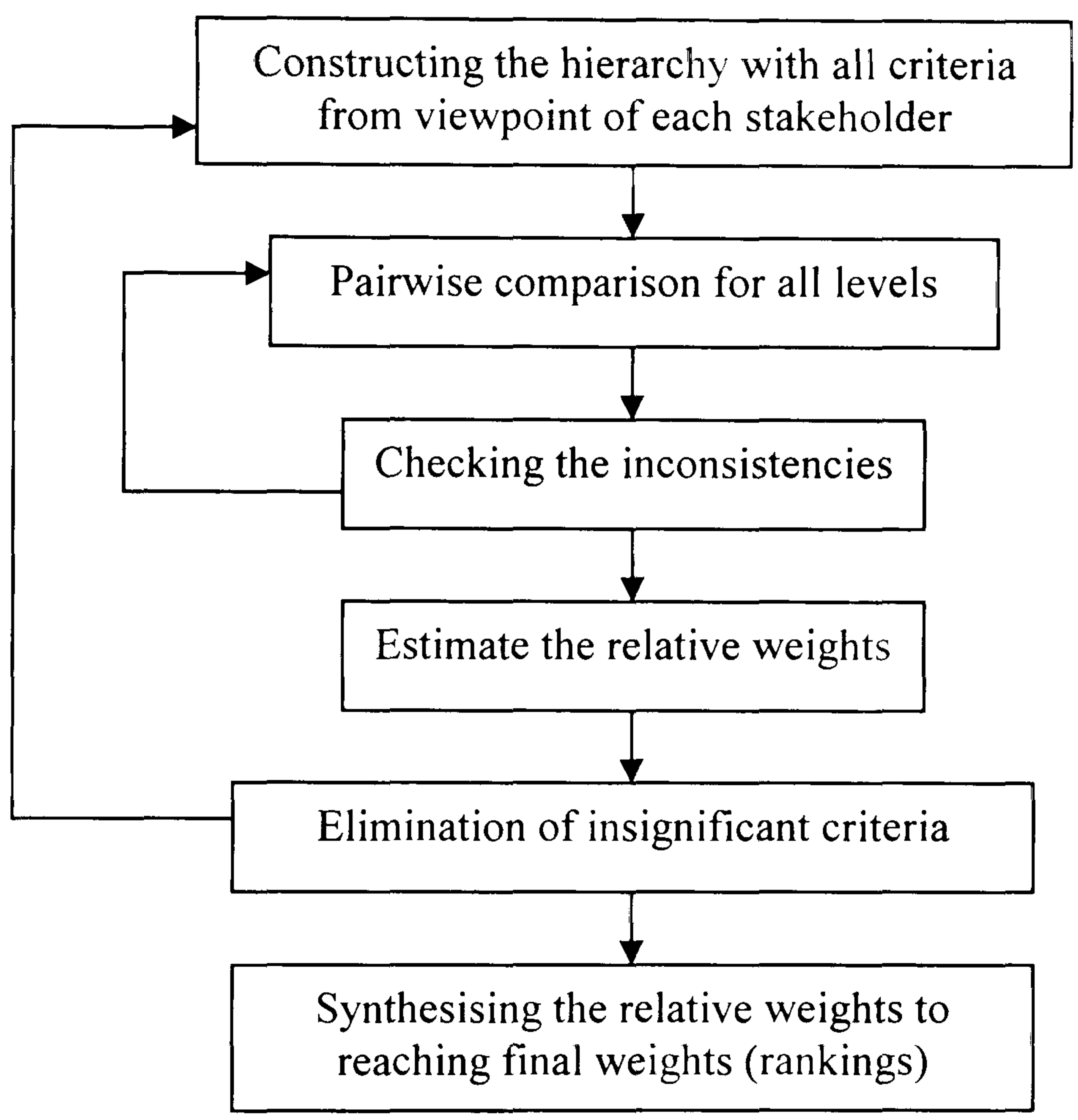

Figure 12 The procedure of using AHP

The result of AHP application is not only a list of ranked alternatives based on their final weights from point of view of individual stakeholders but also detailed weights of each element in the problem (box No.3 in figure 6). Detailed weights include local, global, and partial weights of criteria and sub-criteria.

4.2.3.8. Using AHP as a stand-alone approach for the ICS

Before using AHP, two points should be explained:

1- While customers compared the products of technologies, the managers compared their technologies. It is assumed that a technology is so flexible that it can produce a number of products under the licence of contract. This means that manufacturers cannot produce whatever they want in short-term.

2- Where no data sources for tangible criteria exist, these data are estimated subjectively (Kassicieh, et al., 1993).

4.2.3.8.1. Eliciting the pairwise comparisons for the ICS

To elicit the judgements of stakeholders, two questionnaires were designed by the author, which are shown in Appendix A. Customers' questionnaires were distributed among 150 Iranian people who lived in the U.K. The reason for that was the customers should be familiar with new models of cars' alternatives which were selected as alternatives. 31 questionnaires were returned. The average age of respondents was 34 year and the average annual income was 9900 Pounds. Managers' questionnaires were distributed among 15 members of the boards of three large vehicle manufacturing companies in Iran. Among them 12 members only answered the questions partially. For example, 12 members answered the questions regarding comparisons between the criteria and just 6 of them could answer the questions regarding sub-criteria when they were compared against alternatives.

Final results of pairwise comparisons were obtained by taking the geometric mean of individual judgements. The summaries are shown in tables 44 and 45 in Appendix C. The inconsistency ratio was checked for the group, not for any individual respondent. The consistency ratios for each pairwise comparison by taking geometric mean for both group stakeholders indicated that there were no inconsistencies. However, there were some inconsistencies for pairwise comparisons for each individual respondent but the group inconsistency ratios satisfied the cut off rule of 10%.

4.2.3.8.1.1. Customers' weights for the ICS

After obtaining the geometric means, the data is used as input to Expert Choice software in order to elicit the relative importance of criteria to each other and of alternatives to all criteria. When AHP was used for tangible criteria, the real data was presented to customers to make pairwise comparison. For example, when the price of cars was presented, they used those prices to make comparisons. It is obvious that less price is better when comparing between alternatives but the value of differences between prices may not be the same for every respondent. So when they were asked to make pairwise comparison between two prices, they were asked to take note of this point. For a customer the difference of 1000 dollars may be very high and for another one it may not. For repairing cost criterion, because there was not enough information about that criterion, customers have compared all the alternatives with regard to this criterion subjectively.

Table 4 shows the output of Expert Choice for customers' viewpoints. In this table the weights for tangible criteria are replaced with real normalised data but other output such as final weights for alternatives were not changed. It should be noted that there were no insignificant criteria to be removed based on the defined 90% index.

Table 4 Output of Expert Choice software for customers' viewpoint

Criteria \ Alternatives	Fiat	Honda	Hyundai	Toyota	Volks Wagen	Tangible?	Relative Importance
Comfort (C1)	0.066	0.274	0.085	0.369	0.207	No	0.054
Elegance (C2)	0.081	0.276	0.099	0.375	0.168	No	0.035
Type (C3)	0.073	0.255	0.089	0.382	0.201	No	0.038
Dimension and shape (C4)	0.078	0.241	0.103	0.346	0.232	No	0.031
Modern equipment (C5)	0.080	0.269	0.118	0.349	0.183	No	0.033
Price (C6)	0.181	0.217	0.168	0.193	0.241	Yes	0.143
Fuel consumption (C7)	0.141	0.201	0.217	0.193	0.248	Yes	0.073
Repairing costs (C8)	0.129	0.262	0.189	0.187	0.233	Yes	0.129
Easy to sell second hand (C9)	0.092	0.235	0.114	0.360	0.199	No	0.128
Safety (C10)	0.081	0.254	0.084	0.328	0.253	No	0.128
Durability (C11)	0.087	0.217	0.074	0.303	0.319	No	0.099
Horsepower (C12)	0.102	0.213	0.195	0.190	0.300	Yes	0.044
Easy to repair (C13)	0.127	0.201	0.177	0.327	0.168	No	0.063
Final Weight	0.150	0.216	0.147	0.285	0.202		
Rank	4	2	5	1	3		

4.2.3.8.1.2. Managers' weights for the ICS

The final results of applying AHP to elicit the final weight of alternatives from the point of view of managers are depicted in table 5. When AHP was used for tangible criteria, managers used the real data to make pairwise comparison. For example, the price of technologies was compared with real data. Again, it is obvious that less price is better when comparing between alternatives but the value of differences between prices may not be same for every manager, because it depends on the financial situation of the company. So when they were asked to make pairwise comparison between two prices, they were asked to take note of this point. For one company the difference of 1 million dollars may be very high and for another one it may not.

4.2.3.9. Comparison of ranking between stakeholders

The outcomes of using AHP as a stand-alone methodology may create different rankings because of the presence of multiple stakeholders (box No.4 in figure 6). When the AHP is applied for each stakeholder's viewpoint, two cases may occur: 1) the outcomes (rankings) are identical for all of the stakeholders, and 2) the outcomes (rankings) are not the same. If the former case occurs, the final alternative has been chosen. In this case, the selected alternative is suitable from all of the stakeholders' viewpoints. Sensitivity analysis should then be made to indicate whether the outcome is sensitive to some elements in the AHP hierarchy (box No.6 in figure 6).

If the latter case occurs, it is necessary to aggregate the outcomes in order to reach a single outcome that can satisfy all of the stakeholders as much as possible.

Table 5 Output of Expert Choice software for managers' viewpoint

Criteria \ Alternatives	Fiat	Honda	Hyundai	Toyota	Volks Wagen	Tangible?	Relative Importance
Net Profit (M1)	0.085	0.136	0.339	0.169	0.271	Yes	0.149
Added-value (M2)	0.059	0.118	0.392	0.235	0.196	Yes	0.123
Price of technology (M3)	0.250	0.179	0.071	0.143	0.357	Yes	0.061
Export possibility (M4)	0.150	0.281	0.078	0.200	0.291	No	0.112
National market share (M5)	0.091	0.258	0.074	0.349	0.299	No	0.046
International market share (M6)	0.178	0.230	0.127	0.205	0.260	No	0.108
Manufacturing technology (M7)	0.127	0.197	0.067	0.323	0.286	No	0.037
Accessible to know-how (M8)	0.100	0.113	0.471	0.170	0.146	No	0.051
Flexibility (M9)	0.138	0.223	0.105	0.279	0.254	No	0.032
Quality of technology (M10)	0.092	0.157	0.148	0.285	0.317	No	0.041
National supports (M11)	0.111	0.170	0.281	0.239	0.198	No	0.025
International supports (M12)	0.139	0.155	0.322	0.188	0.196	No	0.040
National make ability (M13)	0.115	0.249	0.162	0.309	0.165	No	0.027
Governments supports (M14)	0.098	0.135	0.463	0.159	0.145	No	0.042
Customer's style (M15)	0.180	0.228	0.131	0.265	0.197	No	0.026
National trust (M16)	0.134	0.247	0.087	0.270	0.262	No	0.050
Suitability with consumption pattern (M17)	0.159	0.190	0.213	0.229	0.209	No	0.030
Final Weight	0.131	0.194	0.236	0.220	0.219		
Rank	5	4	1	2	3		

4.2.3.9.1. Comparison of ranking between stakeholders for the ICS

The result shows that customers' preferences are Toyota, Honda, Volks Wagen, Fiat, and Hyundai when AHP was used as a stand-alone methodology. These results are consistent with the Iranian perception of selecting cars, because most Iranian people prefer Japanese cars and after that they prefer European cars. The results also show that managers' preferences of vehicle industries in Iran are Hyundai, Toyota, Volks Wagen, Honda, and Fiat. It is interesting that while Hyundai is the worst alternative from the viewpoint of customers, it is the best alternative from the point of view of managers. This shows how much stakeholders' viewpoints can differ.

4.2.3.10. Aggregation of different outcomes using heuristic methods

If different outcomes emerge using AHP, it is necessary to aggregate them in order to find a single outcome (box No.5 in figure 6). The approach uses two different methods for aggregation of different outcomes based on a distance function in order to reach a single outcome. The first method uses the final weights of alternatives while second method uses the detailed weights obtained by AHP to aggregate different outcomes.

To aggregate the preferences (weights) of alternatives, Moshiri (1998) developed a method based on the distance function and considering the orders of alternatives in the presence of two stakeholders. He suggested putting AHP alternatives' orders on two axes of a coordinated system where each axis represents the ordering from one stakeholder, and then finding each alternative's point on that system. The index for the aggregated outcome was based on the minimum perpendicular distance between each related point and the ideal line (for two dimension is $y = x$) because it represents the least discrepancy between the stakeholders' orders. The ideal line is a line where any point that lies on it, represents no discrepancies between stakeholders.

The drawbacks of this method are: 1) this method just uses the final ranking of alternatives obtained by AHP and neglects the weights of each alternative that is important when the difference of weights is insignificant or one alternative has taken negligible weights, 2) it always prefers the minimum perpendicular distance between the points and the ideal line, even if the minimum distance would be the least preferred alternative from both viewpoints. Applying this method can select the worst alternative from both viewpoints. In fact, sometimes having a reasonable deviation from the ideal line is better than having none at all.

To clarify the issue, consider the following example. Assume there are three alternatives (A, B, and C) and the weights of them from a stakeholder are 0.50, 0.49, and 0.01 respectively, and from the viewpoint of another stakeholder, the weights are 0.48, 0.40, and 0.12. When the order of alternatives are put in the coordinate system from both viewpoints, the coordinates of them are $A(1,2)$, $B(2,1)$, and $C(3,3)$. The situation of these points as well as the situation of ideal line is shown in figure 13. Using Moshiri's method makes it that the third alternative (C) is the best one, the worst alternative from both viewpoints, because its relevant point has been placed exactly on the ideal line. However, third alternative can be removed from further consideration because of its insignificant weight.

It is worth noting that from the viewpoint of first stakeholder, because of 0.01 differences between the weights of first two alternatives, the place of it on the coordinate system has the significant difference. If for some reasons the weights of the alternative from the first stakeholder change a little to 0.49, 0.50, and 0.01, then in this case, the best alternative is B, because it places exactly on the ideal line. Therefore, this method cannot guarantee the aggregation process works well. However, the advantage of this method is its simplicity because this method does not need any other information.

To overcome the problems of Moshiri's method, two methods are proposed, in this thesis, based on the final weights of alternatives and their detailed weights (global and partial weights). These two methods also use the distance concept from ideal line with different philosophies.

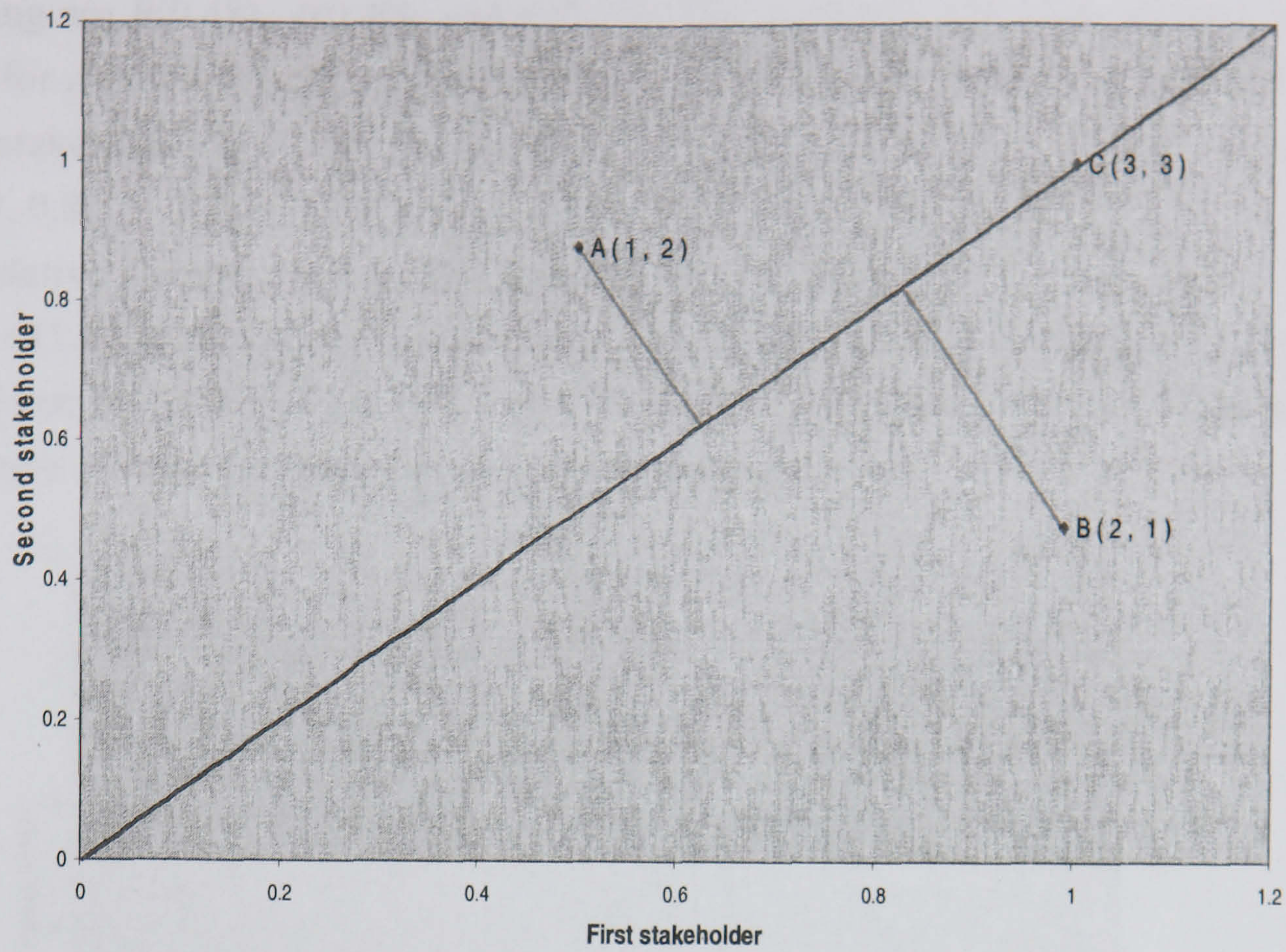

Figure 13 The situations of the alternatives' orders points and the ideal line

4.2.3.10.1. Aggregation using the final weights of alternatives

In this method, the final weights of each alternative obtained by AHP are considered. The philosophy of using the final weights of alternatives is to consider not only the order of alternatives but also their final valuable weights because a problem should be addressed with the best available knowledge (Dym et al. 2002). The method is especially useful when stakeholders construct different hierarchies with different criteria and sub-criteria. In this method, a coordinate system is considered with the ideal line, which each axis represents not only the orders of alternatives but also their associated cumulative weights of each stakeholder. Then the alternative related points are placed in the coordinated system. The chosen alternative is that one with the least summation distances of perpendicular and distance from origin of coordinate system. Perpendicular distance measures the disagreement between multiple stakeholders and how different they are while the distance from the origin of coordination system tries not to select the worst alternative from different stakeholders.

The previous example in section 4.2.3.10 is used to illustrate how this method works. To apply this method, it is necessary to rank the alternatives based on their final weights from point of view of each stakeholder and then obtain the cumulative weights. From the point of view of first stakeholder, the ranking of alternatives are *A* (0.50), *B*(0.49), and *C*(0.01) and from the point of view of second stakeholder this ranking are *B*(0.48), *A*(0.40), and *C*(0.12). The cumulative weights of them will be 0.50 for *A*, 0.99 (= 0.50 + 0.49) for *B*, and 1.00 (= 0.50 + 0.49 + 0.01) for *C* for the first stakeholder while for the second stakeholder, the cumulative weights are 0.48 for *B*, 0.88 (= 0.48 + 0.40) for *A*, and 1.00 (= 0.48 + 0.88 + 0.12) for *C*. With these cumulative weights, the coordination of each point is as: *A*(0.50,0.88), *B*(0.99,0.48), and *C*(1.00,1.00). Now, instead of placing the orders of alternatives on the coordination system, their cumulative weights will be placed. Figure 14 shows the situation of these points on the coordination system.

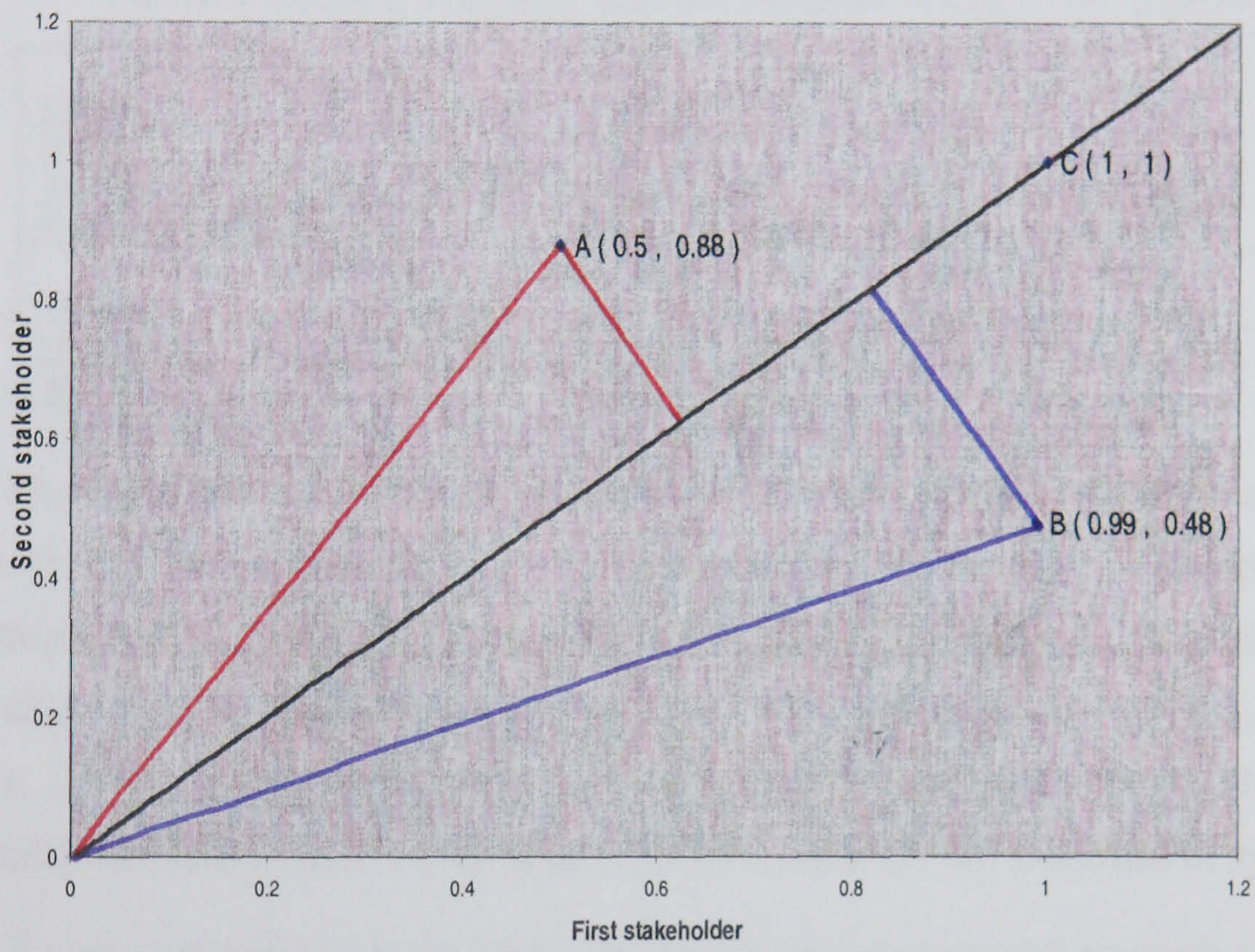

Figure 14 The situations of alternatives' cumulative weights and ideal line

With calculation of perpendicular distance from ideal line add to distance from origin of coordination system, the preferred alternative can be found. It should be noted that the distance between a point like $P_0(x_0,y_0)$ and the line $ax+by+c=0$ is as $D=\frac{|ax_0+by_0+c|}{\sqrt{a^2+b^2}}$ (Anton and Rorres, 2000) and the distance between a point like $P_0(x_0,y_0)$ and the origin of the coordinate system is $D=\sqrt{x_0^2+y_0^2}$. The perpendicular distance and distance from the origin of the coordination system of alternative *i* are represented by D_i^P and D_i^O, respectively.

$$D_A^P + D_A^O = 0.269 + 1.012 = 1.281$$
$$D_B^P + D_B^O = 0.361 + 1.100 = 1.461$$
$$D_C^P + D_C^O = 0.000 + 1.414 = 1.414$$

These distances show that the preferred alternative is *A* because its total distance is less than other alternatives. .

4.2.3.10.1.1. Aggregation using final weights of alternatives for the ICS

The result of the ICS depicted how different stakeholders can choose different alternatives. To achieve a single outcome, it is necessary to aggregate the outcomes. To use the method, it is necessary to obtain the cumulative weights from best to last from both viewpoints. The best alternative then can be obtained by considering the final weights of alternatives. Table 6 shows the orders, weights, and cumulative weights of alternatives from both viewpoints.

Table 6 Orders, weights, and cumulative weights for stakeholders

Customer \ Alternatives	Toyota	Honda	Volks Wagen	Fiat	Hyundai
Orders	1	2	3	4	5
weights	0.285	0.216	0.202	0.150	0.147
Cumulative weights	0.285	0.501	0.703	0.853	1.000
Managers \ Alternatives	Hyundai	Toyota	Volks Wagen	Honda	Fiat
Orders	1	2	3	4	5
Weights	0.236	0.220	0.219	0.194	0.131
Cumulative weights	0.236	0.456	0.675	0.869	1.000

The coordinate of each point can be determined by its cumulative weights. It is assumed that for each point *(x,y)*, *x* represent the coordinate of cumulative weight of customers and *y* represents the cumulative weight of managers. So, the coordinate of each alternative is as follows: Toyota (0.285,0.456), Honda (0.501,0.869), Volks Wagen (0.703,0.675), Fiat (0.853,1.000), and Hyundai (1.000,0.236). Figure 15 represents the situation of each point and ideal line on the coordinate system.

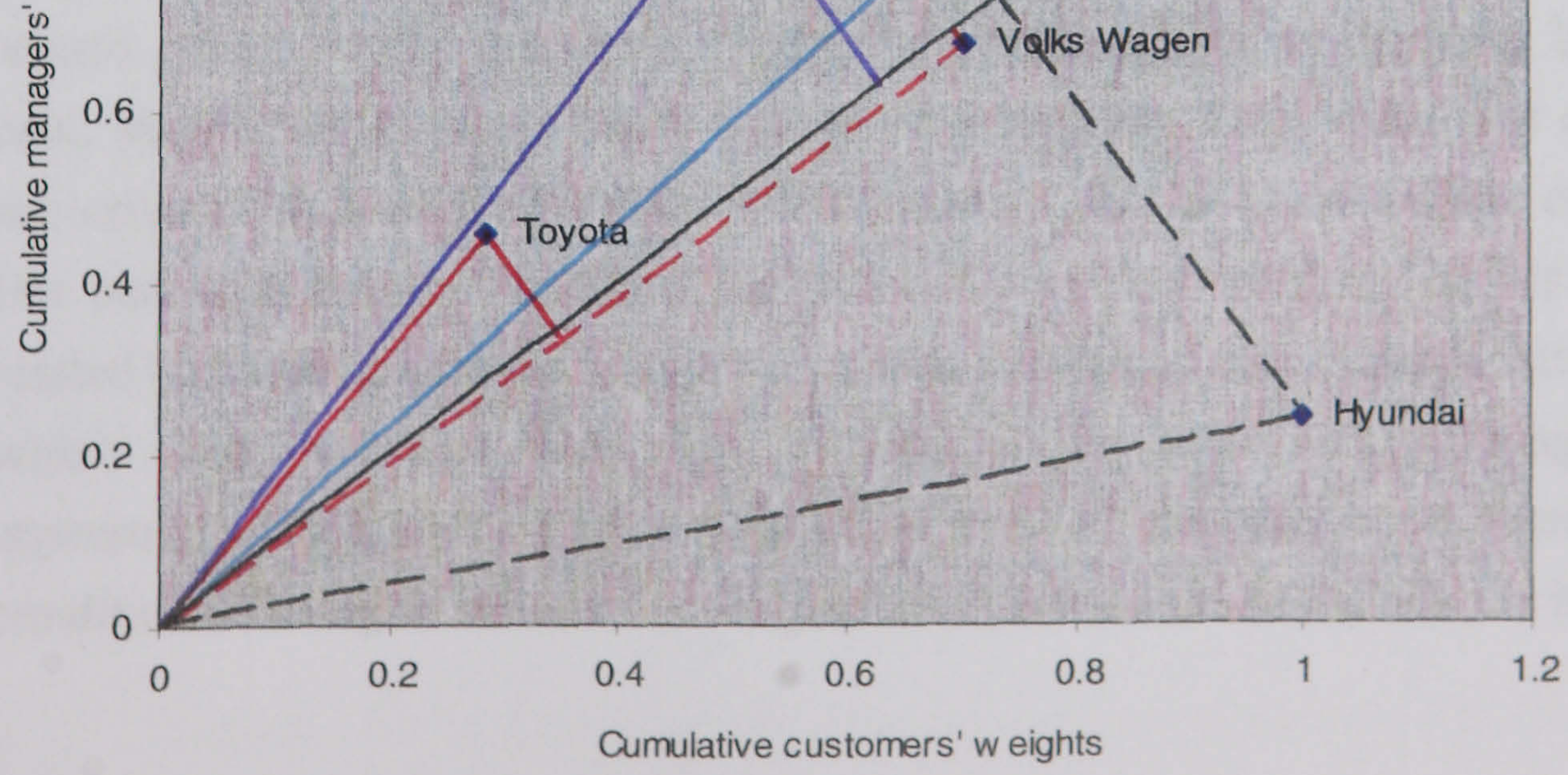

Figure 15 Situation of each point and ideal line

Table 7 represents the perpendicular distance between each point and the ideal line ($y = x$), the distance of each point from the origin of the coordinate system, the sum of these two distances, which are an index for choosing the most appropriate alternative, and finally the aggregated rank of the alternatives.

Table 7 Different distances for the ICS

Type of distance / Alternatives	Perpendicular	Origin of Coordination system	Cumulative	Rank
Fiat	0.104	1.314	1.418	4
Honda	0.260	1.003	1.263	3
Hyundai	0.540	1.027	1.567	5
Toyota	0.121	0.538	0.659	1
Volks Wagen	0.020	0.975	0.995	2

Although Volks Wagen has been placed closer to the ideal line, the method has chosen Toyota alternative because its cumulative distance is less than Volks Wagen. Choosing Toyota, which is the first rank from one stakeholder and the second rank from another stakeholder, is better than choosing Volks Wagen which is third rank from both stakeholders' viewpoints. In other words, considering the perpendicular distance alone is not enough to justify the decision. This result is different when AHP was applied for each stakeholder's viewpoint.

4.2.3.10.2. Aggregation using detailed weights of AHP

The philosophy of this method is to use all available information obtained from AHP. The information includes global and partial weights of criteria and sub-criteria. The framework of this method is based on the effect of a criterion or sub-criterion for choosing an alternative from each stakeholder's viewpoint. If the effect for each alternative from all stakeholders with the same ranking of criteria or sub-criteria is equal, then the most appropriate alternative is that alternative whose related points in the coordinate system are placed exactly on the ideal line. In this case, there is 100% consistency between stakeholders. Otherwise each criterion or sub-criterion related points in coordinate system do not place exactly on the ideal line and therefore, inconsistency between stakeholders emerges. In this case, each related point of criterion or sub-criterion has a perpendicular distance with ideal line which their minimum summation is used as an index for choosing the most appropriate alternative. The steps of this method are shown in figure 16. The condition of using this method is that stakeholders should have common hierarchies.

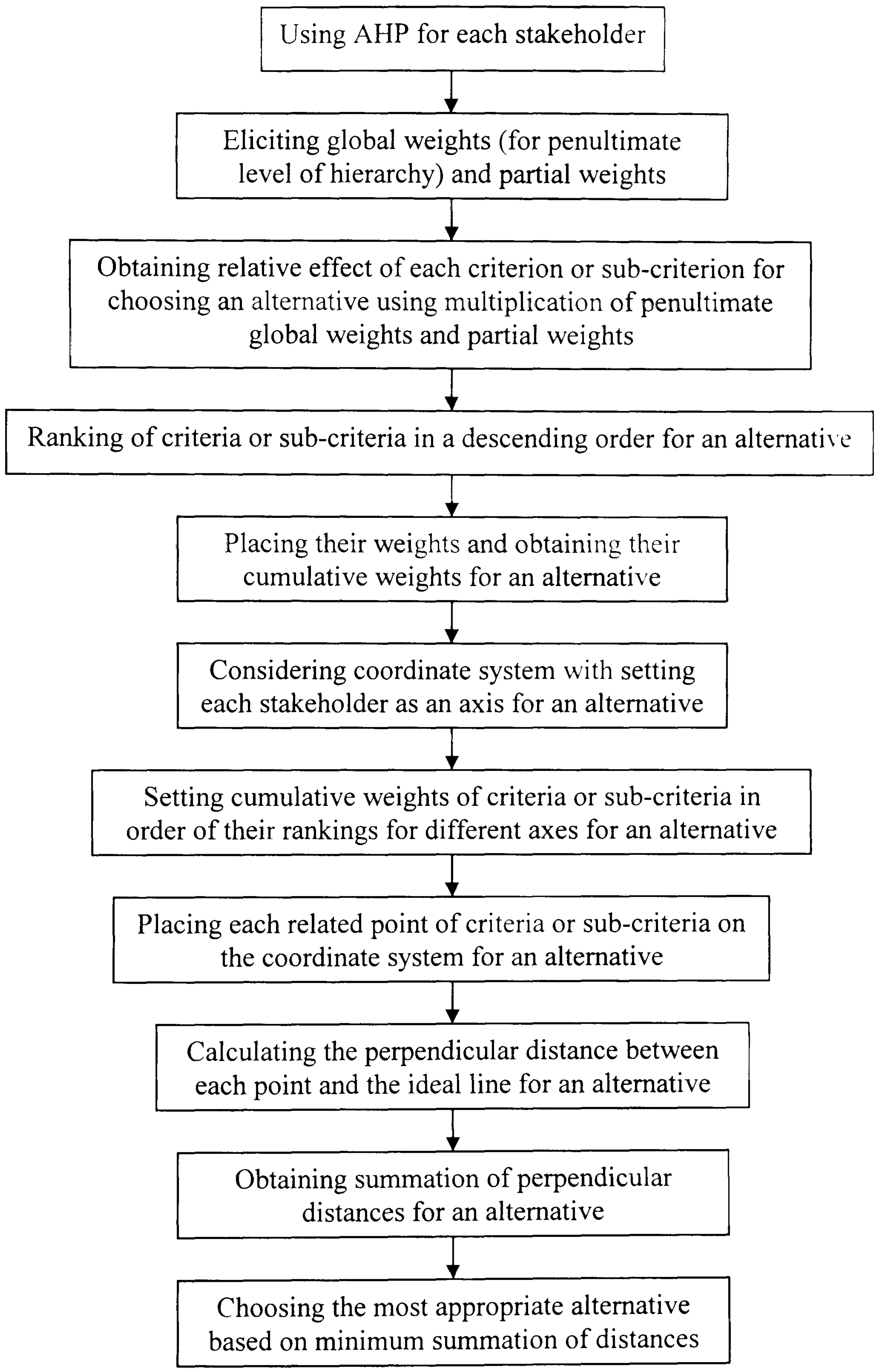

Figure 16 The steps of aggregation method using detailed weights of AHP

4.2.3.10.2.1. Aggregation using detailed weights of alternatives for ICS

This method cannot be used for the ICS because the stakeholders have different hierarchies. To show how this method works, an example is used to clarify its steps.

An example

Assume there are two stakeholders (first and second) which have developed a hierarchy with four levels include criteria (C_1 to C_4) and sub-criteria (C_{11} to C_{42}), for choosing an alternative between three (*A*, *B*, and *C*). Figure 17 shows this hierarchy.

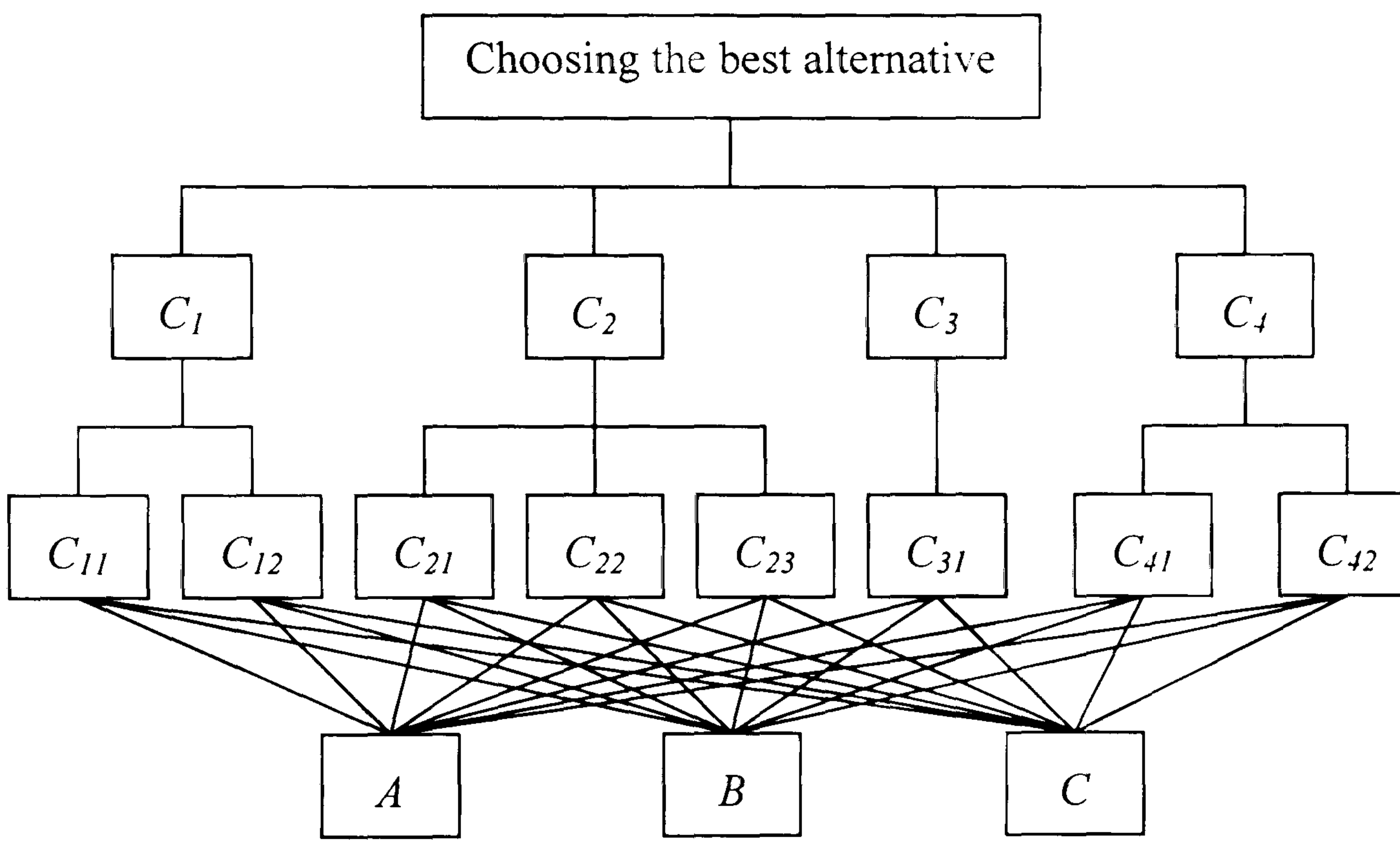

Figure 17 The hierarchy for the example of heuristic aggregation method using detailed weight of AHP

The detailed weights of the elements of this hierarchy as well as the final weights for each individual stakeholder are depicted in table 8. The numbers inside brackets indicate the global weights of the criteria and the sub-criteria. The numbers in the columns of *A*, *B*, and *C* are the partial weights of sub-criteria.

The next step is to obtain the relative effect of each criterion or sub-criterion for an alternative using multiplication of the penultimate global weights and their partial weights for each individual stakeholder. For example, the relative importance of sub-criterion C_{11} to choose alternative *A* is 0.0306 (= 0.123 × 0.249). These weights can be calculated for other sub-criteria and for other alternatives from both stakeholder viewpoints by multiplication of weights in the sub-criteria column and each individual column of alternatives. The result is shown in table 9.

Table 8 Applying AHP for the example

Alternatives			A	B	C	Final weights
Stakeholder 1	C_1 (0.164)	C_{11} (0.123)	0.249	0.594	0.157	*A* (0.358)
		C_{12} (0.041)	0.558	0.122	0.320	*B* (0.290)
	C_2 (0.472)	C_{21} (0.098)	0.186	0.687	0.127	*C* (0.352)
		C_{22} (0.312)	0.249	0.157	0.594	Final ranking
		C_{23} (0.062)	0.364	0.099	0.537	*A*
	C_3 (0.256)	C_{31} (0.256)	0.667	0.111	0.222	*C*
	C_4 (0.108)	C_{41} (0.061)	0.226	0.674	0.101	*B*
		C_{42} (0.027)	0.126	0.416	0.458	
Stakeholder 2	C_1 (0.268)	C_{11} (0.045)	0.208	0.661	0.131	*A* (0.193)
		C_{12} (0.224)	0.172	0.726	0.102	*B* (0.488)
	C_2 (0.086)	C_{21} (0.029)	0.500	0.250	0.250	*C* (0.319)
		C_{22} (0.012)	0.280	0.627	0.094	Final ranking
		C_{23} (0.045)	0.493	0.196	0.311	*B*
	C_3 (0.172)	C_{31} (0.172)	0.186	0.687	0.127	*C*
	C_4 (0.473)	C_{41} (0.079)	0.682	0.103	0.216	*A*
		C_{42} (0.395)	0.069	0.420	0.511	

Table 9 Relative effect of each sub-criterion to choose an alternative

Alternative	Stakeholder	C_{11}	C_{12}	C_{21}	C_{22}	C_{23}	C_{31}	C_{41}	C_{42}
A	1	0.0306	0.0229	0.0182	0.0777	0.0226	0.1708	0.0183	0.0034
	2	0.0094	0.0385	0.0145	0.0034	0.0222	0.0320	0.0539	0.0273
B	1	0.0731	0.050	0.0673	0.0490	0.0061	0.0284	0.0411	0.0112
	2	0.0297	0.1626	0.0073	0.0075	0.0088	0.1182	0.0081	0.1659
C	1	0.0193	0.0131	0.0124	0.1853	0.0333	0.0568	0.0062	0.0124
	2	0.0059	0.0228	0.0073	0.0011	0.0140	0.0218	0.0171	0.2018

The next step is to rank the sub-criteria in a descending order and then obtain the cumulative weights based on their orders for each individual stakeholder. The cumulative weight of each criterion or sub-criterion is used in order to consider its true effect. For example, C_{31} is the most important criterion for the first stakeholder, while it is the third from second stakeholder when considering alternative *A*. This effect is considered with taking into account the cumulative weights. This step is shown in table 10 just for alternative *A*.

In this step, it is necessary to consider a coordinate system in which the *X*-axis represents stakeholder 1 and the*Y*-axis represents stakeholder 2. Now for each stakeholder, its sub-criteria are placed on its axis based on cumulative weights. The coordination of each point is the intersection of their vertical and horizontal lines (its cumulative weight for each axis).

The coordination of each sub-criterion is shown in table 11. In addition, its absolute difference between them is calculated in order to measure the perpendicular distance between each point and the ideal line. The perpendicular distance between point $P_0(x_0,y_0)$ and the ideal line in two dimensions ($x = y$ or $x - y = 0$) is $D = \frac{|x_0 - y_0|}{\sqrt{2}}$. $\sqrt{2}$ can be ignored because it is common element when the perpendicular distance is calculated for each point. The distances are then summed as an index for selection.

Table 10 Ranking the sub-criteria to choose alternative A for each stakeholder

Stakeholder	For Alt. *A*	Sub-criteria							
1	Rank	C_{31}	C_{22}	C_{11}	C_{12}	C_{23}	C_{41}	C_{21}	C_{42}
	Weight	0.1708	0.0777	0.0306	0.0229	0.0226	0.0183	0.0182	0.0034
	Cumulative weight	0.1708	0.2485	0.2791	0.3020	0.3246	0.3429	0.3611	0.3645
2	Rank	C_{41}	C_{12}	C_{31}	C_{42}	C_{23}	C_{21}	C_{11}	C_{22}
	Weight	0.0539	0.0385	0.0320	0.0273	0.0222	0.0145	0.0094	0.0034
	Cumulative weight	0.0539	0.0924	0.1244	0.1517	0.1739	0.1884	0.1978	0.2012

Table 11 The coordination of each point and absolute differences' summation

Sub-criterion	*X* coordination	*Y* coordination	Absolute difference
C_{11}	0.2791	0.1978	0.0813
C_{12}	0.3020	0.0924	0.2096
C_{21}	0.3611	0.1884	0.1727
C_{22}	0.2485	0.2012	0.0473
C_{23}	0.3246	0.1739	0.1507
C_{31}	0.1708	0.1244	0.0464
C_{41}	0.3249	0.0539	0.2710
C_{42}	0.3645	0.1517	0.2128
Summation of absolute differences			1.1918

The same procedure can be used to identify the summation of absolute differences for other alternatives.

4.2.3.11. Sensitivity analysis

Sensitivity analysis, which concerns determining the most critical factors or data that can change the output of a method, should be made in this part of the approach to find which one of the criterion or sub-criterion, pairwised judgement comparison, and other parameters must be reviewed, and measured precisely, in order to obtain a reliable output. In other words, sensitivity analysis can demonstrate how the outcomes of a method are sensitive to their components. After identifying the sensitive parameters, special attention should be given to estimate them accurately because of their effect on the problem. One then seeks a solution that remains a particularly good one for all of the various combinations of likely values of the sensitive parameters (Hillier and Lieberman, 1995).

The method of making sensitivity analysis depends on the problems and data in hand. In this part of the approach, the sensitivity analysis is limited to pairwise comparisons because other components of the problem are assumed to be unchangeable such as the hierarchy. Pairwise comparisons changes will effect the changes of relative importance of criteria or sub-criteria. However, this analysis can be made in the presence of multiple stakeholders to compare the effect of eliciting the judgements through voting or geometric mean methods.

4.2.3.11.1. Sensitivity analysis for the ICS

Two different hierarchies are analysed based on changes of the relative importance of criteria and sub-criteria by the dynamic sensitivity analysis of the Expert Choice software. This analysis is made based on whether the changes of one relative importance will affect the ranking of alternatives.

The customer's hierarchy included style, economical, and technical criteria with relative importance of 19.2%, 47.4%, and 33.4%. When the relative importance of the style criterion changed to 0 and 100%, the result showed that the selected alternative would not be changed. However, the ranking of alternatives may be changed. The same result was obtained when the relative importance of economical and technical criteria changed from 0 to 100%. This result occurred because customers have always preferred one special alternative when they compared the alternatives with regard to these criteria. It is interesting that the same results were repeated when sub-criteria of the style criterion were analysed. In the case of analysing the sub-criteria of the economical criterion and the technical criterion, the same result was obtained for repairing cost, safety, and easy to repair sub-criteria. Other analyses for sub-criteria of the economical and technical criteria are shown in table 12. In this table, when a current relative importance is changed, it affects the selected alternative.

Table 12 Sensitivity analysis for illustrative case study (customer's criteria)

Criteria	Sub-criteria	Current relative importance (%)	Changes to:	Percentage of changes:
Economical	Price	14.3	52.3	265.7
	Fuel consumption	15.3	56.5	269.3
	Easy to sell	27.1	10.4	- 61.6
Technical	Durability	29.7	83.3	180.5
	Horsepower	13.1	48.0	266.4

Between these sub-criteria, the easy to sell sub-criterion is the most important one because its related absolute change is the least. Then durability is the next most important sub-criterion. Therefore, their pairwise comparisons need to be checked again for reliability of outcome.

The same procedure is repeated for the manager's hierarchy. The result is shown in tables 13 and 14.

Table 13 Sensitivity analysis for the ICS (managers' criteria)

Criteria	Current relative importance (%)	Changes to:	Percentage of changes:
Economical	59.9	43.2	- 27.9
Technological	25.2	50.8	101.6
Social	14.9	41.4	177.9

Table 13 shows that from point of view of managers, economical and technological criteria are the most important criteria and that their pairwise comparisons should be checked again. Table 14 was only assigned to analyse the sub-criteria of these two criteria because the social criterion cannot affect the problem as much as they can.

Table 14 Sensitivity analysis for the ICS (managers' sub-criteria)

Criteria	Sub-criteria	Current relative importance (%)	Changes to:	Percentage of changes:
Economical	Net profit	24.9	13.4	- 46.2
	Added value	20.6	10.1	- 51.0
	Price of technology	10.2	-	-
	Export possibility	18.6	31.5	69.4
	National market share	7.6	25.1	230.0
	International market share	18.1	37.2	105.5
Technological	Manufacturing technology	14.9	-	-
	Accessibility to know-how	20.2	29.3	- 45.0
	Flexibility	12.7	-	-
	Quality of technology	16.1	53.8	234.2
	National supports	9.9	52.9	434.3
	International supports	15.8	34.2	116.5
	National make ability	10.4	-	-

The most important sub-criteria for managers are accessibility to know-how and net profit. Again, their pairwise comparisons should be checked.

4.2.4. Combination of AHP and ZOGP

One of the disadvantages of using AHP alone is that AHP does not have any device to measure the discrepancy of non-achievable criterion with its target value when an alternative is chosen. AHP also is not able to consider the effects of constraints such as available budget, limitations of available man power and so on, directly. In addition, aggregation of the outcomes obtained by different stakeholders between stakeholders is not supported. To overcome the problems of using AHP as a stand-alone approach, the combination of AHP and ZOGP is considered.

The combination approach tries to include detailed weights obtained by AHP procedure include global and partial weights, because those weights provide more information about the problem in hand. Using more available information, increase the validity of the outcome (Dym et al. 2002). In this approach, AHP and ZOGP are used to form separate models for each stakeholder's viewpoint. Available data for tangible criteria are used directly into the ZOGP model by their normalised values to form the tangible constraints, while the data for intangible criteria, obtained by AHP, are used indirectly into the model to form intangible constraints by establishing the weights of the alternatives when they are compared to a criterion. The tangible criteria constraints represent the availability of limited resources or some requirements that are necessary to be fulfilled as much as possible, while intangible constraints try to reach the best relative importance of alternatives when they are compared to a criterion by setting their right hand sides as best relative importance of that criterion. The right-hand side of each tangible equation reflects the target value of the resources utilisation.

A crucial step in formulating the ZOGP model is constructing the objective function. This requires developing a quantitative measure of performance relative to each criterion that has been formulated for the problem. If there are multiple criteria, their respective measures are then transformed and combined into a composite measure called overall measure of performance. This overall measure might be something tangible (e.g., profit), or it might be abstract (e.g., utility). In the latter case, the task of developing this measure tends to be a complex one requiring a careful comparison of the criteria and their relative importance (Hillier and Lieberman, 1995). Because AHP has this ability, it is used to obtain the relative importance of criteria or sub-criteria which are then used in the ZOGP model as objective function coefficients. This process is made by eliciting the weights of criteria or sub-criteria when they are compared with each other, in the penultimate level of the hierarchy, through the pairwise comparison. These weights indicate the contribution of each criterion or sub-criterion that affects the objective functions.

The objective function of the combined model for each stakeholder can be developed to minimise the weighted sum of undesirable deviation variables, which means to minimise the sum of the undesirable distance between an ideal alternative against a criterion and the final chosen alternative. Although the objective function can be as maximisation sum of desirable variables, it does not guarantee that undesirable variables are minimised. In addition, decision makers are usually interested only in minimising undesirable variables rather than maximising desirable variables (Romero, 2001).

The weighting method for solving the models is used because, unlike the lexicographic method, the sum of the deviation variables with their attached weights, are minimised, without neglecting those criteria which might be important but have been removed because of its next priority. This means all of the deviation variables are important to decision makers so they do not want to ignore the effect of them. Whenever the resulting undesirable deviation is smaller, the outcome is better.

The procedure of combining AHP and ZOGP is shown in figure 18.

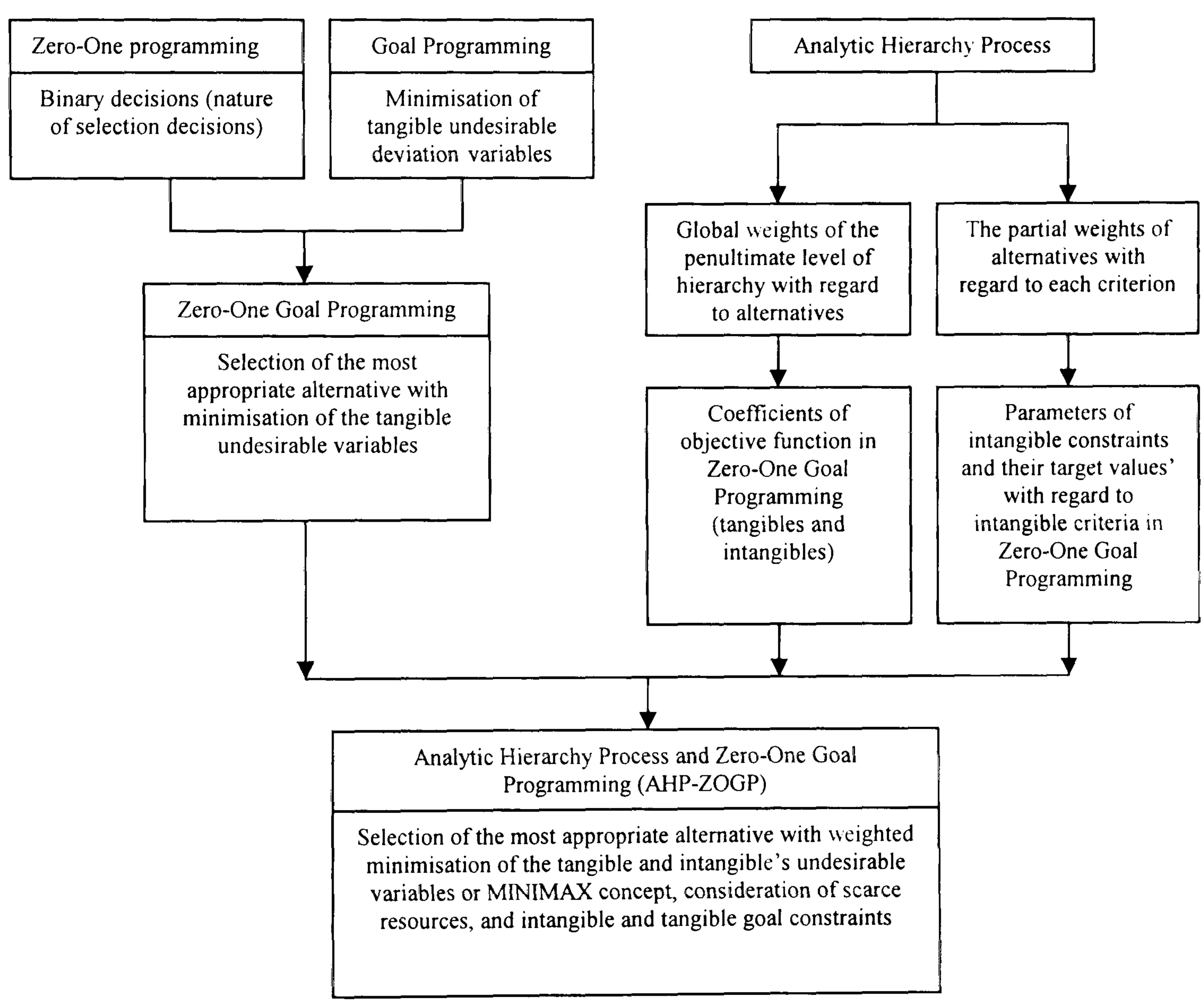

Figure 18 The procedure of combining ZOGP and AHP

The combined approach does not suffer the AHP shortcoming of ignoring resource constraints and difference between target value of a criterion and relative importance of selected alternative nor ZOGP's weakness of ignoring the relative significance of alternative preferences.

The steps of combination method are shown in boxes 7 to 16 in figure 6. These steps will be explained in more detail.

4.2.4.1. Obtaining global and partial weights of criteria or sub-criteria

In this step, the global and partial weights for each criterion or sub-criterion that are directly connected to the available alternatives are determined (box No.7 in figure 6). Remember that global weights measure the effect of all criteria or sub-criteria on the overall goal, while partial weights determine the weights of each alternative when alternatives are compared against a criterion or sub-criterion. The approach needs those weights to establish the objective function and intangible constraints of the ZOGP model.

4.2.4.2. Elimination of tangible criteria or sub-criteria partial weights

In this step, the partial weight of tangible criteria or sub-criteria obtained from AHP, if they are measured subjectively and if real data can be collected for them, are removed from further considerations (box No.8 in figure 6). When the real data are available, they should be considered because it is desirable to proceed with the best available knowledge.

4.2.4.3. Considerations of real values for tangible criteria or sub-criteria

After eliminating the partial weights of tangible criteria or sub-criteria obtained by AHP, the real data for them are considered (box No.9 in figure 6).

4.2.4.4. Normalisations of real values for tangible criteria or sub-criteria

The next step is to normalise the real data which are available for the problem in hand (box No.10 in figure 6). This process is necessary because the data may have different units of measurement. On the one hand, the tradeoffs between the tangible criteria that have different measurements are impossible. On the other hand, the relative importance of intangible criteria obtained by AHP, are measured by a kind of normalisation process, i.e., the relative importance of criteria or sub-criteria are the numbers between zero and one. Therefore, to compare all of the criteria or sub-criteria, they should be normalised in order to remove the units.

4.2.4.5. Replacement of normalised weights for tangible criteria or sub-criteria

In this step, the subjective judgements of partial weights are replaced with their normalised weights in order to use the real data as much as possible (boxes 8 to 10 in figure 6. In fact, this step tries to use all the real information which may exist to improve the decision making process.

4.2.4.5.1. The steps of sections 4.2.4.1 to 4.2.4.5 for the ICS

Tables 4 and 5 included this information for customers and managers viewpoints. In these tables, not only were the tangible data considered but they were also normalised.

4.2.4.6. Establishment of ZOGP model from viewpoint of each stakeholder

In this step, an individual weighted ZOGP model is built for each stakeholder in order to find which alternative is most preferable in the presence of the available tangible and intangible criteria constraints (box No.12 in figure 6). The ZOGP model can take into account the discrepancies (distance) between the target value of a criterion and its real value when an alternative is chosen. The global weights of criteria or sub-criteria obtained by the AHP become the coefficients for the objective function, whilst their normalized weights obtained by the normalization process for tangible criteria or partial weights obtained by AHP for intangible criteria, become the constraint parameters. Although the target value for intangible criteria can be set to any numbers between 0 and 1, depending on the decision maker(s) view, the target values of the intangible constraint equations are chosen to be the largest partial weight for any individual intangible criterion.

The decision maker(s) want to choose an alternative to reach the maximum partial weights of any intangible criteria. In this situation, the discrepancy will be zero if the final chosen alternative is the best alternative from the point of view of a criterion. The target value for the tangible criteria will be the available resource or the requirements of them which are determined by the problem's environment. The ZOGP model is constructed as follows.

$$Min \sum_{i=1}^{I} w_{hi}^{g} d_{hi}^{+/-} \qquad (h = 1,2,...)$$

$$subject\ \ to:$$

$$\sum_{k=1}^{K} w_{hki}^{NORM} x_k - d_{hi}^{+} + d_{hi}^{-} = b_{hii}^{NORM} \quad (i = 1,2,..., I)$$

$$\sum_{k=1}^{K} w_{hki}^{AHP} x_k - d_{hi'}^{+} + d_{hi'}^{-} = b_{hi'} \quad (i' \neq i)$$

$$\sum_{k=1}^{K} x_k = 1$$

$$\forall\ x_k \in (0,1)\ ;\ \forall\ d_{hi}^{+/-} \geq 0\ ;\ \forall\ d_{hi'}^{+/-} \geq 0$$

The first statement is the objective functions of the hth stakeholder (hierarchy) model. The coefficients of the deviation variables in the objective function are the global weights of the criteria obtained by AHP. This objective function minimises the weighted undesirable deviation variables (distances) with regard to the hth tangible and intangible criterion. Each deviation variable has a global contribution weight to account for the significance of the variable. For some criteria the stakeholders want to have a minimum (maximum) amount of some parameters, so in these circumstances, having less (more) than a predetermined level of the parameter is not desirable, so their negative (positive) relative deviation variables should be minimised (maximized) with regard to their weights.

The second equation represents the tangible criteria constraints once their coefficients and target values are normalised. The third equation indicates the intangible criteria constraints, their coefficients are the partial weights derived from AHP. Its target value is the greatest relative importance of alternatives when they are compared with a criterion. The selection of just one alternative is represented in the next equation. The selection variable is binary in nature and all of the deviation variables must be equal to or greater than zero. Definition of the parameters and variables are given as follows:

K: Number of alternatives

I Number of sub-criteria (criteria) which have been directly connected to the alternatives

x_k : Binary selection variable of kth alternative (1 = selection, 0 = non-selection)

w_{hi}^{g}: Global weight of ith sub-criterion in the penultimate level of hth hierarchy

$d_{hi}^{+/-}$: Deviation variables for sub-criteria of the hth hierarchy that can be desirable or undesirable

w_{hki}^{NORM} : ith normalised weight of tangible sub-criteria for the hth hierarchy with regard to the kth alternative

b_{hii}^{NORM} : Normalised target value of ith tangible sub-criterion of the hth hierarchy

$b_{hi'}$: Target value of i'th intangible sub-criterion of the hth hierarchy

w_{hki}^{AHP} : ith AHP weight of intangible sub-criteria for the hth hierarchy with regard to the kth alternative

Deviation variables (d) with a plus or minus index and a positive value show that the full attainment of a goal (right hand side of an equation) is not possible. For those constraints that the less (more) is better (like cost for former and alignment for latter), the deviation variable with plus (minus) index accompanying with its weights, is minimised. Each deviation variable is recognised by d and one index.

4.2.4.6.1. Establishment of ZOGP models and their sensitivity analysis for the ICS

There are three points which must be explained before constructing the model from viewpoints of customers and managers.

1- The target values of tangible criteria are normalised. For example, the target value of budget constraint (customer viewpoint) for price of vehicles is 0.145. This value is the normalised value of 7900 Pounds (12000 U.S. dollars) respect to the price of the considered vehicles.

2- The target values of intangible criteria are set to the maximum relative importance of each alternative when they are compared to an intangible criterion. For example 0.369 which has placed at the right hand side of comfort constraint (customer viewpoint) is the relative importance of the best alternative regard to that constraint (Toyota has the greatest relative importance regard to comfort criterion).

3- For those constraints which were tangible in nature but the data were not available for them, were compared subjectively as intangible criteria. Therefore, their target values were set the same as intangible constraints. Repairing cost is an example of this sort of constraint.

Using the data derived by AHP and other available data, the following ZOGP models from the both viewpoints are constructed.

4.2.4.6.1.1. Customers' model and its sensitivity analysis

$$Min\ 0.054\, d_{cc}^{-} + 0.035\, d_{ce}^{-} + 0.038\, d_{ct}^{-} + 0.031\, d_{cd}^{-} + 0.033\, d_{cm}^{-} + 0.143\, d_{cp}^{+} + 0.073\, d_{cf}^{+} + 0.129\, d_{cr}^{-} + 0.128\, d_{ces}^{-} +$$
$$0.128\, d_{cs}^{-} + 0.099\, d_{cdu}^{-} + 0.044\, d_{ch}^{-} + 0.063\, d_{cer}^{-}$$

Subject to

$$0.066\, Fiat + 0.274\, Honda + 0.085\, Hyundai + 0.369\, Toyota + 0.207\, Volks - d_{cc}^{+} + d_{cc}^{-} = 0.369 \quad \text{(Comfort)}$$
$$0.081\, Fiat + 0.276\, Honda + 0.099\, Hyundai + 0.375\, Toyota + 0.168\, Volks - d_{ce}^{+} + d_{ce}^{-} = 0.375 \quad \text{(Elegance)}$$
$$0.073\, Fiat + 0.255\, Honda + 0.089\, Hyundai + 0.382\, Toyota + 0.201\, Volks - d_{ct}^{+} + d_{ct}^{-} = 0.382 \quad \text{(Type)}$$
$$0.078\, Fiat + 0.241\, Honda + 0.103\, Hyundai + 0.346\, Toyota + 0.232\, Volks - d_{cd}^{+} + d_{cd}^{-} = 0.346 \quad \text{(Dimension and shape)}$$
$$0.080\, Fiat + 0.269\, Honda + 0.118\, Hyundai + 0.349\, Toyota + 0.183\, Volks - d_{cm}^{+} + d_{cm}^{-} = 0.349 \quad \text{(Modern equipment)}$$
$$0.181\, Fiat + 0.217\, Honda + 0.168\, Hyundai + 0.193\, Toyota + 0.241\, Volks - d_{cp}^{+} + d_{cp}^{-} = 0.145 \quad \text{(Price)}$$
$$0.141\, Fiat + 0.201\, Honda + 0.217\, Hyundai + 0.193\, Toyota + 0.248\, Volks - d_{cf}^{+} + d_{cf}^{-} = 0.172 \quad \text{(Fuel consumption)}$$
$$0.129\, Fiat + 0.262\, Honda + 0.189\, Hyundai + 0.187\, Toyota + 0.233\, Volks - d_{cr}^{+} + d_{cr}^{-} = 0.233 \quad \text{(Repairing Costs)}$$
$$0.092\, Fiat + 0.235\, Honda + 0.114\, Hyundai + 0.360\, Toyota + 0.199\, Volks - d_{ces}^{+} + d_{ces}^{-} = 0.360 \quad \text{(Easy to sell second hand)}$$
$$0.081\, Fiat + 0.254\, Honda + 0.084\, Hyundai + 0.328\, Toyota + 0.253\, Volks - d_{cs}^{+} + d_{cs}^{-} = 0.328 \quad \text{(Safety)}$$
$$0.087\, Fiat + 0.217\, Honda + 0.074\, Hyundai + 0.303\, Toyota + 0.319\, Volks - d_{cdu}^{+} + d_{cdu}^{-} = 0.319 \quad \text{(Durability)}$$
$$0.102\, Fiat + 0.213\, Honda + 0.195\, Hyundai + 0.190\, Toyota + 0.300\, Volks - d_{ch}^{+} + d_{ch}^{-} = 0.173 \quad \text{(Horsepower)}$$
$$0.127\, Fiat + 0.201\, Honda + 0.177\, Hyundai + 0.327\, Toyota + 0.168\, Volks - d_{cer}^{+} + d_{cer}^{-} = 0.327 \quad \text{(Easy to repair)}$$
$$Fiat + Honda + Hyundai + Toyota + Volks = 1$$
$$Fiat, Honda, Hyundai, Toyota, Volks \in (0,1) \quad ; \quad d_{ij}^{+/-} \geq 0 \quad \forall \ all\ i, j$$

Index c for deviation variables imply that they are related to the customers' model. The customers' preferences using the model are Toyota, Honda, Volks Wagen, Hyundai, and Fiat respectively. The main competition from the viewpoint of customers is among Toyota, Honda, and Volks Wagen. It is interesting when the target value of intangible constraints change to second level and third level of relative importance obtained by AHP, the ranking will be unchanged. That is because the Toyota alternative almost has the greatest relative importance with regard to the most important criteria. In other words, the outcome is not sensitive to the target values of the intangible criteria. If the available resources for tangible constraints increase or decrease, the outcome will not be changed again because of the greatest contribution of important criteria which Toyota has.

If the coefficient of durability in the objective function increase to 0.299 instead of 0.099 and contributions of easy to sell second hand and safety reduce each by 0.100, then the ranking are changed as Toyota, Volks Wagen, Honda, Fiat, and Hyundai. The reason for changing those parameters are because durability is the only intangible criterion that Toyota is not the best alternative for, so increasing its contribution may change the ranking outcome. On the other hand, decreasing easy to sell second hand and safety criteria is because of relatively high contribution of those criteria that Toyota has. In fact, two effective coefficients of selected alternative are decreased and one coefficient of non-selected alternatives is increased. So, if the relative importance of easy to sell second hand, safety, and durability will change, then the outcome of the ranking will be changed. However, the best alternative is unchanged (Toyota). In fact, a parametric sensitivity analysis is necessary to change the current ranking. In parametric analysis, more than one parameter can be changed (Taha, 1997).

Generally, the small changes in target values, availability of resources, and relative importance of criteria and parameters of main variables in constraints will not change the obtained outcome. As it has been shown, when great change occurs with regard to some important parameters simultaneously, the outcome may be changed. Even individual changes can hardly change the ranking of alternatives.

4.2.4.6.1.2. Managers' model and its sensitivity analysis

$$Min\ 0.149d^-_{mnp} + 0.123d^-_{ma} + 0.061d^+_{mp} + 0.112d^-_{me} + 0.046d^-_{mnm} + 0.108d^-_{mim} + 0.037d^-_{mm} + 0.051d^-_{mk} + 0.032d^-_{mf} +$$

$$0.041d^-_{mq} + 0.025d^-_{mns} + 0.040d^-_{mis} + 0.027d^-_{mma} + 0.042d^-_{mg} + 0.026d^-_{mc} + 0.050d^-_{mnt} + 0.030d^-_{ms}$$

Subject to

$$0.085\,Fiat + 0.136\,Honda + 0.339\,Hyundai + 0.169\,Toyota + 0.271\,Volks - d^+_{mnp} + d^-_{mnp} = 0.271 \quad \text{(Net profit)}$$

$$0.059\,Fiat + 0.118\,Honda + 0.392\,Hyundai + 0.235\,Toyota + 0.196\,Volks - d^+_{ma} + d^-_{ma} = 0.294 \quad \text{(Added - value)}$$

$$0.250\,Fiat + 0.179\,Honda + 0.071\,Hyundai + 0.143\,Toyota + 0.357\,Volks - d^{+}_{mp} + d^{-}_{mp} = 0.179 \quad \text{(Price of technology)}$$

$$0.150\,Fiat + 0.281\,Honda + 0.078\,Hyundai + 0.200\,Toyota + 0.291\,Volks - d^{+}_{me} + d^{-}_{me} = 0.291 \quad \text{(Export possibility)}$$

$$0.091\,Fiat + 0.258\,Honda + 0.074\,Hyundai + 0.349\,Toyota + 0.299\,Volks - d^{+}_{mnm} + d^{-}_{mnm} = 0.349 \quad \text{(National market share)}$$

$$0.178\,Fiat + 0.230\,Honda + 0.127\,Hyundai + 0.205\,Toyota + 0.260\,Volks - d^{+}_{mim} + d^{-}_{mim} = 0.260 \quad \text{(International market share)}$$

$$0.127\,Fiat + 0.197\,Honda + 0.067\,Hyundai + 0.323\,Toyota + 0.286\,Volks - d^{+}_{mm} + d^{-}_{mm} = 0.323 \quad \text{(Manufacturing technology)}$$

$$0.100\,Fiat + 0.113\,Honda + 0.471\,Hyundai + 0.170\,Toyota + 0.146\,Volks - d^{+}_{mk} + d^{-}_{mk} = 0.471 \quad \text{(Accessible to know - how)}$$

$$0.138\,Fiat + 0.223\,Honda + 0.105\,Hyundai + 0.279\,Toyota + 0.254\,Volks - d^{+}_{mf} + d^{-}_{mf} = 0.279 \quad \text{(Flexibility)}$$

$$0.092\,Fiat + 0.157\,Honda + 0.148\,Hyundai + 0.285\,Toyota + 0.317\,Volks - d^{+}_{ma} + d^{-}_{ma} = 0.317 \quad \text{(Quality of technology)}$$

$$0.111\,Fiat + 0.170\,Honda + 0.281\,Hyundai + 0.239\,Toyota + 0.198\,Volks - d^{+}_{mns} + d^{-}_{mns} = 0.281 \quad \text{(National supports)}$$

$$0.139\,Fiat + 0.155\,Honda + 0.322\,Hyundai + 0.188\,Toyota + 0.196\,Volks - d^{+}_{mis} + d^{-}_{mis} = 0.322 \quad \text{(International supports)}$$

$$0.115\,Fiat + 0.249\,Honda + 0.162\,Hyundai + 0.309\,Toyota + 0.165\,Volks - d^{+}_{mma} + d^{-}_{mma} = 0.309 \quad \text{(National make ability)}$$

$$0.098\,Fiat + 0.135\,Honda + 0.463\,Hyundai + 0.159\,Toyota + 0.145\,Volks - d^{+}_{mg} + d^{-}_{mg} = 0.463 \quad \text{(Government supports)}$$

$$0.180\,Fiat + 0.228\,Honda + 0.131\,Hyundai + 0.265\,Toyota + 0.197\,Volks - d^{+}_{mc} + d^{-}_{mc} = 0.265 \quad \text{(customer' style)}$$

$$0.134\,Fiat + 0.247\,Honda + 0.087\,Hyundai + 0.270\,Toyota + 0.262\,Volks - d^{+}_{mnt} + d^{-}_{mnt} = 0.270 \quad \text{(National trust)}$$

$$0.159\,Fiat + 0.190\,Honda + 0.213\,Hyundai + 0.229\,Toyota + 0.209\,Volks - d^{+}_{ms} + d^{-}_{ms} = 0.229 \quad \text{(Suitability with consumption pattern)}$$

$$Fiat + Honda + Hyundai + Toyota + Volks = 1$$

$$Fiat, Honda, Hyundai, Toyota, Volks \in (0,1) \quad ; \quad d^{+/-}_{ij} \geq 0 \quad \forall \quad all\ i,j$$

The right hand side of the first three constraints which related to target values of net profits, added-value, and price of technology are the normalised numbers of real values which were 80, 15, and 500 units, respectively. The managers' preferences using the model are Volks Wagen, Toyota, Hyundai, Honda, and Fiat accordingly. When the target values of intangible constraints change to the second level of relative importance, the place of third and fourth alternatives are replaced with each other and the others will be unchanged. If those values change to third level then the best alternative changes to Toyota. In fact, the place of Volks Wagen and Toyota changed and other will be as second level for target values of intangible constraints.

If the target value of net profit constraint changes to 0.171, that means to decrease the level of profit during 5 years, then the outcome will change. In this situation Toyota will be selected as the best alternative. In other words, the resulting outcome is sensitive to that target value. Changing other target values for both tangible and intangible constraints does not change the outcome.

Different sensitivity analyses show that the competition is between Volks Wagen and Toyota. The result alternatively changes when some parameters of the model are changed.

4.2.5. Comparison of ranking between stakeholders

In this step the ZOGP models are solved sequentially, using available softwares to generate the rankings of alternatives from each stakeholder's viewpoint (box No.13 in figure 6). To do this, first, the original formulated ZOGP model is solved. The outcome will be selection of an alternative, say A. To obtain the ranking of other alternatives, the selected alternative from original ZOGP model is set up to zero ($A = 0$) which will be added to the set of constraints. The existence of this new constraint ($A = 0$) prevents the model to select the previous alternative (A) again. In this new situation, the outcome of the new model is the next preferable alternative. This procedure repeats until all of alternatives are selected.

The aim of this step is to find if there are different rankings between stakeholders (box No.14 in figure 6). The outcomes of models (ranking of alternatives) may be the same. In this case, sensitivity analysis should be made in order to investigate what parameters or criteria in the solution are sensitive (box No.6 in figure 6). Then taking careful view of determining of those parameters and associated variable with them, the solution process is repeated to ensure that the derived outcome is acceptable. On the other hand, it is quite possible that the rankings of alternatives obtained by solution of individual ZOGP models are not the same. In this case, it is necessary to aggregate the models in order to reach a single outcome from all stakeholders' viewpoints (box No.15 in figure 6).

4.2.5.1. Computer supports for ZOGP

There are so many packages that can support ZOGP such as Lindo (Lindo Systems Inc.), Lingo, Solver, SCIMOD, LOQO. Among them, Lindo is used here because: 1) it is accessible through Internet, 2) it is user-friendly software, and 3) for the purposes of this thesis which involve the small size of models without having too many variables and constraints, the solution can be rapidly found.

4.2.5.2. Comparison of ranking between stakeholders for illustrative case study

Table 15 shows the different outcome when ZOGP models are used to rank the alternatives. Therefore, it is necessary to aggregate the outcomes.

Table 15 Comparison of ranking between stakeholders for illustrative case study

Stakeholders \ Rank	1	2	3	4	5
Customers	Toyota	Honda	Volks Wagen	Hyundai	Fiat
Managers	Volks Wagen	Toyota	Hyundai	Honda	Fiat

4.2.6. Aggregation of viewpoints based on another ZOGP model

To overcome the problem of selecting a single alternative which fulfil the requirement of all the stakeholders involved in the decision making process as much as possible, it is necessary to construct an aggregated model whose outcome creates the most appropriate alternative (box No.15 in figure 6). Figure 19 represents the method of aggregation of separated models graphically. In this figure, for simplicity, it has been assumed that there are just two stakeholders' models (A and B) that should be aggregated.

The objective function of the aggregated model is assumed to be: 1) a linear additive of the objective functions of the single models, and 2) the minimum of the maximum (MINIMAX) sum of dispersions between all of the stakeholders' objective function. The former aggregated objective function attempts to minimise the weighted sum of undesirable deviation variables from all stakeholders, while the latter aggregated objective function tries to minimise the maximum summation of weighted deviations of undesirable variables. However, this objective function is a non-linear one but it can be rewritten as a linear objective function with a well-known amendment to facilitate finding the outcome of the model (Taha, 1997).

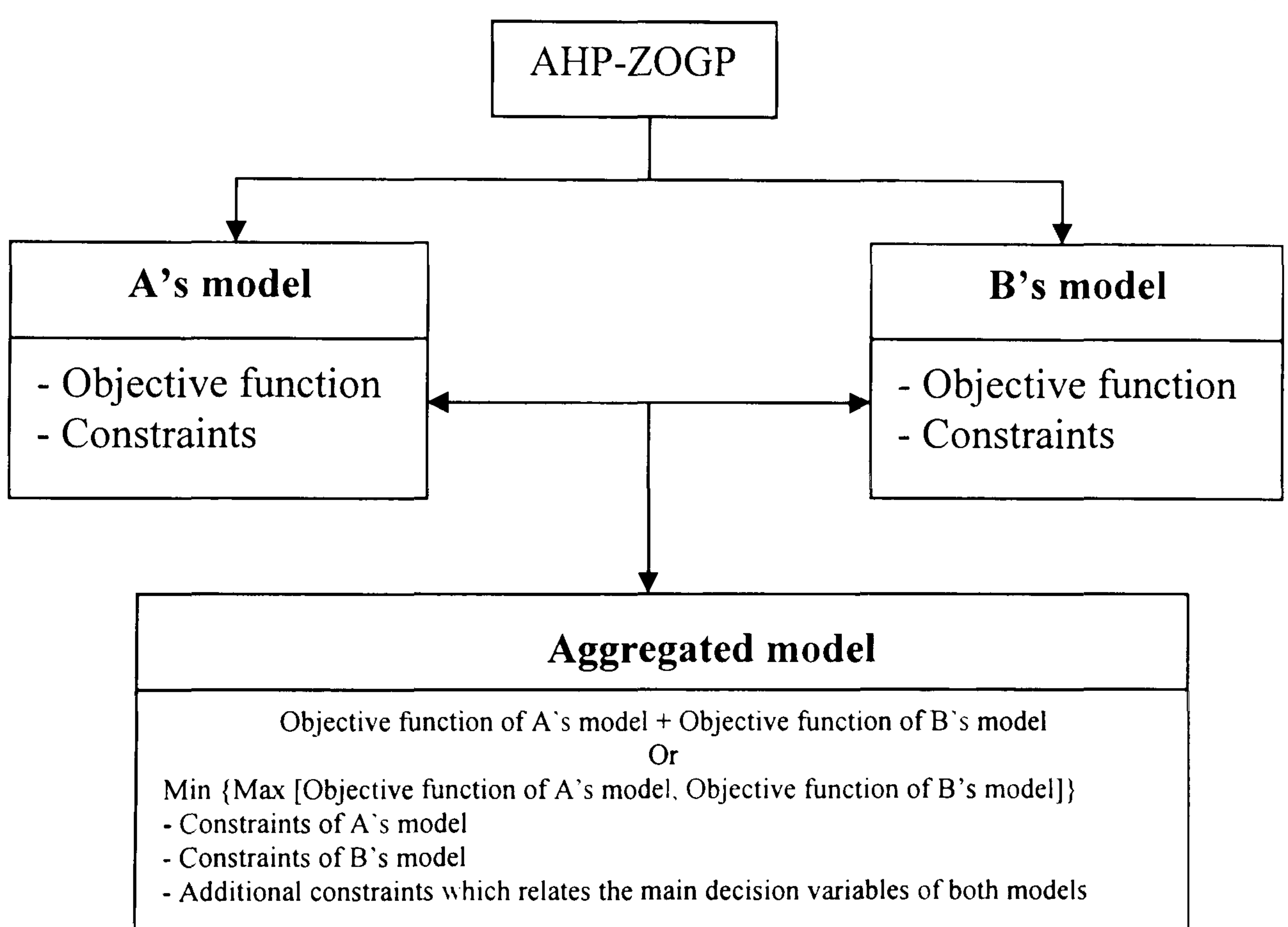

Figure 19 The method for aggregating two models

To choose between AHP-ZOGP aggregated objective function (weighted or MINIMAX), one should note to the nature of stakeholders involved in the decision. If for decision maker(s), the most sum of deviation variables (related to criteria) are significant, then he chooses the MINIMAX method because in this method, the most sum of deviations are minimised. But if all the criteria are important for him equally, then he selects the weighted method objective function.

The constraints from single models, without any changes, will be placed in the aggregated models (with two different objective functions). If there are some kinds of special variables from single models, which are necessary to relate them, they are connected by expressing them as additional constraints in the aggregated model. For example, constraints that relate the variable of technology selection and the products of those technologies are such as $y_{ij}-x_i \leq 0$, which y_{ij} represents the variable of ith technology that can produce jth product and x_i represents the variable of selected ith technology. These sorts of constraints are well defined in the literature (Hillier and Lieberman, 1995). A single outcome is yielded with using the aggregated ZOGP model.

4.2.6.1. Aggregation of outcomes based on ZOGP model for the ICS

Different stakeholders selected different alternatives. Two different ZOGP models are aggregated into another ZOGP model in order to reach a single outcome. The aggregated model is constructed by putting all constraints of two previous models into the new model and forming the objective function which will have two different shapes. The first objective function is to add individual objective functions of two ZOGP models and second one is as minimum of maximum added undesirable variables from the viewpoint of each stakeholder. The general format of aggregated model using weighted method is as follows

$$Min\ w^m \sum_{j=1}^{J} w_{mj}^g d_{mj}^{+/-} + w^c \sum_{i=1}^{I} w_{ci}^g d_{ci}^{+/-}$$

subject to

$$\sum_{k=1}^{K} w_{mkj}^{NORM} x_k - d_{mj}^+ + d_{mj}^- = b_{mj} \quad (j=1,2,\dots,J)$$

$$\sum_{k=1}^{K} w_{mkj}^{AHP} x_k - d_{mj'}^+ + d_{mj'}^- = b_{mj'} \quad (j' \neq j)$$

$$\sum_{k=1}^{K}\sum_{l=1}^{L} w_{cki}^{NORM} x_k - d_{ci}^+ + d_{ci}^- = b_{ci} \quad (i=1,2,\dots,I)$$

$$\sum_{k=1}^{K}\sum_{l=1}^{L} w_{cki}^{AHP} x_k - d_{ci'}^+ + d_{ci'}^- = b_{ci'} \quad (i' \neq i)$$

$$\sum_{k=1}^{K} x_k = 1$$

$$\forall x_k \in (0,1)\ ;\ \forall d_{mj}^{+/-} \geq 0\ ;\ \forall d_{mj'}^{+/-} \geq 0\ ;\ \forall d_{ci}^{+/-} \geq 0\ ;\ \forall d_{ci'}^{+/-} \geq 0$$

. The parameters and variables definitions are the same as individual models. w^m and w^c indicate the weight of each stakeholder which their sum must be one.

These weights are useful to obtain additional information when sensitivity analysis is made.

4.2.6.1.1. Aggregated model using weighted method

In this model, the individual objective functions of ZOGP models are added to each other with the attached weights which are equal at first. However, these weights can be changed for sensitivity analysis. All the constraints will be put as constraints in new model. Therefore, it is not necessary to write a new model.

4.2.6.1.2. Aggregated model using MINIMAX method

In this model, the objective function of aggregated model is to minimise the maximum added undesirable variables regard to each individual objective function. The constraints of the model will be as constraints of individual models. Therefore, it is just necessary to write the new objective function.

$$Min\{ Max[0.054d_{cc}^{-} + 0.035d_{ce}^{-} + 0.038d_{ct}^{-} + 0.031d_{cd}^{-} + 0.033d_{cm}^{-} + 0.143d_{cp}^{+} + 0.073d_{cf}^{+} + 0.129d_{cr}^{+} +$$
$$0.128d_{ces}^{-} + 0.128d_{cs}^{-} + 0.099d_{cdu}^{-} + 0.044d_{ch}^{-} + 0.063d_{cer}^{-}, 0.149d_{mnp}^{-} + 0.123d_{ma}^{-} + 0.061d_{mp}^{+} + 0.112d_{me}^{-} +$$
$$0.046d_{mnm}^{-} + 0.108d_{mim}^{-} + 0.037d_{mm}^{-} + 0.051d_{mk}^{-} + 0.032d_{mf}^{-} + 0.041d_{mq}^{-} + 0.025d_{mns}^{-} + 0.040d_{mis}^{-} +$$
$$0.027d_{mma}^{-} + 0.042d_{mg}^{-} + 0.026d_{mc}^{-} + 0.050d_{mnt}^{-} + 0.030d_{ms}^{-}]\}$$

This non-linear objective function can be converted to the following equivalent linear objective function with two new constraints.

$$Min\ Z$$
$$0.054d_{cc}^{-} + 0.035d_{ce}^{-} + 0.038d_{ct}^{-} + 0.031d_{cd}^{-} + 0.033d_{cm}^{-} + 0.143d_{cp}^{+} + 0.073d_{cf}^{+} + 0.129d_{cr}^{+} + 0.128d_{ces}^{-} +$$
$$0.128d_{cs}^{-} + 0.099d_{cdu}^{-} + 0.044d_{ch}^{-} + 0.063d_{cer}^{-} \le Z$$
$$0.149d_{mnp}^{-} + 0.123d_{ma}^{-} + 0.061d_{mp}^{+} + 0.112d_{me}^{-} + 0.046d_{mnm}^{-} + 0.108d_{mim}^{-} +$$
$$0.037d_{mm}^{-} + 0.051d_{mk}^{-} + 0.032d_{mf}^{-} + 0.041d_{mq}^{-} + 0.025d_{mns}^{-} + 0.040d_{mis}^{-} + 0.027d_{mma}^{-} + 0.042d_{mg}^{-} + 0.026d_{mc}^{-} +$$
$$0.050d_{mnt}^{-} + 0.030d_{ms}^{-} \le Z$$

The above model when all the constraints of two previous models will be put as new constraints will form the MINIMAX model.

4.2.6.2. Obtaining single outcome

The aggregated model is solved to find the ranking of alternatives which satisfy all the stakeholders in the problem as much as possible (box No.15 in figure 6). The chosen alternative has minimum dispersion values between stakeholders, depends on which kind of objective function has been used for aggregated model. The solving procedure may generate a new ranking of alternatives, which differs from the ranking created by AHP alone, aggregated by heuristics methods, or generated by individual models. The new ranking needs to be carefully analysed to discover the sensitive parameters, variables, or weights that have been obtained by applying pairwise comparison in the AHP, in order to find with changing which of them, the final ranking, obtained by this aggregated model or individual models, can be affected. In this process, what is important is to find which small modification can change the final outcome.

Sensitivity analysis also involves obtaining a sequence of outcomes that comprise a series of changed inputs on a model in order to find with new circumstances, what will be happened to a problem. For example, changing some pairwised judgements, some parameters of ZOGP models, some target values, and so forth, may create other outcomes which should be presented to decision maker(s) for comparison between them. With these outcomes decision makers have enough information to make the final decisions. Also, it is possible to determine the range of all parameters of the models which can preserve the current outcome. In other words, the range of critical parameters, which are thought to be important for decision making, can be found.

4.2.6.2.1. Obtaining single outcome for the ICS using weighted method

The weighted aggregate model outcomes select Toyota, Volks Wagen, Honda, Hyundai, and Fiat, respectively when the attached weights for each part of the objective function are equal. The outcome will change if the attached weights of the managers' and customers' objective functions change to 0.97 and 0.03, respectively. That means that if managers' viewpoints are more than 30 times important of customers' viewpoint, then the outcome will change. It is also interesting that when changes at individual models were applied simultaneously, they could not change the outcome of the aggregated model. Even replacing the target values to a set with a second level of relative importance of the intangible criteria could not change the ranking, while when those changes occurred individually, it changed the ranking of the individual models. This shows that the aggregated model is less sensitive than individual models and therefore it has more reliability rather than individual models.

4.2.6.2.2. Obtaining single outcome for the ICS using MINIMAX method

The MINIMAX aggregated model outcomes show the ranking are as the weighted aggregated model. In fact, there is no difference between ranking using this method and weighted method. This indicates that for the problem in hand, these two approaches have no difference because the relative importance of Toyota alternative in most cases from point of view of both stakeholders are greater than other alternatives. The changes which alter the ranking of individual models are not able to change the aggregated model because again of greater importance of one alternative with regard to important criteria.

4.2.7. Submission of all results to decision maker(s) for making the final decision

In this step, all the outcomes obtained by AHP alone, viewpoints aggregated using heuristic methods, the separated models which reflect the viewpoints of each stakeholder, the aggregated model of individual models, and the outcomes of making sensitivity analysis for all cases, are submitted to the decision maker(s) for the final decision.

4.2.7.1. Submission of all results to decision maker(s) for the ICS

Several methods were used for the problem of choosing a vehicle manufacturing technology. These methods created different ranking for the problem. A compared outcome of these methods has been indicated in the table 16. This table shows that with the exception of mangers' viewpoints, other single or aggregated methods selected the Toyota as the most appropriate alternative. However, managers have selected that alternative as second one. Although it seems that aggregated methods have almost ranked the alternatives similarly, but aggregation by ZOGP models is preferred because it is able to make sensitivity analysis more efficiently. Some sensitivity analyses made for individual models and aggregated models showed that the ranking of alternatives could be changed if the parameters of the models are changed. In fact, when the sensitivity analyses are applied for the models, it includes both AHP and ZOGP model sensitivity analysis and therefore it is more valuable than individual sensitivity analysis.

Table 16 Different ranking using different methods

Methods \ Alternatives	Fiat	Honda	Hyundai	Toyota	Volks Wagen
AHP for customers	4	2	5	1	3
AHP for managers	5	4	1	2	3
Aggregated based on heuristic distance method	4	3	5	1	2
AHP-ZOGP model for customers	5	2	4	1	3
AHP-ZOGP model for managers	5	4	3	2	1
Aggregated ZOGP model (weighted method)	5	3	4	1	2
Aggregated ZOGP model (MINIMAX method)	5	3	4	1	2

It is interesting that the methods for aggregating the outcomes have created the same result for the first two alternatives. Thus the orders of alternatives for selecting the most appropriate alternative can be accepted from all stakeholders who are involved in the decision.

4.2.7.2. Upshot of the ICS

The case study used AHP as a stand-alone methodology to rank the alternatives in addition of a combination of AHP and ZOGP. The heuristic distance method and ZOGP models were used for aggregation of outcomes based on final weights obtained from AHP and a combination of individual models were built for individual stakeholders.

The values of deviation variables of individual or aggregated model provide additional information of the attainability of tangible and intangible criteria which is important beside the result of sensitivity analysis. This information especially for intangible criteria can help the decision maker(s) to understand which criterion or sub-criterion has not been satisfied with its target value. Based on this additional information, one may change his initial perception and therefore, it affects the outcome of the model. For example, deviation variable for accessibility to know-how criterion for managers' ZOGP model is 0.325. That means with selection of Volks Wagen alternative, it is not possible to obtain the know-how of this alternative 100%. If this value is measured with the target value of that criterion (0.471), it identifies that 69% of that criterion is unattainable. If this value is valuable for decision maker, he may change his mind about selection of Volks Wagen alternative. In this case, it is necessary to carefully compare this criterion against other criteria which cause to create another model.

4.3. Towards a software tool

The methodology used Expert Choice and Lindo softwares. The former is applied when AHP is used alone to generate the weights of elements (final, detail, and partial weights) in a hierarchy. The latter uses the output of Expert Choice as the parameters of ZOGP's objective function, intangible constraints, and the right hand side of intangible constraints. Figure 20 shows how these two softwares can be integrated to generate a single tool which its final output is the ranking of alternatives based on the combination of AHP and ZOGP.

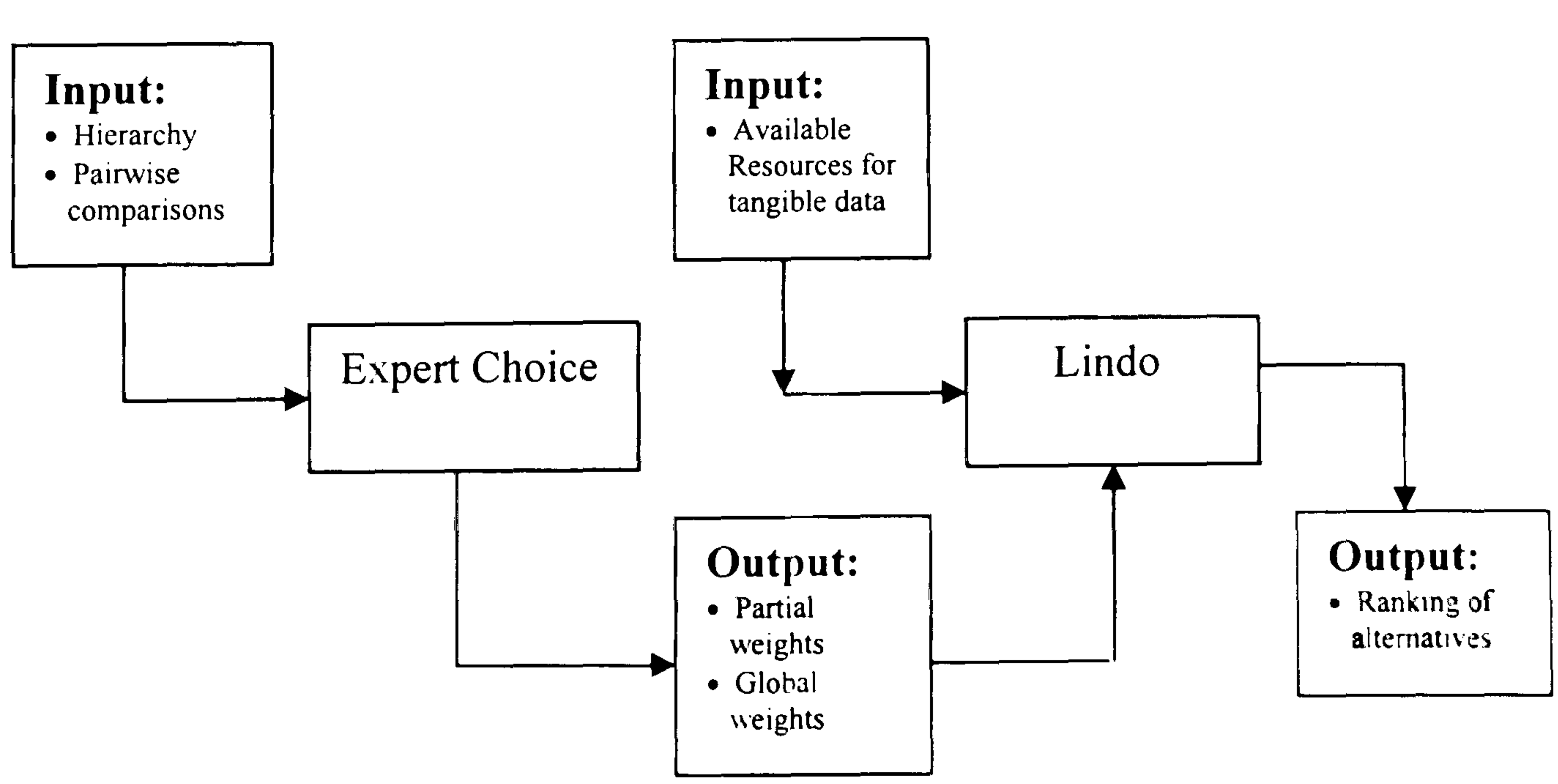

Figure 20 Integration of Expert Choice and Lindo softwares

4.4. Concluding remarks

The proposed approach is a systematic and easy to use method for MCDM-MSDM selection problems with the presence of multiple criteria and multiple stakeholders, especially when stakeholders have different objectives, different criteria or sub-criteria, and diverse hierarchies. The approach can use AHP as a stand-alone approach or use the combination of AHP and ZOGP.

Global and partial weights of AHP are synthesised through a linear additive function to produce final weights of alternatives, without taking into account the real constraints. Although AHP considers the relative importance of criteria and sub-criteria, it cannot consider the satisfactory level of a criterion or sub-criterion which may be identified by stakeholders. When the combination of AHP and ZOGP is used to construct individual models for each stakeholder viewpoint, AHP global and partial weights are used for the objective function's coefficients and parameters of ZOGP constraints, respectively.

The advantage of using AHP and ZOGP simultaneously is that it can consider the effect of real constraints directly into the model and it is able to take into account the distance differences between the final chosen alternative and the best alternative from the point of view of a criterion. The combined approach is able to produce more information which is vital for better decision making. Information about the consumption of resources, how close a final selected concept design is to its requirements, and which of stakeholders plays more important roles in the selection of concept design alternatives are some examples.

The approach also offers three methods to aggregate the outcomes from the point of view of individual stakeholders. When AHP is used as a stand-alone approach, it offers two heuristic distance methods which are easy to use and understandable for stakeholders because they apply simple mathematical rules. Although the framework of these two methods is the same, the difference between them is about the level of information they need. The first method uses the final weights of alternatives while second method uses detailed weights of AHP. Both methods use a distance function to produce an index for aggregation. Although using the heuristic methods have the advantage of simplicity, they are not able to consider the dispersion concept and real constraints.

When ZOGP model is used to aggregate outcomes of several stakeholders, the model uses the detailed information from AHP and individual ZOGP models. The ZOGP aggregated model can take into account the distances between the final selected concept design and the ideal concept design with regard to a criterion, real constraints and the satisfactory level for any criterion or sub-criterion, from the point of view of each individual stakeholder.

The use of the approach depends on the stakeholders' attitudes and their satisfaction of using the AHP as a stand-alone methodology or using the combination of AHP and ZOGP which is able to minimise the effect of undesirable criteria or sub-criteria as well as considering the distance concept and taking the constraints into account.

CHAPTER 5
METHODOLOGY APPLICATIONS

5.1. Overview

In this chapter, the proposed approach is evaluated by application to real world problems. In addition to applying the approach for selection of vehicle manufacturing technology, which was discussed earlier in chapter 4, three other problems including selection of a peristaltic pump, selection of a swivel joint design, and justification of advanced manufacturing systems, are considered to test the approach. Out of these problems, the data for justification of advanced manufacturing systems and swivel joint design problem have been obtained from secondary sources.

The aim of this chapter is to show that the proposed approach is able to solve the problems which:

1- Have single or multiple stakeholders.

2- Have multiple conflicting criteria.

3- Have both tangible and intangible criteria.

4- Stakeholders can be individuals or a group.

5- Can have constraints.

5.2. Selection of a peristaltic pump

The aims of using this case study are: 1) to clarify the stages of the approach in a systematic manner, 2) to demonstrate that the approach can be applied for selection of a concept design alternatives, 3) to indicate that using the proposed approach can generate more useful information for the decision maker(s), and 4) to aggregate the outcomes made by each individual stakeholder in order to achieve a single decision.

5.2.1. Problem statement summary

Verderflex, industrial peristaltic pumps manufacturer in United Kingdom, is considering the redesigning of current products in order to increase its market share. For this reason, the company intends to design new products with the following general characteristics:

1- The new pump must be as cheap as possible (the target being 50% of the current cost),

2- The new pump must be either smaller or no longer than the current range,

3- The new pumps must have high quality,

4- The new pumps must perform better than the current range and competition, be more reliable, easier to assemble and maintain, more compact, and provide higher flow rates.

There are other special characteristics which should be achieved by designing new pumps, such as capability of delivering up to at least 12 bars pressure, increasing flow range, ability to run dry for short periods, and so forth. These characteristics can be found as the criteria or sub-criteria in the Appendix B.

The application of the proposed approach is to select the most appropriate peristaltic pump among three developed concept designs which are depicted in figure 21. These three new concept designs are introduced as Helical Linear (*A*), Lobe (*B*), and Eccentric (*C*) by the design department. Each alternative is a potentially successful design for manufacturing. Although each concept design may have a better characteristic from viewpoint of a criterion and point of view of a stakeholder, but none of them is a dominant alternative. So it is necessary to implement a MCDM-MSDM approach to find out what concept design should be chosen.

Figure 21 Three new peristaltic pump new designs

5.2.2. Using the approach for peristaltic pump selection

5.2.2.1. Identifying the stakeholders

For this problem, there were three stakeholders whose views were deemed important and they should be taken into account for making a decision. They were the manufacturing department, the marketing department, and the customers. The stakeholders had different views to select an alternative. These views cause different stakeholders choose different alternatives. It should be noted that the information for this case study was obtained from experts in the company.

5.2.2.2. Identifying the criteria

For choosing a peristaltic pump, a set of criteria and sub-criteria were identified by different stakeholders based on the requirements of each individual stakeholder. The first evaluation of the total number of criteria or sub-criteria were more than 40, however, they were decreased by elimination of those criteria which performed the same (more or less) for all the alternatives. The initial criteria are depicted in tables 17 to 19. However, non-effective criteria and sub-criteria will be removed to facilitate the application of the approach.

Table 17 Initial manufacturing departments' criteria and sub-criteria

	Criteria	Sub-criteria
Manufacturing department	**Mass and size (*D*)**	Pump mass (include GMU) (*D1*)
		Pump envelope (include GMU) (*D2*)
	Ergonomics (*E*)	Assembly time (*E1*)
		Assembly ease (*E2*)
		Accessible fastenings (*E3*)
	Aesthetics (*F*)	Conveys elements of Verder & Verderflex branding (*F1*)
		Conveys recommendations made from affective design study (*F2*)
	Cost (*G*)	GMU purchase cost (*G1*)
		Manufacturing process cost (*G2*)
		Material cost (*G3*)
	Maintenance (*H*)	Hose replacement time (*H1*)
		Bearing replacement time (*H2*)
		Hose burst bearing protection (*H3*)
		GMU replacement time (*H4*)
	Performance (*I*)	May be cleaned / sterilised by CIP / SIP (*I1*)
		Inlet / discharge (*I2*)
		Fluid path (*I3*)
		Load support (*I4*)
		Hose support (*I5*)
		Zero cross contamination (*I6*)
	Quality (*J*)	Surface tolerance requirements (*J1*)
	Safety (*K*)	Disaster-proof design (*K1*)

Table 18 Initial customers' criteria and sub-criteria

	Criteria	Sub-criteria
Customers	**Performance (*L*)**	Continuous max flow (*L1*)
		Flow repeatability (*L2*)
		Load dynamics (*L3*)
		Efficiency (*L4*)
		Discharge pressure (*L5*)
		Occlusions per rev (*L6*)
		May be run dry (*L7*)
		Needs Verderlube (*L8*)
		Flow accuracy (*L9*)
	Reliability (*M*)	Pump head reliability (*M1*)
		GMU reliability (*M2*)
		Hose life (*M3*)

Table 19 Initial marketing departments' criteria and sub-criteria

	Criteria	Sub-criteria
Marketing department	**Customers (*P*)**	Applicable to key functions: dosing/metering, filtering and general fluid transfer (*P1*)
		Potential customers: pharmaceutical and food manufacturers (*P2*)
	Market Constraints (*Q*)	Is easy comparable against other makes of industrial peristaltic pump (*Q1*)
		Market acceptance due to aesthetics (*Q2*)
		Posesses traditional 'hallmarks' of high quality (*Q3*)
	Competition (*R*)	Performance against direct competition such as Bredel, Abaque and Delasco (*R1*)
		Performance against indirect competition such as AOD and PC pumps (*R2*)
	Target product cost (*S*)	Estimated kit purchase cost (*S1*)

5.2.2.2.1. Using controlled convergence method

The controlled convergence method (Pugh, 1991) is used to: 1) identify the criteria or sub-criteria which should be considered because of different assigned symbols to alternatives from each individual stakeholder, 2) remove the criteria or sub-criteria which had the same assigned symbols to facilitate the application of the approach, and 3) to compare the result of the proposed approach with an available method, in terms of how it can provide more information and how it is able to handle the multiple stakeholders between stakeholders. It is assumed when the alternatives are compared with a datum with regard to a criterion or sub-criterion and the assigned symbols to the alternatives are the same, that criterion or sub-criterion can be eliminated because it reflects no difference between alternatives. The result of initial application of controlled convergence method for this problem is summarised in table 20. In this table, criteria and sub-criteria are identified with their symbols which were introduced in tables 17, 18, and 19.

To choose the most appropriate alternative using this method, one can add the numbers of "+" and "-" algebraically as a guidance for selection. Using the summation, the ranking of alternatives are *C*, *B*, and *A*, respectively. Table 21 summarises the results of table 20. As table 21 shows, different stakeholders ranked the alternatives differently.

Table 20 Initial application of controlled convergence method for choosing a pump

			Design's Alternatives			
Stakeholder	**Criteria**	**Sub-criteria**	***A***	***B***	***C***	**Result**
Manufacturing	*D*	*D1*	+	+	+	**1st: *C* 2nd: *B* 3rd: *A***
		D2	+	+	+	
	E	*E1*	0	0	0	
		E2	+	+	+	
		E3	++	++	++	
	F	*F1*	-	+	+	
		F2	0	+	+	
	G	*G1*	+	0	+	
		G2	0	+	++	
		G3	0	+	+	
	H	*H1*	++	+	+	
		H2	-	0	+	
		H3	+	+	0	
		H4	+	++	++	
	I	*I1*	0	+	+	
		I2	+	0	+	
		I3	++	0	-	
		I4	++	+	++	
		I5	++	+	++	
		I6	0	0	+	
	J	*J1*	-	+	+	
	K	*K1*	0	0	+	
	Algebraic sum		**14**	**17**	**23**	
Customers	*L*	*L1*	+	+	++	**1st: *C* 2nd: *A* 3rd: *B***
		L2	+	+	++	
		L3	+	0	0	
		L4	++	++	+	
		L5	+	+	++	
		L6	+	+	+	
		L7	+	+	+	
		L8	++	++	++	
		L9	+	+	+	
	M	*M1*	++	++	+	
		M2	+	0	+	
		M3	0	+	+	
	Algebraic sum		**14**	**13**	**15**	
Marketing	*P*	*P1*	0	+	0	**1st: *B* 2nd: *C* 3rd: A**
		P2	++	++	++	
	Q	*Q1*	-	0	0	
		Q2	-	+	+	
		Q3	+	+	+	
	R	*R1*	+	++	++	
		R2	+	++	+	
	S	*S1*	+	++	++	
	Algebraic sum		**4**	**11**	**9**	

Table 21 The ranking of alternatives from different stakeholders

Stakeholders \ **Alternatives**	**Helical Linear (*A*)**	**Lobe (*B*)**	**Eccentric (*C*)**
Manufacturing	3	2	1
Customers	2	3	1
Marketing	3	1	2
All stakeholders	3	2	1

The results of tables 20 and 21 were obtained by considering initial criteria and sub-criteria. After removing those criteria or sub-criteria which had the same assigned symbols for all alternatives, in order to facilitate the procedure of pairwise comparisons, table 22 emerged with the same results. For example, criteria *D* and *E* with all relevant sub-criteria will be removed. The results of applying controlled convergence method for new categorisation of criteria and sub-criteria indicated that there was no difference between the final rankings. Therefore, the criteria and sub-criteria shown in table 22 are used for further considerations.

Table 22 Secondary application of controlled convergence method for choosing a pump

			Design's Alternatives			
Stakeholder	**Criteria**	**Sub-criteria**	***A***	***B***	***C***	**Result**
Manufacturing	*F*	*F1*	-	+	+	**1st: *C* 2nd: *B* 3rd: *A***
		F2	0	+	+	
	G	*G1*	+	0	+	
		G2	0	+	++	
		G3	0	+	+	
	H	*H1*	++	+	+	
		H2	-	0	+	
		H3	+	+	0	
		H4	+	++	++	
	I	*I1*	0	+	+	
		I2	+	0	+	
		I3	++	0	-	
		I4	++	+	++	
		I5	++	+	++	
		I6	0	0	+	
	J	*J1*	-	+	+	
	K	*K1*	0	0	+	
	Algebraic sum		**9**	**12**	**18**	
Customers	*L*	*L1*	+	+	++	**1st: *C* 2nd: *A* 3rd: *B***
		L2	+	+	++	
		L3	+	0	0	
		L4	++	++	+	
		L5	+	+	++	
	M	*M1*	++	++	+	
		M2	+	0	+	
		M3	0	+	+	
	Algebraic sum		**9**	**8**	**10**	
Marketing	*P*	*P1*	0	+	0	**1st: *B* 2nd: *C* 3rd: *A***
	Q	*Q1*	-	0	0	
		Q2	-	+	+	
	R	*R1*	+	++	++	
		R2	+	++	+	
	S	*S1*	+	++	++	
	Algebraic sum		**1**	**8**	**6**	

The result of table 21 is valid as before. Applying the summation of "+"and "-" algebraically, identifies that the ranking of alternatives have been unchanged. In other words, elimination of these criteria has no effect on alternatives' ranking.

5.2.2.3. Constructing the hierarchies

To use the controlled convergence method, the experts of the company developed a series of criteria and their sub-criteria in a hierarch fashion which has been shown in the tables 17, 18, and 19. To construct the hierarchies from point of view of each individual stakeholder, those hierarchies were used when the company applied the controllod convergence method for making the decision. In other words, the company's experts accepted these hierarchies as a guide for using the methodology suggested in this thesis. After eliminating those criteria or sub-criteria which did not have any impact on the decision (because all of these criteria or sub-criteria performed the same result for any alternative) using controlled convergence method, three new hierarchies were emerged which are shown in the table 22. As can be seen in the figures 22, 23, and 24, each hierarchy has four levels. First level is the aim of the hierarchy which is selection of the most appropriate alternative based on a special view. The second level is the set of criteria that are determined in order to achieve that aim. The third level is the set of sub-criteria that are determined in for each criterion in its above level, and finally the fourth level is the design alternatives.

5.2.3. Using AHP as a stand-alone methodology

The pairwise comparisons were made for every level of hierarchy from the point of view of different stakeholders. It is necessary to make pairwise comparisons between criteria and sub-criteria to obtain their relative importnces. The same procedure is repeated for lower levels, to reach finally the last level, in which alternatives are compared with each other regard to a criterion or sub-criterion.

Removing those criteria or sub-criteria which did not change the outcome of applying controlled convergence method, caused to decrease the number of pairwise comparisons sharply because of the exponential relationship between the number of pairwise comparisons and criteria or sub-criteria. The number of criteria for choosing a peristaltic pump decreased from 14 to 12 and the numbers of sub-criteria decreased from 42 to 31. To make pairwise comparisons, a questionnaire was designed including all redundant questions which were completed by relevant experts in the company.

There was no need to check pairwise comparisons because they satisfied the cut off rule of 10% inconsistency ratio. In addition, there was no need to eliminate some criteria or sub-criteria in this stage because all of the global weights have satisfied the rule of 90%.

5.2.3.1. Obtaining the weights

The final output of application of AHP using Expert Choice software from each individual stakeholder is shown in table 23. These weights represent the final weights of alternatives.

Table 23 The final weights and alternative rankings from viewpoint of stakeholders

Stakeholder	Alternatives		
	A	*B*	*C*
Manufacturing	0.391 (1)	0.295 (3)	0.314 (2)
Customers	0.460 (1)	0.238 (3)	0.302 (2)
Marketing	0.326 (2)	0.399 (1)	0.275 (3)

The meanings of criteria and sub-criteria, such as *F*, *G*, *F1*, *F2*, *G1*, and etc. have been noted in the Appendix B.

The results are different when controlled convergence method is used. One of the reasons is that because controlled convergence method compares each alternative with a datum, a steady state alternative with an ordinal scale, and equal importance for all of the sub-criteria. When alternatives are compared in pairwise manner using ratio scale, the decision maker has a better idea about how well alternatives can satisfy a criterion.

5.2.3.2. Comparison of ranking between stakeholders

As table 23 shows, the outcomes from each stakeholder viewpoint using AHP are different. For example, from the point of view of manufacturing department and customers, the most appropriate alternative is alternative A, while from viewpoint of marketing department it is alternative B. Therefore, it is necessary to aggregate the outcomes.

5.2.4. Aggregation of different outcomes using heuristic methods

Three different stakeholders have produced different ranking and weights. To find out which alternative is the most appropriate alternative, it is necessary to aggregate the obtained weights using the heuristic method based on AHP's final weights and detailed weights.

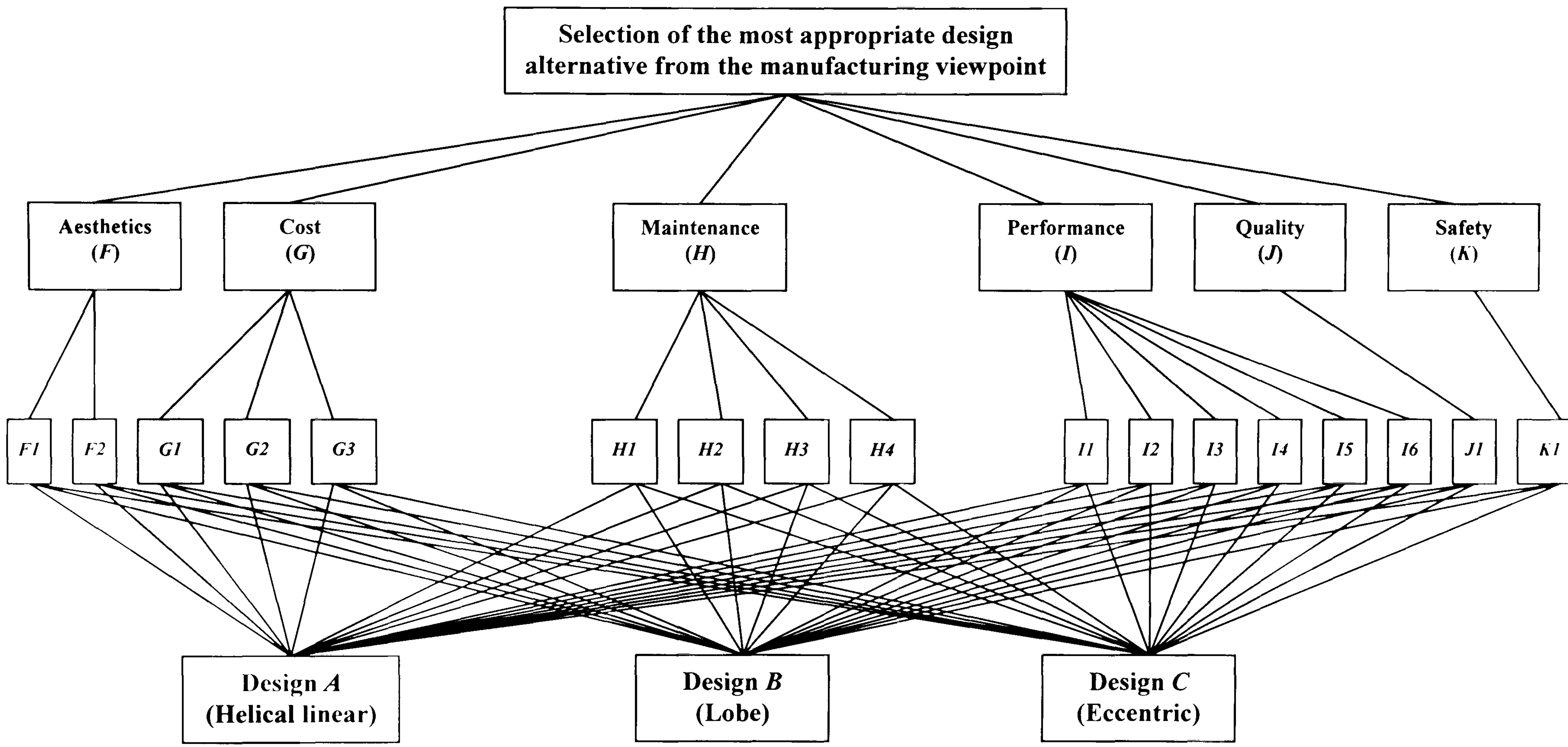

Figure 22 The hierarchy from the manufacturing viewpoint

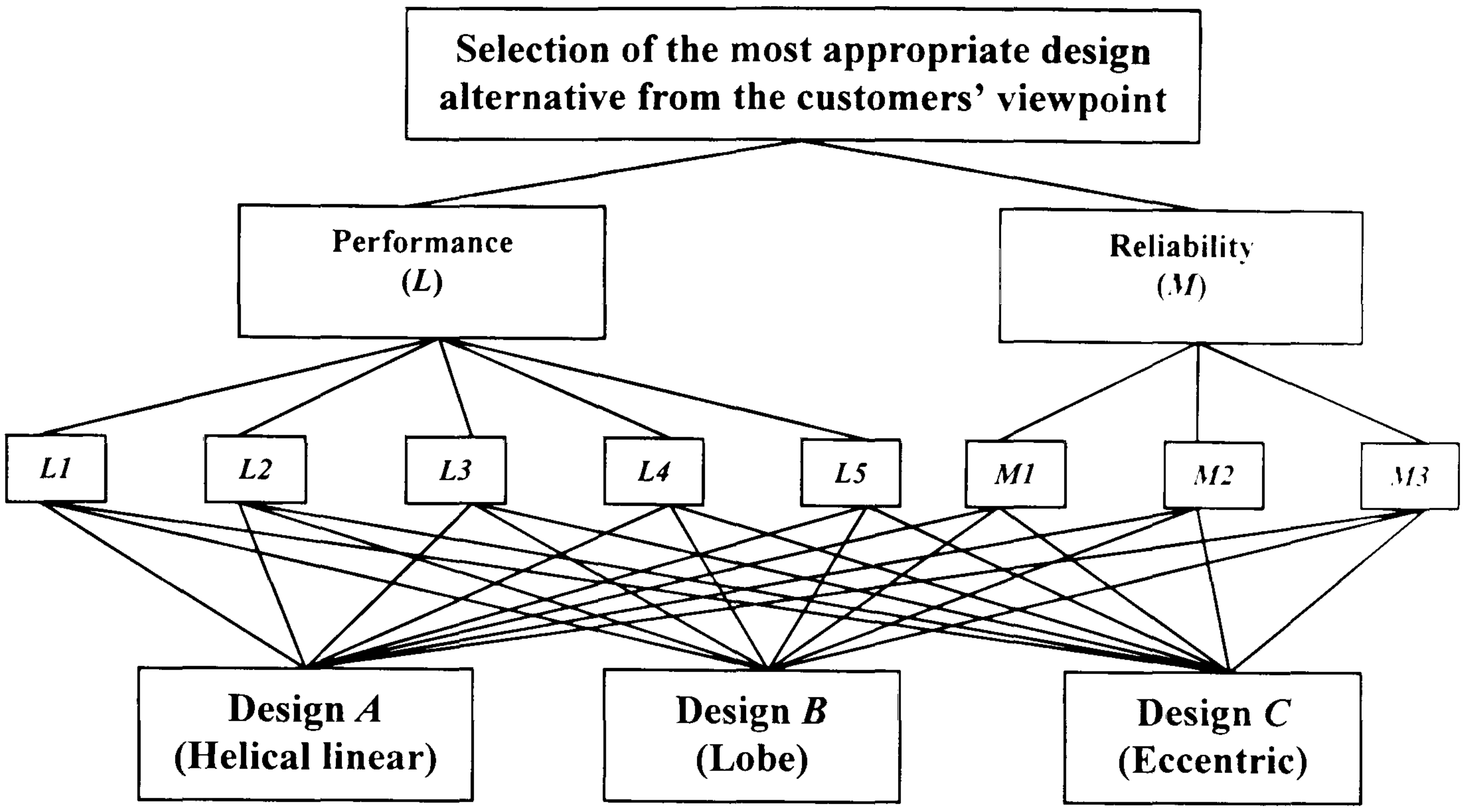

Figure 23 The hierarchy from the customers' viewpoint

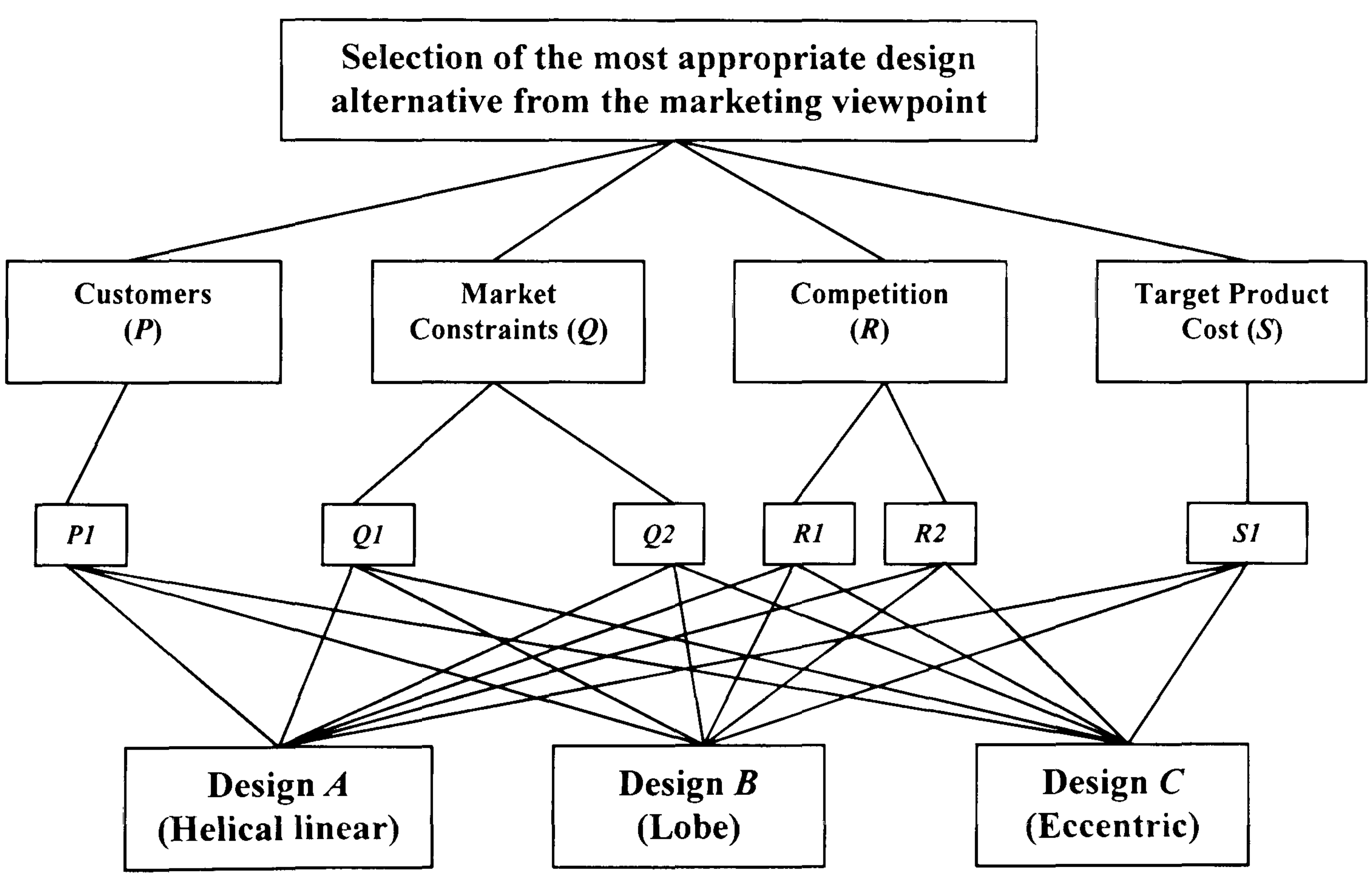

Figure 24 The hierarchy from the marketing viewpoint

5.2.4.1. Aggregation of outcomes based on final weights of AHP

To aggregate the ranking or weights of alternatives based on their final weights, it is necessary to consider a coordinate system with three axes and ideal line in 3-dimension space. Each axis reflects one stakeholder's viewpoint with relevant order of alternatives and cumulative weights placed along the axis. The equation of each line in 3-dimension space can be constructed as $ax + by + cz + d = 0$. The ideal line in this space is as $x = y = z$. This line can be rewritten as $x - 2y + z = 0$. If the coordinate of p_0 point in 3-dimension space is as (x_0, y_0, z_0) then the distance between this point and ideal line is $D = \frac{|x_0 - 2y_0 + z_0|}{\sqrt{6}}$. On the other hand, the distance between origin of coordinate system and the p_0 point is as $\sqrt{x_0^2 + y_0^2 + z_0^2}$.

To use the distance heuristic method, it is necessary to obtain the cumulative weights of alternatives from individual stakeholders. These weights are depicted in table 24.

Table 24 Stakeholders' Cumulative weights

Manufacturing \ Rank	1	2	3
Alternatives	*A*	*C*	*B*
Weights	0.391	0.314	0.295
Cumulative weights	0.391	0.705	1.000
Customers \ Rank	1	2	3
Alternatives	*A*	*C*	*B*
Weights	0.460	0.302	0.238
Cumulative weights	0.460	0.762	1.000
Marketing \ Rank	1	2	3
Alternatives	*B*	*A*	*C*
Weights	0.399	0.326	0.275
Cumulative weights	0.399	0.725	1.000

Based on table 24, the coordinate of each point related to the alternatives are as:

$$A(0.391, 0.460, 0.725), B(1.000, 1.000, 0.399), and\ C(0.705, 0.762, 1.000).$$

The distances between each point, perpendicular line and origin from the coordinate system can be now calculated. The results are as follow.

$$D_A^O + D_A^P = 0.943 + 0.080 = 1.023$$
$$D_B^O + D_B^P = 1.469 + 0.245 = 1.714$$
$$D_C^O + D_C^P = 1.441 + 0.074 = 1.515$$

Therefore, the aggregated ranking when AHP's final weights is used is A, C, and B, respectively. The obtained ranking differs when using controlled convergence method.

5.2.4.2. Aggregation of outcomes based on detailed weights of AHP

This method cannot be used in this case study because there are different hierarchies with different criteria and sub-criteria.

5.2.5. Sensitivity analysis of AHP

The method of making sensitivity analysis depends on the problem and data in hand. For this case study, the sensitivity analysis is made based on the changes of relative importance of criteria and sub-criteria in order to find which of them are important and need to be carefully considered. Because there are three stakeholders, the sensitivity analysis is made for each individual stakeholder. Table 25 indicates the sensitivity analysis of criteria for each individual stakeholder. In this table, when there is a value in the column of "changes to:" indicates that the ranking of alternatives are changed. Percentage of changes column shows which criteria are important. The most important criteria were shown with an asterisk; therefore their relevant pairwise comparisons should be carefully checked.

Table 25 Sensitivity analysis of each individual stakeholder

Stakeholder	Criteria	Current local weight (%)	Changes to:	Percentage of changes
Manufacturing	Aesthetic	7.0	23.3	233.0
	Cost	20.3	81.2	300.0
	Maintenance	9.3	28.7	209.0
	Performance	28.1	-	-
	Quality	13.2	96.0	627.0
	Safety	22.2	7.9	- 64.4 *
Customers	Performance	50.0	14.3	- 71.4 *
	Reliability	50.0	93.9	87.8
Marketing	Customers	29.7	100.0	236.7
	Market constraints	22.5	81.5	262.2
	Competition	10.0	27.5	175.0
	Target product cost	37.7	15.2	- 59.7 *

The same procedure is repeated for sub-criteria. Safety criterion in manufacture stakeholder and target product cost in marketing stakeholder do not have any sub-criterion. Therefore, all of the pairwise comparisons of these criteria need to be checked. Among performance criterion from the viewpoint of customers, L2 and L5 sub-criteria are the most important.

5.2.6. Using the combination of AHP and ZOGP

To use the combination of AHP and ZOGP, it is necessary to follow the steps 6 to 11 in figure 6.

5.2.6.1. Obtaining global and partial weights of criteria or sub-criteria

These weights are obtained using Expert Choice software. Global weights are shown in the objective function of each individual ZOGP model and partial weights are the parameters of intangible constraints. However, there are some other partial weights for tangible criteria that are explained in next section.

5.2.6.2. Eliminations of tangible criteria or sub-criteria partial weights

Tangible criteria or sub-criteria partial weights are removed from further consideration if there are real data for them. For example, typical GMU purchase cost is a tangible criterion which has real data.

5.2.6.3. Considerations of real values for tangible criteria or sub-criteria

After removing the partial weights of tangible criteria or sub-criteria, their real values are considered. For example, typical GMU purchase cost criterion for each alternative is 80, 100, and 80.

5.2.6.4. Normalisations of real values for tangible criteria or sub-criteria

The real values for tangible criteria or sub-criteria are normalised. For example for typical GMU purchase cost, the values of 80, 100, and 80 are normalised as 0.308, 0.384, and 0.308, respectively.

5.2.6.5. Replacement of normalised weights for tangible criteria or sub-criteria

In this step, the normalised values for tangible criteria or sub-criteria are considered instead of their partial weights.

The steps of 5.2.6.2 to 5.2.6.5 are shown in table 26.

Table 26 Real, normalised and aspiration levels of tangible criteria

Tangible criteria \ Alternatives	*A*	*B*	*C*	Aspiration level
Typical GMU purchase cost	£80 (0.308)	£100 (0.384)	£80 (0.308)	£80 (0.308)
Estimated manufacturing process cost	£20 (0.308)	£20 (0.308)	£25 (0.384)	£20 (0.308)
Estimated material cost	£7 (0.250)	£9 (0.321)	£12 (0.429)	£10 (0.357)
Estimated hose replacement time	5 min (0.200)	10 min (0.400)	10 min (0.400)	5 min (0.200)
Estimated bearing replacement time	60 min (0.445)	45 min (0.333)	30 min (0.222)	30 min (0.222)
Estimated GMU replacement time	10 min (0.333)	10 min (0.333)	10 min (0.333)	10 min (0.333)
Continuous maximum flow	1200 l/h (0.286)	1200 l/h (0.286)	1800 l/h (0.428)	1500 l/h (0.357)
Hose life	1 year (0.351)	0.6 year (0.211)	1.25 year (0.438)	2 year (0.702)

5.2.6.6. Establishment of ZOGP models from viewpoint of each individual stakeholder

There are three different stakeholders and therefore, it is necessary to construct three ZOGP models in order to find the most appropriate concept design alternative from the point of view of each individual stakeholder. In these models, A, B, and C are concept design alternatives and deviation variables which measure the distance from target values as recognised by d with indexes of p, c, and m which represent the manufacturing, customers, and marketing viewpoints, respectively. The next section shows these three ZOGP models.

5.2.6.6.1. ZOGP model for manufacturing stakeholder

$$Min\ 0.056\, d_{1p}^{-} + 0.014\, d_{2p}^{-} + 0.087\, d_{3p}^{+} + 0.029\, d_{4p}^{+} + 0.087\, d_{5p}^{+} + 0.023\, d_{6p}^{+} + 0.010\, d_{7p}^{+} + 0.036\, d_{8p}^{-} + 0.025\, d_{9p}^{+} + 0.014\, d_{10p}^{-} + 0.071\, d_{11p}^{-} + 0.019\, d_{12p}^{-} + 0.055\, d_{13p}^{-} + 0.033\, d_{14p}^{-} + 0.089\, d_{15p}^{-} + 0.132\, d_{16p}^{-} + 0.222\, d_{17p}^{-}$$

$s.t.$

$$0.100A + 0.600B + 0.300C + d_{1p}^{-} - d_{1p}^{+} = 0.600 \quad (P-F1)$$
$$0.143A + 0.571B + 0.286C + d_{2p}^{-} - d_{2p}^{+} = 0.571 \quad (P-F2)$$
$$0.308A + 0.384B + 0.308C + d_{3p}^{-} - d_{3p}^{+} = 0.308 \quad (P-G1)$$
$$0.308A + 0.308B + 0.384C + d_{4p}^{-} - d_{4p}^{+} = 0.308 \quad (P-G2)$$
$$0.250A + 0.321B + 0.429C + d_{5p}^{-} - d_{5p}^{+} = 0.357 \quad (P-G3)$$
$$0.200A + 0.400B + 0.400C + d_{6p}^{-} - d_{6p}^{+} = 0.200 \quad (P-H1)$$
$$0.445A + 0.333B + 0.222C + d_{7p}^{-} - d_{7p}^{+} = 0.222 \quad (P-H2)$$
$$0.333A + 0.333B + 0.333C + d_{8p}^{-} - d_{8p}^{+} = 0.333 \quad (P-H3)$$
$$0.333A + 0.333B + 0.333C + d_{9p}^{-} - d_{9p}^{+} = 0.333 \quad (P-H4)$$
$$0.333A + 0.333B + 0.333C + d_{10p}^{-} - d_{10p}^{+} = 0.333 \quad (P-I1)$$
$$0.637A + 0.258B + 0.105C + d_{11p}^{-} - d_{11p}^{+} = 0.637 \quad (P-I2)$$
$$0.637A + 0.105B + 0.258C + d_{12p}^{-} - d_{12p}^{+} = 0.637 \quad (P-I3)$$
$$0.309A + 0.109B + 0.582C + d_{13p}^{-} - d_{13p}^{+} = 0.582 \quad (P-I4)$$
$$0.740A + 0.094B + 0.167C + d_{14p}^{-} - d_{14p}^{+} = 0.740 \quad (P-I5)$$
$$0.333A + 0.333B + 0.333C + d_{15p}^{-} - d_{15p}^{+} = 0.333 \quad (P-I6)$$
$$0.333A + 0.333B + 0.333C + d_{16p}^{-} - d_{16p}^{+} = 0.333 \quad (P-J1)$$
$$0.540A + 0.163B + 0.297C + d_{17p}^{-} - d_{17p}^{+} = 0.540 \quad (P-K1)$$
$$A + B + C = 1$$
$$A, B, C \in (0,1)\ ;\ d_{kp}^{+/-} \geq 0 \quad \forall\ k = 1,2,\ldots,17$$

5.2.6.6.2. ZOGP model for customers stakeholder

$$Min\, 0.052\, d_{1c}^{-} + 0.167\, d_{2c}^{-} + 0.089\, d_{3c}^{-} + 0.042\, d_{4c}^{-} + 0.150\, d_{5c}^{-} + 0.270\, d_{6c}^{-} + 0.148\, d_{7c}^{-} + 0.082\, d_{8c}^{-}$$

$s.t.$

$$0.286A + 0.286B + 0.428C + d_{1c}^{-} - d_{1c}^{+} = 0.357 \quad (C - L1)$$

$$0.297A + 0.163B + 0.540C + d_{2c}^{-} - d_{2c}^{+} = 0.540 \quad (C - L2)$$

$$0.595A + 0.276B + 0.128C + d_{3c}^{-} - d_{3c}^{+} = 0.595 \quad (C - L3)$$

$$0.309A + 0.109B + 0.582C + d_{4c}^{-} - d_{4c}^{+} = 0.582 \quad (C - L4)$$

$$0.637A + 0.258B + 0.105C + d_{5c}^{-} - d_{5c}^{+} = 0.637 \quad (C - L5)$$

$$0.637A + 0.258B + 0.105C + d_{6c}^{-} - d_{6c}^{+} = 0.637 \quad (C - M1)$$

$$0.333A + 0.333B + 0.333C + d_{7c}^{-} - d_{7c}^{+} = 0.333 \quad (C - M2)$$

$$0.351A + 0.211B + 0.438C + d_{8c}^{-} - d_{8c}^{+} = 0.702 \quad (C - M3)$$

$$A + B + C = 1$$

$$A,B,C \in (0,1)\ ;\ d_{kc}^{+/-} \geq 0 \ \ \forall\ k = 1,2,\ldots,8$$

5.2.6.6.3. ZOGP model for marketing stakeholder

$$Min\ 0.297\, d_{1m}^{-} + 0.075\, d_{2m}^{-} + 0.150\, d_{3m}^{-} + 0.067\, d_{4m}^{-} + 0.033\, d_{5m}^{-} + 0.377\, d_{6m}^{+}$$

$s.t.$

$$0.333\,A + 0.333\,B + 0.333\,C + d_{1m}^{-} - d_{1m}^{+} = 0.333 \quad (M - P1)$$

$$0.106\,A + 0.701\,B + 0.193\,C + d_{2m}^{-} - d_{2m}^{+} = 0.701 \quad (M - Q1)$$

$$0.333\,A + 0.333\,B + 0.333\,C + d_{3m}^{-} - d_{3m}^{+} = 0.333 \quad (M - Q2)$$

$$0.444\,A + 0.111\,B + 0.444\,C + d_{4m}^{-} - d_{4m}^{+} = 0.444 \quad (M - R1)$$

$$0.429\,A + 0.143\,B + 0.429\,C + d_{5m}^{-} - d_{5m}^{+} = 0.429 \quad (M - R2)$$

$$0.309\,A + 0.582\,B + 0.109\,C + d_{6m}^{-} - d_{6m}^{+} = 0.109 \quad (M - S1)$$

$$A + B + C = 1$$

$$A,B,C\ \in (0,1)\ ;\ d_{km}^{+/-} \geq 0 \ \ \forall\ k = 1,2,\ldots,6$$

5.2.6.7. Comparison of ranking between stakeholders using AHP-ZOGP

The outcome of the manufacturing model reveals that from this stakeholder viewpoint the ranking of alternatives is A, C, and B, respectively. This outcome is the same as outcome when AHP was used but differ from controlled convergence method. The sensitivity analysis indicates that even with changing the target value of intangible constraints to their second priority of AHP, the outcome will remain unchanged. In other words, the ranking is not sensitive to target values of intangible constraints. The values of deviation variables indicate that with choosing the most appropriate alternative, which of criteria or sub-criteria is satisfied exactly and which of them are underachieved or overachieved. For example, $d_{1p}^{-} = 0.500$ shows that not only $F1$ sub-criterion was not satisfied exactly but also its undesirable distance from target value is 0.500, which means it was underachieved. In other words, choosing alternative A cannot fulfil the requirement of $F1$ sub-criterion.

The outcome of customers' model shows that the ranking of alternatives are A, C, and B, respectively. The outcome differs from outcome obtained by AHP. If the target value of intangible constraints change to second level of AHP's partial weights, the ranking outcome will change to A, B, and C, respectively. This outcome is the same when AHP was used. In fact, the result of using AHP as a stand-alone methodology is the same result when the target value of intangible criteria changes to second level of partial weights. The outcome shows again that some of the criteria experience underachievement or overachievement.

The ranking outcome of marketing model is to select alternatives C, A, and B, respectively. It is interesting that when the target product cost changes not too much, the ranking will not change. In other words, the ranking outcome is not sensitive to insignificant changes of target product cost. If the target product costs increase extensively, the ranking will change as B, C, and A respectively. The summary outcomes of these models are shown in table 27.

Table 27 Summary outcome of individual ZOGP models for pump problem

Ranks	Manufacturing	Customers	Marketing
1	*A*	*A*	*C*
2	*C*	*C*	*A*
3	*B*	*B*	*B*

The outcomes of these models indicate that individual stakeholder created different ranking. These ranking are different even when they are compared with ranking obtained by AHP. One of the reasons for difference between rankings of alternatives between AHP and ZOGP models' ranking is because ZOGP model has this ability to take into account the undesirable and desirable concepts of satisfying the criteria or sub-criteria neglected using the AHP. For example, overachievement of flexibility criterion is a positive concept and it is desirable. AHP does not use this concept. In other words, AHP does not have any device to differ between achieving and non-achieving a criterion or sub-criterion.

5.2.6.8. Aggregation of outcomes based on another ZOGP model

The aggregated model in weighted method is the same as the individual models for each stakeholder unless all the constraints in individual models are put as the constraints consecutively. Its objective function will be as linear additive of individual ZOGP models with an attached weight for each part of objective function. Therefore, it is not necessary to write the aggregated model again.

In the MINIMAX method, the objective function of aggregated model is to minimise the maximum added undesirable variables regard to each individual objective function. The constraints of the model will be as constraints of individual models. Therefore, it is just necessary to write the new objective function. The new objective function can be written as following:

$$Min\{ Max[manufacturing\ objective\ function, customers'\ objective\ function, \\ marketing\ objective\ function] \}$$

The above objective function is a non-linear one but it can be converted to linear one using below transformation (Taha, 1997).

$$\begin{aligned} &Min\ Z \\ &Manufacturing\ objective\ function \leq Z \\ &Customers'\ objective\ function \leq Z \\ &Marketing\ bjective\ function \leq Z \end{aligned}$$

Therefore, the new constraints which should be added to original constraints of the aggregated model can be rewritten as below.

$$\begin{aligned} &0.056\ d_{1p}^{-} + 0.014\ d_{2p}^{-} + 0.087\ d_{3p}^{+} + 0.029\ d_{4p}^{+} + 0.087\ d_{5p}^{+} + 0.023\ d_{6p}^{+} + \\ &0.010\ d_{7p}^{+} + 0.036\ d_{8p}^{-} + 0.025\ d_{9p}^{+} + 0.014\ d_{10p}^{-} + 0.071\ d_{11p}^{-} + 0.019\ d_{12p}^{-} + \\ &0.055\ d_{13p}^{-} + 0.033\ d_{14p}^{-} + 0.089\ d_{15p}^{-} + 0.132\ d_{16p}^{-} + 0.222\ d_{17p}^{-} \leq Z \end{aligned}$$

$$\begin{aligned} &0.052\ d_{1c}^{-} + 0.167\ d_{2c}^{-} + 0.089\ d_{3c}^{-} + 0.042\ d_{4c}^{-} + 0.150\ d_{5c}^{-} + 0.270\ d_{6c}^{-} + \\ &0.148\ d_{7c}^{-} + 0.082\ d_{8c}^{-} \leq Z \end{aligned}$$

$$0.297\ d_{1m}^{-} + 0.075\ d_{2m}^{-} + 0.150\ d_{3m}^{-} + 0.067\ d_{4m}^{-} + 0.033\ d_{5m}^{-} + 0.377\ d_{6m}^{+} \leq Z$$

5.2.6.9. Obtaining single outcome

Both aggregated models generate the same outcome as choosing *A*, *C*, and *B* if the attached weights for weighted methods are equal. The sensitivity analysis of weighted aggregated model shows that if, for example, the attached weight of manufacturing department, customers, and marketing department in objective function changes to 0.20, 0.10, and 0.70, then the outcome is different. In this case, the ranking of alternatives are *C*, *A*, and *B*, respectively. The value of deviation variables can reveal which criteria or sub-criteria are fully satisfied and which of them are underachieving or overachieving.

The results which are submitted to the decision maker(s) can be as table 28. This Table includes different methods which created different results.

Table 28 The results of all methods for choosing a peristaltic pump

Method	Stakeholder	Rank		
		1	2	3
Controlled Convergence Method	Manufacturing	*C*	*B*	*A*
	Customers	*C*	*A*	*B*
	Marketing	*B,C*	*B,C*	*A*
AHP	Manufacturing	*A*	*C*	*B*
	Customers	*A*	*B*	*C*
	Marketing	*B*	*A*	*C*
ZOGP Models	Manufacturing	*A*	*C*	*B*
	Customers	*A*	*C*	*B*
	Marketing	*C*	*A*	*B*
Heuristic distance method for aggregation (final weights)	All	*A*	*B*	*C*
Weighted ZOGP Model for aggregation	All	*A*	*C*	*B*
Weighted MINIMAX ZOGP Model for aggregation	All	*A*	*C*	*B*

5.2.7. Upshot of the peristaltic pump case study

The problem, which involved the selection of a single peristaltic pump design, had the characteristics of the type of problems this approach is intended to support: the number of stakeholders and presence of both tangible and intangible criteria. The problem showed how it is possible to consider many criteria from different stakeholders to yield a single outcome that covers the requirements of the stakeholders as much as possible by aggregation methods.

The problem showed when making a concept design selection decision involving different stakeholders with a diverse range of conflicting criteria, the proposed approach could be a useful decision support tool because it can produce more information compared with current approaches. The information is not only about the underachievement or overachievement of the criteria or sub-criteria but also it can reveal the range of each global weight or the target values of criteria or sub-criteria which retain the current outcome by making sensitivity analysis. In addition, aggregation by ZOGP model has this advantage to reveal the weights of each individual stakeholder that can retain the current outcome of the aggregated model.

5.3. Selection of a swivel joint design

The aims of using this case study are: 1) to show that proposed approach is able to solve an MCDM-MSDM problem with the same hierarchy. 2) to compare the proposed approach with weighted objectives method, 3) to compare the proposed approach with AHP as a stand-alone methodology, 4) to aggregate the AHP outcomes obtained by each stakeholder through heuristics methods using final and detailed weights of AHP, and 5) to indicate that proposed approach provide more useful information for the decision maker(s).

5.3.1. Problem statement summary

The selection of a swivel joint design used in an underwater marine environment as part of a current-metering system among available designs is a problem that has been introduced by Cross (2000). A previous design was considered unsuitable because of its high cost and poor performance.

Three different new designs have been developed by the design department in order to make one of them by manufacturing department. These new designs have been shown in figure 25.

Design *A* Design *B* Design *C*

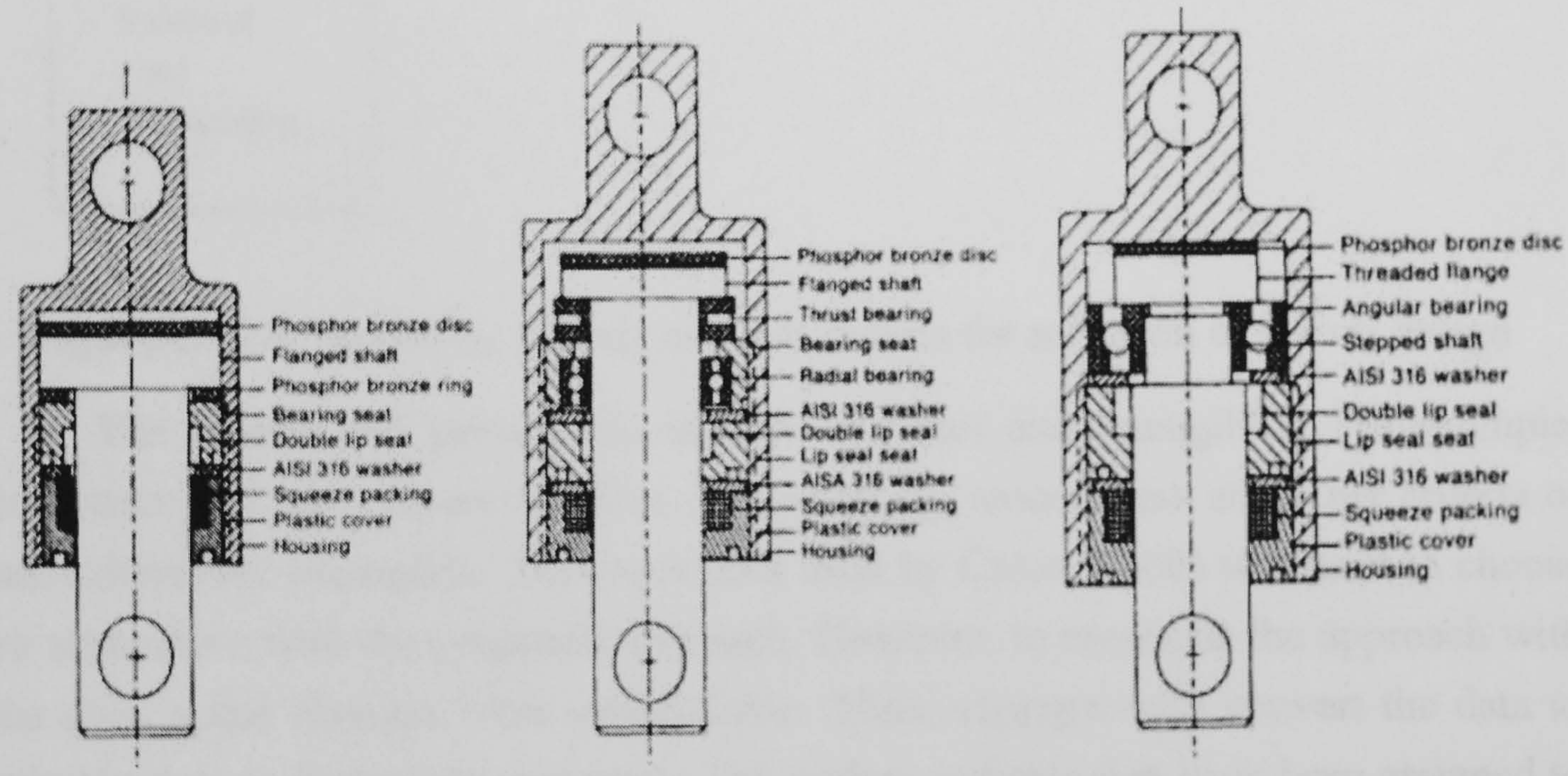

Figure 25 New swivel joint designs for selection

The problem is which of these alternatives should be selected as the most appropriate alternative.

5.3.1.1. Using weighted objective method

The weighted objective method was used to select the most appropriate design alternative (Cross, 2000). To select a concept design alternative, there are different viewpoints, say manufacturing department and marketing department viewpoints that should be considered because they have diverse idea about the relative importance of criteria in the selection process. The criteria for selection are identical for both viewpoints but the relative importance of them is different. The hierarchy, criteria and sub-criteria for selection process are depicted in figure 26.

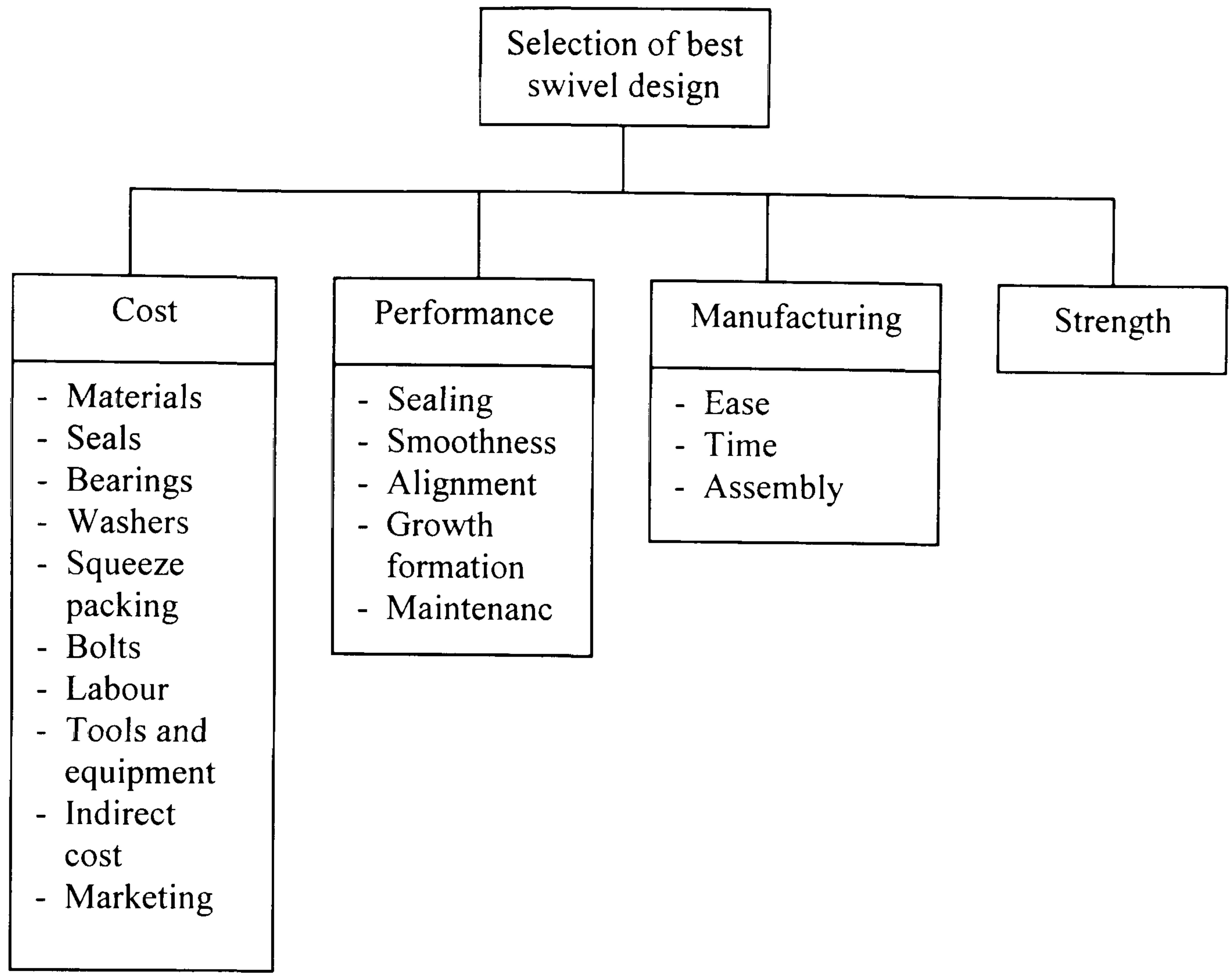

Figure 26 The hierarchy, criteria and sub-criteria for selection of swivel design

The criteria and sub-criteria include tangibles and intangibles. For example, cost, time and strength are tangible, while sealing, smoothness and other criteria or sub-criteria are intangible. The same data used by Cross (2000) was used to choose an alternative with the proposed approach. However, to reconcile the approach with the data, some changes were unavoidable. These changes only convert the data to suitable data to fit into the approach. The various weights that have been assigned to a criteria or sub-criteria based on a 10 score, are some samples that turned into new normalised weights. In addition, it is necessary to compare sub-criteria against each other and against alternatives. Unfortunately, these sorts of data were not available and so, these data are established arbitrarily by making pairwise comparisons. Because there were no real data for the problem at hand, so subjective measurement of tangible criteria or sub-criteria were used in each part of the approach.

Cross (2000) assigned a weight (W) from 1 to 100, and a score of quality (S) of each design (from 1 to 10) to each sub-criterion and then calculates the utility of each sub-criterion (U = $W \times S$). Adding the utility of all of the sub-criteria from a design determines the best alternative. The winning alternative design (C) is that which has a greatest total utility.

5.3.2. Using AHP as a stand-alone methodology

The pairwised comparison is applied from each viewpoint in order to estimate the global and partial weights. In this process, the tangible criteria or sub-criteria are compared with other criteria, sub-criteria, and alternatives subjectively. It means that this process does not consider the real parameters of tangible criteria as they actually exist. Since all criteria or sub-criteria and consistency ratios satisfied the rules of 90% and 10%, the elimination or modification were not necessary.

5.3.2.1. Obtaining the weights

The results from viewpoints of the marketing and manufacturing department are shown in the figure 27 and 28, respectively.

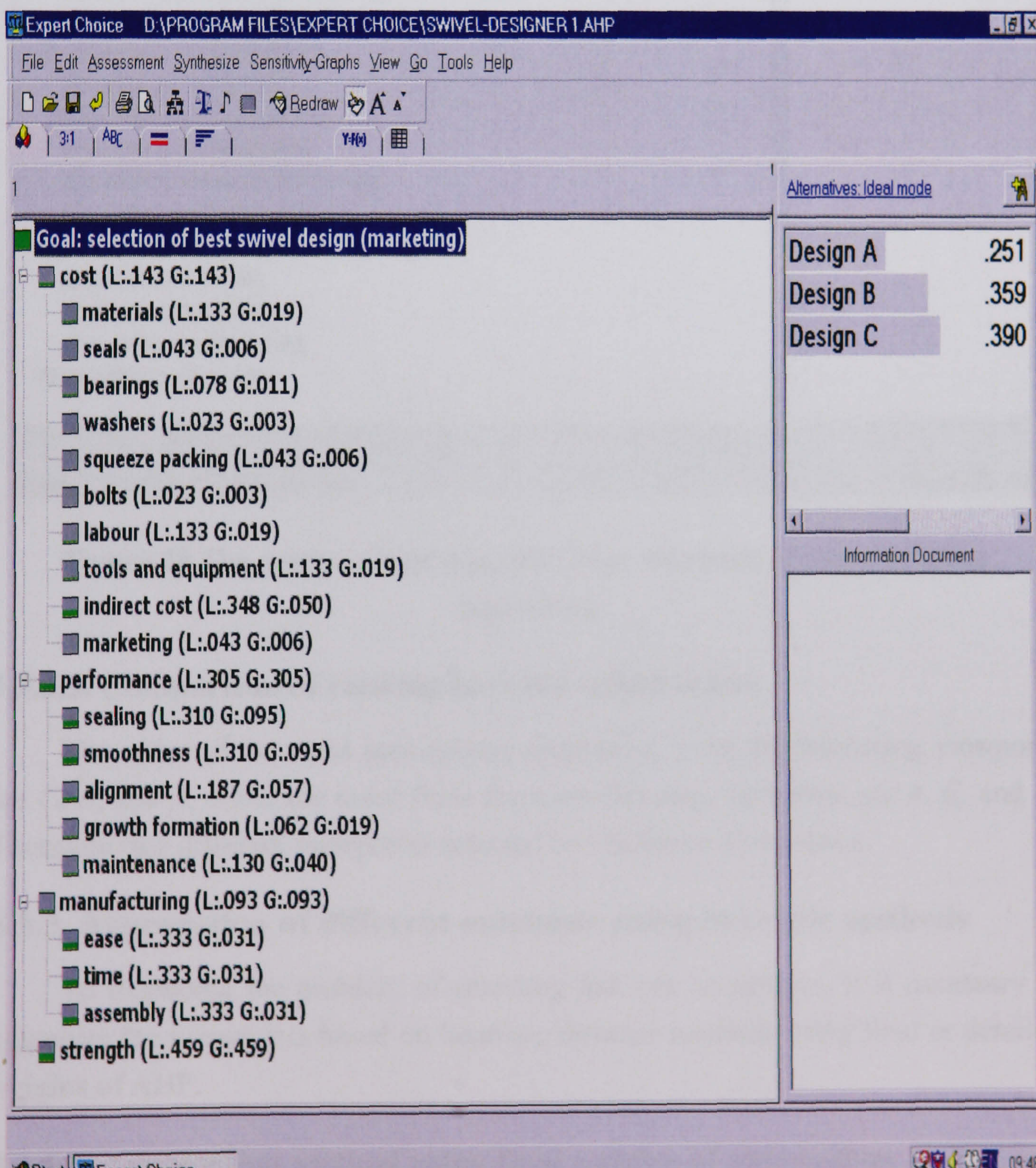

Figure 27 The results of applying AHP from viewpoint of marketing department

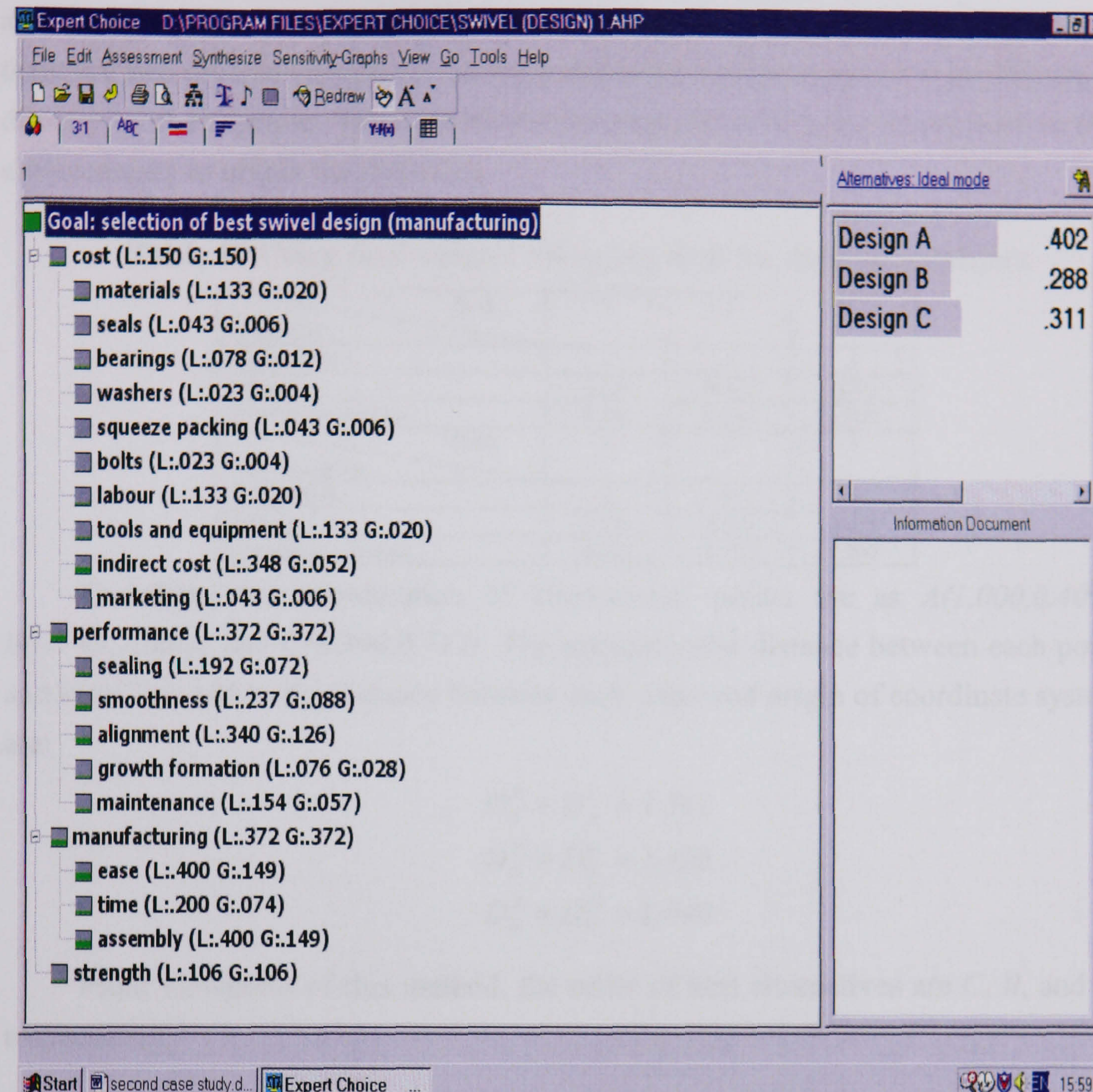

Figure 28 The results of applying AHP from viewpoint of manufacturing department

5.3.2.2. Comparison of ranking between stakeholders

The order of the most appropriate alternatives from the marketing viewpoint are *C*, *B*, and *A*, while the order from the manufacturing viewpoint are *A*, *C*, and *B*. Therefore two different viewpoints selected two different alternatives.

5.3.3. Aggregation of different outcomes using heuristic methods

To overcome the problem of selecting just one alternative, it is necessary to aggregate the viewpoints based on heuristic distance methods using final or detailed weights of AHP.

5.3.3.1. Aggregation method using final weights of alternatives

To use the heuristic methods, it is necessary to determine the perpendicular distance of an alternative's point from an ideal line and the distance of the same alternative's point from the origin of coordinate system. Because in this application, there are two diverse viewpoints, so these distances can be determined graphically or directly by the formula. Table 29 shows the cumulative weights of alternatives that are necessary to obtain the distances.

Table 29 Using final weights for aggregation the different outcomes

Marketing \ Rank	1	2	3
Alternatives	*C*	*B*	*A*
weights	0.390	0.359	0.251
Cumulative weights	0.390	0.749	1.000
Manufacturing \ Rank	1	2	3
Alternatives	*A*	*C*	*B*
Weights	0.402	0.310	0.288
Cumulative weights	0.402	0.712	1.000

Therefore, the coordination of alternatives' points are as *A(1.000,0.402)*, *B(0.749,1.000)*, and *C(0.390,0.712)*. The perpendicular distance between each point and ideal line add to the distance between each point and origin of coordinate system are:

$$D_A^P + D_A^O = 1.501$$
$$D_B^P + D_B^O = 1.426\,.$$
$$D_C^P + D_C^O = 1.040$$

From viewpoint of this method, the order of best alternatives are *C*, *B*, and *A*, respectively.

5.3.3.2. Aggregation method using detailed weights of alternatives

Because the hierarchy, criteria, and sub-criteria are common between stakeholders, the detailed weights aggregation methods can be used to reach a single outcome. Table 30 indicates how this method can be used. In this table, the criterion are introduced with their first letter while their associated sub-criteria are introduced with their first, second, and third letters whichever are appropriate. For example *C* shows the Cost criterion and *CMAT* indicates the sub-criteria of Cost of MATerial.

The next step is to obtain relative effect of each criterion or sub-criterion for an alternative using multiplication of penultimate global weights and their partial weights for each individual stakeholder. These weights can be calculated for other sub-criteria and for other alternatives from both stakeholder viewpoints by multiplication of weights in the sub-criteria column and each individual column of alternatives. The result is shown in table 31.

The penultimate step is to rank the sub-criteria from each stakeholder viewpoint and obtain their cumulative weights. The detail of this step is shown in tables 32 to 37.

Table 30 Global and partial weights of sub-criteria and alternatives

Alternatives			A	B	C	Final weights
Marketing department	C (0.143)	CMAT (0.019)	0.297	0.356	0.347	A (0.251)
		CS (0.006)	0.333	0.333	0.333	B (0.359)
		CB (0.011)	0.421	0.286	0.293	C (0.390)
		CW (0.003)	0.302	0.275	0.423	Final ranking
		CSQ (0.006)	0.333	0.333	0.333	C
		CBO (0.003)	0.432	0.279	0.289	B
		CL (0.019)	0.186	0.452	0.362	A
		CT (0.019)	0.437	0.275	0.288	
		CI (0.050)	0.345	0.322	0.333	
		CMAR (0.006)	0.224	0.358	0.418	
	P (0.305)	PSE (0.095)	0.333	0.333	0.333	
		PSM (0.095)	0.091	0.455	0.455	
		PA (0.057)	0.122	0.320	0.558	
		PG (0.019)	0.333	0.333	0.333	
		PM (0.040)	0.333	0.333	0.333	
	M (0.093)	ME (0.031)	0.550	0.210	0.240	
		MT (0.031)	0.238	0.476	0.286	
		MA (0.031)	0.558	0.122	0.320	
	S (0.459)	SS (0.459)	0.296	0.352	0.352	
Manufacturing department	C (0.150)	CMAT (0.020)	0.297	0.356	0.347	A (0.402)
		CS (0.006)	0.333	0.333	0.333	B (0.288)
		CB (0.012)	0.421	0.286	0.293	C (0.311)
		CW (0.004)	0.302	0.275	0.423	Final ranking
		CSQ (0.006)	0.333	0.333	0.333	A
		CBO (0.004)	0.432	0.279	0.289	C
		CL (0.020)	0.186	0.452	0.362	B
		CT (0.020)	0.437	0.275	0.288	
		CI (0.052)	0.345	0.322	0.333	
		CMAR (0.006)	0.224	0.358	0.418	
	P (0.372)	PSE (0.072)	0.500	0.250	0.250	
		PSM (0.088)	0.140	0.528	0.322	
		PA (0.126)	0.169	0.387	0.444	
		PG (0.028)	0.200	0.400	0.400	
		PM (0.057)	0.500	0.250	0.250	
	M (0.372)	ME (0.149)	0.600	0.200	0.200	
		MT (0.074)	0.238	0.476	0.286	
		MA (0.149)	0.630	0.152	0.218	
	S (0.106)	SS (0.106)	0.296	0.352	0.352	

Table 31 Relative effect of each sub-criterion to choose an alternative

Sub-Criteria	Stakeholders					
	Marketing			Manufacturing		
	A	B	C	A	B	C
CMAT	0.006	0.007	0.007	0.006	0.007	0.007
CS	0.002	0.002	0.002	0.002	0.002	0.002
CB	0.005	0.003	0.003	0.005	0.003	0.004
CW	0.001	0.001	0.001	0.001	0.001	0.002
CSQ	0.002	0.002	0.002	0.004	0.004	0.004
CBO	0.001	0.001	0.001	0.002	0.001	0.001
CL	0.004	0.009	0.007	0.004	0.009	0.007
CT	0.008	0.005	0.005	0.009	0.006	0.006
CI	0.017	0.016	0.017	0.018	0.017	0.017
CMAR	0.001	0.002	0.003	0.001	0.002	0.003
PSE	0.032	0.032	0.032	0.036	0.018	0.018
PSM	0.009	0.043	0.043	0.012	0.046	0.028
PA	0.007	0.018	0.032	0.021	0.049	0.056
PG	0.006	0.006	0.006	0.006	0.011	0.011
PM	0.013	0.013	0.013	0.029	0.014	0.014
ME	0.017	0.007	0.007	0.089	0.030	0.030
MT	0.007	0.015	0.009	0.018	0.035	0.021
MA	0.017	0.004	0.010	0.094	0.023	0.032
SS	0.136	0.162	0.162	0.031	0.037	0.037

Table 32 Cumulative weights for alternative *A* based on sub-criteria ranking

Stakeholder	Marketing			Manufacturing		
	Rank	Weight	Cumulative weight	Rank	Weight	Cumulative weight
Sub-criteria	*SS*	0.136	0.136	*MA*	0.094	0.094
	PSE	0.032	0.168	*ME*	0.089	0.183
	CI	0.017	0.185	*PSE*	0.036	0.219
	ME	0.017	0.202	*SS*	0.031	0.250
	MA	0.017	0.219	*PM*	0.029	0.279
	PM	0.013	0.232	*PA*	0.021	0.300
	PSM	0.009	0.241	*CI*	0.018	0.318
	CT	0.008	0.249	*MT*	0.018	0.336
	PA	0.007	0.256	*PSM*	0.012	0.348
	MT	0.007	0.263	*CT*	0.009	0.357
	CMAT	0.006	0.269	*CMAT*	0.006	0.363
	PG	0.006	0.275	*PG*	0.006	0.369
	CB	0.005	0.280	*CB*	0.005	0.374
	CL	0.004	0.284	*CSQ*	0.004	0.378
	CS	0.002	0.286	*CL*	0.004	0.382
	CSQ	0.002	0.288	*CS*	0.002	0.384
	CW	0.001	0.289	*CBO*	0.002	0.386
	CBO	0.001	0.290	*CW*	0.001	0.387
	CMAR	0.001	0.291	*CMAR*	0.001	0.388

Table 33 The coordination of each point and absolute differences' summation for alternative *A*

Sub-criterion	Marketing	Manufacturing	Absolute difference
CMAT	0.269	0.363	0.094
CS	0.286	0.384	0.098
CB	0.280	0.374	0.094
CW	0.289	0.387	0.098
CSQ	0.288	0.378	0.090
CBO	0.290	0.386	0.096
CL	0.284	0.382	0.098
CT	0.249	0.357	0.108
CI	0.185	0.318	0.133
CMAR	0.291	0.388	0.097
PSE	0.168	0.219	0.051
PSM	0.241	0.348	0.107
PA	0.256	0.300	0.044
PG	0.275	0.369	0.094
PM	0.232	0.279	0.047
ME	0.202	0.183	0.019
MT	0.263	0.336	0.073
MA	0.219	0.094	0.125
SS	0.136	0.250	0.114
Summation of absolute differences			1.680

Table 34 Cumulative weights for alternative *B* based on sub-criteria ranking

Stakeholder	Marketing			Manufacturing		
	Rank	Weight	Cumulative weight	Rank	Weight	Cumulative weight
Sub-criteria	*SS*	0.162	0.162	*PA*	0.049	0.049
	PSM	0.043	0.205	*PSM*	0.046	0.095
	PSE	0.032	0.237	*SS*	0.037	0.132
	PA	0.018	0.255	*MT*	0.035	0.167
	CI	0.016	0.271	*ME*	0.030	0.197
	MT	0.015	0.286	*MA*	0.023	0.220
	PM	0.013	0.299	*PSE*	0.018	0.238
	CL	0.009	0.308	*CI*	0.017	0.255
	CMAT	0.007	0.315	*PM*	0.014	0.269
	ME	0.007	0.322	*PG*	0.011	0.280
	PG	0.006	0.328	*CL*	0.009	0.289
	CT	0.005	0.333	*CMAT*	0.007	0.296
	MA	0.004	0.337	*CT*	0.006	0.302
	CB	0.003	0.340	*CSQ*	0.004	0.306
	CS	0.002	0.342	*CB*	0.003	0.309
	CSQ	0.002	0.344	*CS*	0.002	0.311
	CMAR	0.002	0.346	*CMAR*	0.002	0.313
	CW	0.001	0.347	*CW*	0.001	0.314
	CBO	0.001	0.348	*CBO*	0.001	0.315

Table 35 The coordination of each point and absolute differences' summation for alternative *B*

Sub-criterion	Marketing	Manufacturing	Absolute difference
CMAT	0.315	0.296	0.019
CS	0.342	0.311	0.031
CB	0.340	0.309	0.031
CW	0.347	0.314	0.033
CSQ	0.344	0.306	0.038
CBO	0.348	0.315	0.033
CL	0.308	0.289	0.019
CT	0.333	0.302	0.031
CI	0.271	0.255	0.016
CMAR	0.346	0.313	0.033
PSE	0.237	0.238	0.001
PSM	0.205	0.095	0.110
PA	0.255	0.049	0.206
PG	0.328	0.280	0.048
PM	0.299	0.269	0.030
ME	0.322	0.197	0.125
MT	0.286	0.167	0.119
MA	0.337	0.220	0.117
SS	0.162	0.132	0.030
Summation of absolute differences			1.070

Table 36 Cumulative weights for alternative *C* based on sub-criteria ranking

Stakeholder	Marketing			Manufacturing		
	Rank	Weight	Cumulative weight	Rank	Weight	Cumulative weight
Sub-criteria	*SS*	0.162	0.162	*PA*	0.056	0.056
	PSM	0.063	0.225	*SS*	0.037	0.093
	PSE	0.032	0.257	*MA*	0.032	0.125
	PA	0.032	0.289	*ME*	0.030	0.155
	CI	0.017	0.306	*PSM*	0.028	0.183
	PM	0.013	0.319	*MT*	0.021	0.204
	MA	0.010	0.329	*PSE*	0.018	0.222
	MT	0.009	0.338	*CI*	0.017	0.239
	CMAT	0.007	0.345	*PM*	0.014	0.253
	CL	0.007	0.352	*PG*	0.011	0.264
	ME	0.007	0.359	*CMAT*	0.007	0.271
	PG	0.006	0.365	*CL*	0.007	0.278
	CT	0.005	0.370	*CT*	0.006	0.284
	CB	0.003	0.373	*CB*	0.004	0.288
	CMAR	0.003	0.376	*CSQ*	0.004	0.292
	CS	0.002	0.378	*CMAR*	0.003	0.295
	CSQ	0.002	0.380	*CS*	0.002	0.297
	CW	0.001	0.381	*CW*	0.002	0.299
	CBO	0.001	0.382	*CBO*	0.001	0.300

Table 37 The coordination of each point and absolute differences' summation for alternative *C*

Sub-criterion	Marketing	Manufacturing	Absolute difference
CMAT	0.345	0.271	0.074
CS	0.378	0.297	0.081
CB	0.373	0.288	0.085
CW	0.381	0.299	0.082
CSQ	0.380	0.292	0.088
CBO	0.382	0.300	0.082
CL	0.352	0.278	0.074
CT	0.370	0.284	0.086
CI	0.306	0.239	0.067
CMAR	0.376	0.295	0.081
PSE	0.257	0.222	0.035
PSM	0.225	0.183	0.042
PA	0.289	0.056	0.233
PG	0.365	0.264	0.101
PM	0.319	0.253	0.066
ME	0.359	0.155	0.204
MT	0.338	0.204	0.134
MA	0.329	0.125	0.204
SS	0.162	0.093	0.069
Summation of absolute differences			1.888

The ranking of alternatives using this heuristic method are as *B*, *A*, and *C*, respectively.

5.3.4. Sensitivity analysis

Sensitivity analysis of using AHP alone shows that strength criterion is the most important one, which its pairwised comparison against other criteria and against the alternatives should be carefully considered and checked.

5.3.5. Combination of AHP and ZOGP

To use the combination of AHP and ZOGP, it is necessary to follow steps 6 to 11 in figure 6.

5.3.5.1. Obtaining global and partial weights of criteria or sub-criteria

These weights are obtained using Expert Choice software. Global weights are shown in the objective function of each individual ZOGP model and partial weights are the parameters of intangible constraints. However, there are some other partial weights for tangible criteria which are explained in the next section. Partial weights of intangible criteria are shown in table 38.

Table 38 The intangible data (obtained from AHP)

Viewpoints / Intangible Factors	Marketing			Manufacturing		
	Designs			Designs		
	A	*B*	*C*	*A*	*B*	*C*
Sealing	0.333	0.333	0.333	0.500	0.250	0.250
Smoothness	0.091	0.455	0.455	0.140	0.528	0.332
Alignment	0.122	0.320	0.558	0.169	0.387	0.444
Growth formation	0.333	0.333	0.333	0.200	0.400	0.400
Maintenance	0.333	0.333	0.333	0.500	0.250	0.250
Ease	0.550	0.210	0.240	0.600	0.200	0.200
Assembly	0.558	0.122	0.320	0.630	0.152	0.218

5.3.5.2. Eliminations of tangible criteria or sub-criteria partial weights

Tangible criteria or sub-criteria partial weights are removed from further consideration if there are real data for them.

5.3.5.3. Considerations of real values for tangible's criteria or sub-criteria

After removing the partial weights of tangible criteria or sub-criteria, their real values are considered.

5.3.5.4. Normalisations of real values for tangible criteria or sub-criteria

In this step, the real values for tangible criteria or sub-criteria are normalised. These data are shown in table 39. It is necessary to remind that the full costs of alternatives are available, not every part of them. So the full costs of alternatives are used to construct the model rather than use the partial cost of each part.

Table 39 The tangible data for problem

Tangible Criteria \ Designs	*A*	*B*	*C*	Ideal availability of resources
Cost	0.250	0.300	0.450	0.350
Manufacturing Time	0.238	0.476	0.286	0.300
Strength	0.296	0.352	0.352	0.350

5.3.5.5. Replacement of normalised weights for tangible criteria or sub-criteria

In this step, the normalised values for tangible criteria or sub-criteria are considered instead of their partial weights.

5.3.6. Establishment of ZOGP models from viewpoint of each individual stakeholder

First, a model from the viewpoint of the marketing department is made. Then this process is repeated to make another model from the viewpoint of manufacturing department. If the outcomes of these two models are not identical, the models will be aggregated in order to obtain a unique model and therefore a single outcome.

The index of 1 and 2 in the deviation variables describe the marketing view and manufacturing view, respectively. *A*, *B*, and *C* are the binary variables.

5.3.6.1. Marketing department model and its sensitivity analysis

The model has been shown below. The coefficients of the objective function for cost and strength criteria are global weights when using AHP; for others they are the global weights of each sub-criterion. Solving the model shows that the order of alternatives is *C*, *B*, and *A*.

$$Min\ 0.143\, d^{+}_{1co} + 0.095\, d^{-}_{1se} + 0.095\, d^{-}_{1sm} + 0.057\, d^{-}_{1al} + 0.019\, d^{-}_{1gr} + 0.040\, d^{-}_{1ma} +$$
$$0.031\, d^{-}_{1ea} + 0.031\, d^{+}_{1ti} + 0.031\, d^{-}_{1as} + 0.459\, d^{-}_{1st}$$

$s.t.$

$$0.250\, A + 0.300\, B + 0.450\, C + d^{-}_{1co} - d^{+}_{1co} = 0.350 \quad \text{(cost - tangible)}$$
$$0.333\, A + 0.333\, B + 0.333\, C + d^{-}_{1se} - d^{+}_{1se} = 0.333 \quad \text{(sealing - intangible)}$$
$$0.091\, A + 0.455\, B + 0.455\, C + d^{-}_{1sm} - d^{+}_{1sm} = 0.455 \quad \text{(smoothnes s - intangible)}$$
$$0.122\, A + 0.320\, B + 0.558\, C + d^{-}_{1al} - d^{+}_{1al} = 0.588 \quad \text{(alignment - intangible)}$$
$$0.333\, A + 0.333\, B + 0.333\, C + d^{-}_{1gr} - d^{+}_{1gr} = 0.333 \quad \text{(growth formation - intangible)}$$
$$0.333\, A + 0.333\, B + 0.333\, C + d^{-}_{1ma} - d^{+}_{1ma} = 0.333 \quad \text{(maintenan ce - intangible)}$$
$$0.550\, A + 0.210\, B + 0.240\, C + d^{-}_{1ea} - d^{+}_{1ea} = 0.550 \quad \text{(ease - intangible)}$$
$$0.238\, A + 0.476\, B + 0.286\, C + d^{-}_{1ti} - d^{+}_{1ti} = 0.300 \quad \text{(time - tangible)}$$
$$0.558\, A + 0.122\, B + 0.320\, C + d^{-}_{1as} - d^{+}_{1as} = 0.558 \quad \text{(assembly - intangible)}$$
$$0.296\, A + 0.352\, B + 0.352\, C + d^{-}_{1st} - d^{+}_{1st} = 0.350 \quad \text{(strength - tangible)}$$
$$A + B + C = 1$$
$$A, B, C \in (0,1)\ ;\ d^{+,-}_{1k} \geq 0\ \forall\ all\ k$$

If, for example, the relative importance of the cost criterion increased by 0.200 and at the same time, the relative importance of strength criterion decreased by 0.200, then the best orders of alternatives change as *B*, *C*, and *A* respectively. Now, assume that the previous changes have occured and the target value of cost criterion increased by 0.050, i.e., from 0.350 to 0.400. In this case, the best orders will be again as *C*, *B*, and *A*. In fact, the parametric sensitivity analysis can be applied in order to recognise which factors are more important than others to change the current outcome. In addition, the values of deviation variables can be used for determining what percentages of each criterion with regard to its target values have been attained. In other words, the underachievement and overachievement of a specified criterion can be recognised. Usually this information is not available when AHP is used as a stand-alone approach.

5.3.6.2. Manufacturing department model and its sensitivity analysis

$$Min\ 0.150d^{+}_{2co}+0.072d^{-}_{2se}+0.088d^{-}_{2sm}+0.126d^{-}_{2al}+0.028d^{-}_{2gr}+0.057d^{-}_{2ma}+0.149d^{-}_{2ea}+$$
$$0.074d^{+}_{2ti}+0.149d^{-}_{2as}+0.106d^{-}_{2st}$$

$s.t.$

$$0.250A+0.300B+0.450C+d^{-}_{2co}-d^{+}_{2co}=0.350 \quad \text{(cost-tangible)}$$
$$0.500A+0.250B+0.250C+d^{-}_{2se}-d^{+}_{2se}=0.500 \quad \text{(sealing-intangible)}$$
$$0.140A+0.528B+0.332C+d^{-}_{2sm}-d^{+}_{2sm}=0.528 \quad \text{(smoothnes-intangible)}$$
$$0.169A+0.387B+0.444C+d^{-}_{2al}-d^{+}_{2al}=0.444 \quad \text{(alignment-intangible)}$$
$$0.200A+0.400B+0.400C+d^{-}_{2gr}-d^{+}_{2gr}=0.400 \quad \text{(growthformation-intangible)}$$
$$0.500A+0.250B+0.250C+d^{-}_{2ma}-d^{+}_{2ma}=0.500 \quad \text{(maintenance-intangible)}$$
$$0.600A+0.200B+0.200C+d^{-}_{2ea}-d^{+}_{2ea}=0.600 \quad \text{(ease-intangible)}$$
$$0.238A+0.476B+0.286C+d^{-}_{2ti}-d^{+}_{2ti}=0.300 \quad \text{(time-tangible)}$$
$$0.630A+0.152B+0.218C+d^{-}_{2as}-d^{+}_{2as}=0.630 \quad \text{(assembly-intangible)}$$
$$0.296A+0.352B+0.352C+d^{-}_{2st}-d^{+}_{2st}=0.350 \quad \text{(strength-tangible)}$$
$$A+B+C=1$$
$$A,B,C\in(0,1)\ ;\ d^{+,-}_{2k}\geq 0\ \ \forall allk$$

Outcome of this model depicts that the order of alternatives are *A*, *B*, and *C*. This outcome is identical with applying the AHP from viewpoint of manufacturing department. If the cost criterion coefficient decrease by 0.050 and assembly relative importance increase by 0.050, then the best orders will be *A*, *C*, and *B* respectively. When these changes happen individually, the orders of alternatives remain unchanged. In fact, the simultaneous changes will cause orders to be changed.

5.3.7. Comparison of ranking between stakeholders

Different stakeholders have chosen different alternatives when individual ZOGP models were used. The summary of the outcomes of ZOGP models are shown in table 40.

Table 40 Ranking of alternatives using individual ZOGP models

Stakeholders	Alternatives		
	A	*B*	*C*
Marketing	Third	Second	First
Manufacturing	First	Second	Third

5.3.8. Aggregation of viewpoints based on another ZOGP model

The outcome of individual models from the point of view of the marketing and manufacturing departments show that from each viewpoint, the outcome alternatives are different. In order to obtaining a single outcome, it is necessary to aggregate individual ZOGP models.

5.3.8.1. Aggregated model using weighted method

The objective function's aggregated model is the weighted linear additive of individual objective functions. The constraints of individual models are put consecutively in the aggregated model. The outcome of the aggregated model, if the weights of both stakeholders are alike ($w^1 = w^2$), is A, C, and B. It is interesting that this order does not accord with the outcomes of individual models. That shows satisfying the criteria of two stakeholders simultaneously can create another outcome. If the weight of marketing and manufacturing stakeholders are 62% and 38%, respectively, then the best order of alternatives will be as A, C, and B. If these values change to 62.5% and 37.5%, respectively, then the order of alternatives will be changed as C, A, and B. In fact, a range of weights have been created for decision making. If the decision maker(s) gives more than 62.5% importance to marketing department in comparison with manufacturing department, then the best alternative is C; otherwise the best alternative will be A.

5.3.8.2. Aggregated model using MINIMAX method

The objective function of MINIMAX method, as previously mentioned, is non-linear. The non-linear objective function is converted to linear one using appropriate transformation discussed in Chapter 4. The aggregated model is as follows:

$Min\, Z$

Subject to

$$0.143d_{1co}^{+} + 0.095d_{1se}^{-} + 0.095d_{1sm}^{-} + 0.057d_{1al}^{-} + 0.019d_{1gr}^{-} + 0.040d_{1ma}^{-} + 0.031d_{1ea}^{-} +$$
$$0.031d_{1ti}^{+} + 0.031d_{1as}^{-} + 0.459d_{1st}^{-} \leq Z$$
$$0.150d_{2co}^{+} + 0.072d_{2se}^{-} + 0.088d_{2sm}^{-} + 0.126d_{2al}^{-} + 0.028d_{2gr}^{-} + 0.057d_{2ma}^{-} + 0.149d_{2ea}^{-} +$$
$$0.074d_{2ti}^{+} + 0.149d_{2as}^{-} + 0.106d_{2st}^{-} \leq Z$$

Other constraints

The order of alternatives is *A*, *B*, and *C*. Choosing alternative *A* will cause to maximum discrepancies between the individual objective functions to be minimised.

5.3.9. Comparison of methods for this case study

Table 41 illustrates the different outcomes can be obtained when there are different stakeholders using different methods for aggregation. All this information along with the overachievement and underachievement of criteria leave the final decision to the decision maker(s).

Table 41 Comparison between different methods

Method \ Orders	First	Second	Third
AHP (Marketing)	*C*	*B*	*A*
AHP (Manufacturing)	*A*	*B*	*C*
AHP Final weights aggregation	*C*	*B*	*A*
AHP detailed weight aggregation	*B*	*A*	*C*
Marketing ZOGP model	*C*	*B*	*A*
Manufacturing ZOGP model	*A*	*B*	*C*
Weighted aggregation ZOGP model	*A*	*C*	*B*
MINIMAX aggregation ZOGP model	*A*	*B*	*C*

5.3.10. Upshot of the swivel joint case study

The case study indicated that using AHP as a stand-alone methodology is insufficient to create a single outcome in the presence of multiple stakeholders. However, the information obtained by AHP was applied to heuristics methods to generate a single outcome. Aggregation by detailed weights of AHP is preferred to its final weights because detailed weights carry more information about the problem with the same hierarchy. Nevertheless, aggregation by final weights of AHP is a useful method when stakeholders construct different hierarchies with their components.

The application presented in this section has illustrated how an MCDM-MSDM problem can be solved by combining AHP and ZOGP. AHP-ZOGP approach permits a more flexible and inclusive use of available data about design selection decision. This case study illustrated how the AHP weightings can be combined into a ZOGP model to include tangible and intangible constraints in the design selection process.

This case study also showed how ZOGP models can minimise the dispersions between final selected alternative and the ideal alternative when alternatives compare to all of the criteria or sub-criteria. Sensitivity analysis for ZOGP models could provide straightforward information about the range of the objective function coefficients (global weights of AHP) and right-hand sides of constraints (target values) to retain the current outcome unchanged. In addition, aggregation by ZOGP model had the advantage of knowing with what range of each stakeholder weight, the current outcome will change.

5.4. Justification of advanced manufacturing systems

The aims of using this case study are: 1) to show that proposed approach is able to solve an MCDM problem with just one stakeholder, 2) remove the drawback(s) of AHP method when it is used as a stand-alone methodology, and 3) providing more useful information for decision maker(s) compared with other available methods.

For this purpose, problem of justification of Advance Manufacturing Systems (AMS) which has been previously solved by AHP method is considered (Datta et al., 1992). The reasons for choosing that problem are:

1- No need to construct a hierarchy,
2- No need to find criteria,
3- No need to make pairwise comparisons,
4- No need to solve the problem by AHP,
5- Ready to use all weights related to intangible criteria which are necessary for using the approach.

In next section, a brief definition of the problem is given. Then the problem will be solved using the proposed approach. Finally a comparison will be made between using AHP as a stand-alone methodology and the proposed approach.

5.4.1. Problem statement summary

Advanced Manufacturing Systems (AMS) affect many activities inside an organisation such as product design, assembly, material handling, quality control, etc. (Datta et al., 1992). Decision making on selection of an appropriate AMS is a complex task due to the following:

1- Involving very high initial investment of capital,

2- Taking long time to make the system fully operational,

3- Misunderstanding of cost patterns for cost estimation and pricing policies for innovative products,

4- Presence of intangible benefits that cannot be fully transferable to monetary values,

5- Limitation of capital,

6- No expectation to obtain benefits in the short-term.

The above factors necessitate applying MCDM approach for analysing the problem because traditional financial methods are not able to include the intangible benefits associated with AMS. In addition, the status-quo alternative cannot be available because the nature of AMS justification is to increase the market share. It should be remembered because this problem has just a single stakeholder, thus it is not necessary to use the methods for aggregating the outcomes.

5.4.1.1. Solving the problem using AHP alone

This problem has been solved using AHP as a stand-alone approach by Datta et al. (1992). All the criteria and pairwise comparisons have satisfied their associated rules. The hierarchy, criteria, alternatives, relative importance of criteria, and final weights of alternatives have been depicted in figure 29. The numbers inside the brackets indicate the relative importance of criteria and alternatives. Applying AHP indicates that the ranking of alternatives are *FMS*, *TL*, *FMC*, *FMM*, and *JS*, respectively. The interested readers are referred to the reference for full description of criteria and alternatives.

5.4.1.2. Combination of AHP and ZOGP

To solve the problem using the combination of AHP and ZOGP, it is necessary to construct the constraints and objective function of the ZOGP model. The alternatives should be evaluated by pairwise comparison against a criterion in order to obtain the partial weights which will form the parameters of constraints in ZOGP model. In other words, the winner alternative can be determined from point of view of each criterion by the relative importance of available alternatives. These partial weights can be found in the original paper in table 4 at page 230 (Datta et al., 1992). To construct the objective function, the weighted method is used to solve the problem based on the proposed approach.

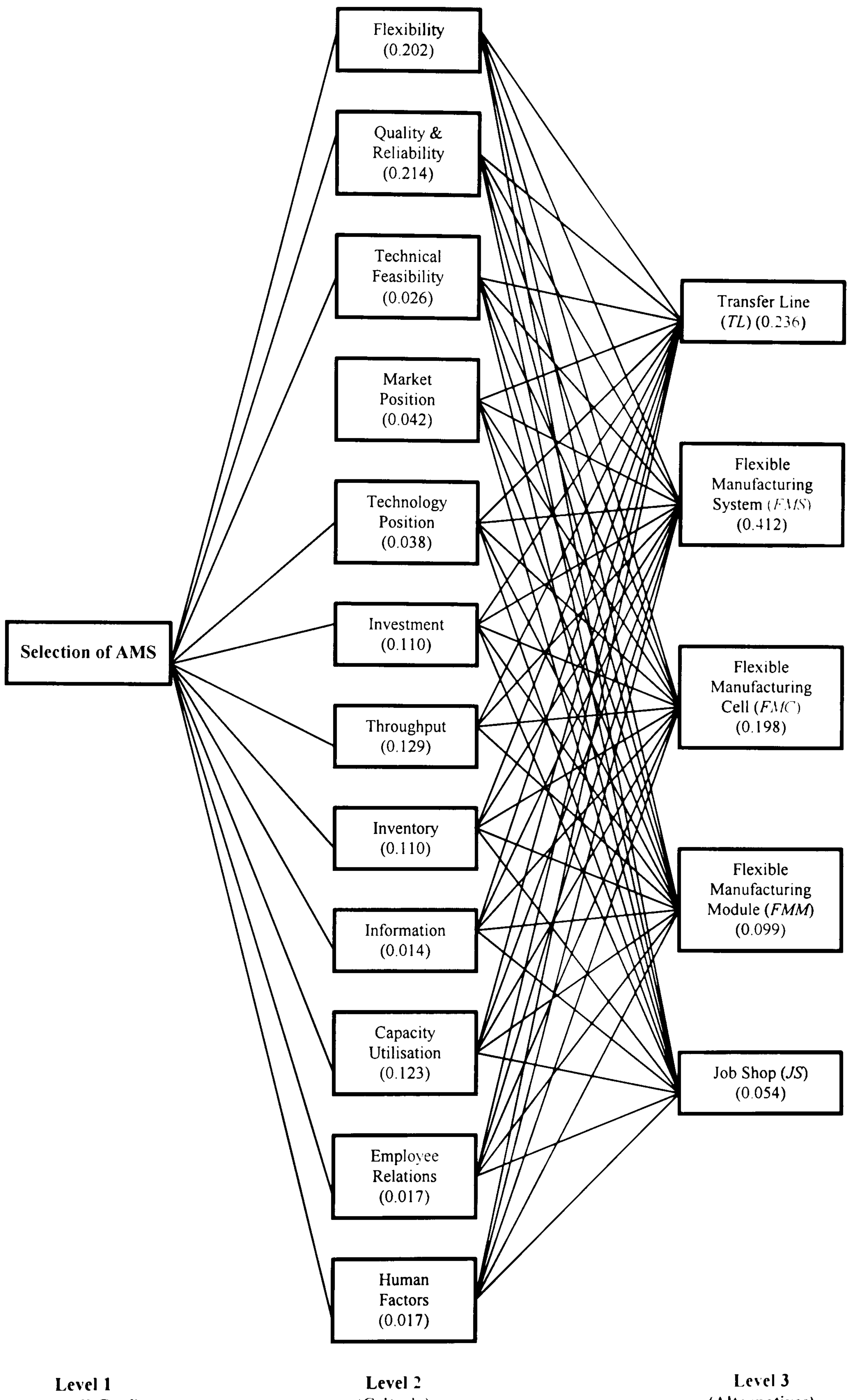

Figure 29 Hierarchy, criteria, and alternatives of AMS problem

5.4.1.2.1. Weighted method and its sensitivity analysis

The ZOGP model of this problem is based on minimisation sum of individual relative importance of criteria or sub-criteria and using partial weights for parameters of constraints is as follows:

$$Min\, 0.202d_{01}^{-} + 0.214d_{02}^{-} + 0.026d_{03}^{-} + 0.042d_{04}^{-} + 0.038d_{05}^{-} + 0.068d_{06}^{+} + 0.129d_{07}^{+} + 0.110d_{08}^{-} + 0.014d + 0.123d_{10}^{-} + 0.017d_{11}^{-} + 0.017d_{12}^{-}$$

Subject to

$$0.036TL + 0.499FMS + 0.239FMC + 0.149FMM + 0.077JS + d_{01}^{-} - d_{01}^{+} = 0.499 \quad \text{(Flexibility)}$$
$$0.141TL + 0.491FMS + 0.243FMC + 0.086FMM + 0.039JS + d_{02}^{-} - d_{02}^{+} = 0.491 \quad \text{(Quality \& Reliability)}$$
$$0.149TL + 0.483FMS + 0.218FMC + 0.107FMM + 0.044JS + d_{03}^{-} - d_{03}^{+} = 0.483 \quad \text{(Technical Feasibility)}$$
$$0.146TL + 0.537FMS + 0.193FMC + 0.081FMM + 0.043JS + d_{04}^{-} - d_{04}^{+} = 0.537 \quad \text{(Market Position)}$$
$$0.150TL + 0.506FMS + 0.210FMC + 0.091FMM + 0.042JS + d_{05}^{-} - d_{05}^{+} = 0.506 \quad \text{(Technology Position)}$$
$$0.130TL + 0.493FMS + 0.242FMC + 0.098FMM + 0.036JS + d_{06}^{-} - d_{06}^{+} = 0.036 \quad \text{(Investment)}$$
$$0.445TL + 0.284FMS + 0.151FMC + 0.079FMM + 0.041JS + d_{07}^{-} - d_{07}^{+} = 0.041 \quad \text{(Throughput)}$$
$$0.462TL + 0.297FMS + 0.126FMC + 0.079FMM + 0.037JS + d_{08}^{-} - d_{08}^{+} = 0.462 \quad \text{(Inventory)}$$
$$0.118TL + 0.503FMS + 0.252FMC + 0.087FMM + 0.039JS + d_{09}^{-} - d_{00}^{+} = 0.503 \quad \text{(Information)}$$
$$0.505TL + 0.261FMS + 0.132FMC + 0.067FMM + 0.035JS + d_{10}^{-} - d_{10}^{+} = 0.505 \quad \text{(Capacity Utilisation)}$$
$$0.027TL + 0.069FMS + 0.136FMC + 0.266FMM + 0.502JS + d_{11}^{-} - d_{11}^{+} = 0.502 \quad \text{(Employee Relations)}$$
$$0.115TL + 0.482FMS + 0.261FMC + 0.100FMM + 0.042JS + d_{12}^{-} - d_{12}^{+} = 0.482 \quad \text{(Human Factors)}$$
$$TL + FMS + FMC + FMM + JS = 1$$
$$TL, FMS, FMC, FMM, JS = 0\, or\, 1$$
$$All\; d_j^{+/-} \geq 0$$

For example, 0.036 in first constraint is the relative importance of transfer line alternative (*TL*) when all the alternatives are compared against flexibility criterion. Objective function coefficients are the relative importance of each criterion which has been shown in figure 29 (level 2). The initial target values of constraints have been selected as the best parameters of relative constraint, to reflect that with choosing the best alternative from a special criterion, there is no distance or difference between target value and the chosen alternative. However, when a non-optimal alternative is chosen with respect to that criterion, there is a distance, which is considered with its global weight that is now the coefficient of objective function. It is worth noting that the nature of the objective function will minimise the undesirable distances. The target values and objective function's coefficients may be changed during sensitivity analysis.

Although investment and throughput time are tangible criteria which can be measured by money and time, they have been used in the literature subjectively (Datta et al., 1992). In other words, those information have been approximated from real sources. The parameters of tangible constraints such as investment criterion and its target value are changed by some arbitrary values in order to measure what will be happened if these parameters are estimated objectively.

The result of AHP and AHP-ZOGP approach are shown in table 42. These results are based on the above ZOGP model without any changes to parameters or coefficients. The only changes occur in the target values of constraints, instead of considering the best values for them, the second best values are taken into account. Decision maker(s) in some cases prefer to attain a feasible "satisficing" solution instead of getting the best result. For this reason, the second and third best values are compared to target values to see whether there are any changes between the orders.

Table 42 Result of AHP and AHP-ZOGP (weighted method)

Alternatives	Orders using AHP	Orders Using AHP-ZOGP (Best values for target value)	Orders Using AHP-ZOGP (Second best values for target value)	Orders Using AHP-ZOGP (Third best values for target value)
TL	Second	Third	Fourth	Fourth
FMS	First	First	Second	Third
FMC	Third	Second	First	First
FMM	Fourth	Fourth	Third	Second
JS	Fifth	Fifth	Fifth	Fifth

In the next step, the parameters of alternatives for investment are chosen to be some arbitrary values. In addition, the target value of investment is selected arbitrarily to see whether the investment constraint has an important role in the decision making process. Other constraints are considered without any changes.

Assume that the normalised values of alternatives for investment constraints are 0.200, 0.400, 0.250, 0.100, and 0.050, respectively. Moreover, assume that the target value of that constraint is 0.300 which means the decision maker(s) prefer not to spend more than 0.300 for investment. In this case, the investment constraint is changed to $0.200TL + 0.400FMS + 0.250FMC + 0.100FMM + 0.050JS + d_{06}^{-} - d_{06}^{+} = 0.300$. Sensitivity analysis of this constraint shows that the ranking of alternatives are unchanged because other criteria are more important than investment criterion. Looking at the weight of investment criterion (0.068) when it is compared with other criteria (for example weights 0.202 and 0.214) gives the answer to the question of why rankings are unchanged even with changing target values for that constraint and its parameters.

Since the *FMS* alternative from the viewpoint of majority criteria is the best alternative, sensitivity analysis shows the changes in the values of just one criterion with regard to that alternative cannot change the best outcome unless its related parameters change simultaneously.

5.4.2. Upshot of the advanced manufacturing system case study

This case study is used to show that the proposed approach can give the decision maker(s) useful aids in order to make a final decision. These aids include the deviations from each target value which means with selecting a specified alternative, what criteria are satisfied exactly and how much attainability has been occurred for the other ones. Having this information helps the decision maker(s) to change the relative importance of criteria against alternatives in the AHP procedure. Sensitivity analysis can also give them effective suggestions about the level of expectation they may not be aware of when they select a specified alternative.

5.5. Concluding remarks

When making a selection decision involving different stakeholders with a diverse range of conflicting criteria, the proposed approach could be a useful decision support tool. The case studies show that the approach could be applied for design selection problem. The case studies, which involved selection of a peristaltic pump, selection of a swivel joint design, and justification of advanced manufacturing systems, possessed the characteristics of the type of problems this approach is intended to support. The case studies showed how it is possible to consider many criteria from different stakeholders to yield a single outcome.

The case studies demonstrated that the use of AHP alone for a selection problem is insufficient, because AHP is not able to consider the availability of resources explicitly or consider multiple stakeholders between stakeholders. This approach introduced resource limitations and criteria constraints in order to remove the drawbacks of AHP when it is used alone. In this method, the weights yielded by AHP become the coefficients for the objective function and constraints equations of the ZOGP model. In this way, resource limitations and criteria constraints are considered. To take into account the different viewpoints of multiple stakeholders, heuristics methods and ZOGP were used to resolve the possibility of conflicting selection outcomes from different stakeholders.

CHAPTER 6
DISCUSSION

6.1. Overview

The first aim of this chapter is to explain why different approaches (AHP, AHP and heuristic methods for aggregation, AHP-ZOGP individual models, and AHP-ZOGP for aggregation outcomes of different stakeholders) generated different ranking. The second aim is to discuss about how good the generated rankings are and in what conditions one can use them. The third aim is to discuss some points which may affect the proposed methodology. These points include relevant theorems, other views for aggregation methods, the easiest and more efficient approaches for making sensitivity analysis, and the assessment of both the methodology and the models used in the approach. In the penultimate section, the assessment of the approach and the models used in the approach are discussed to show that the proposed approach is a useful method for design and manufacturing selection decisions. Finally a conclusion is made.

6.2. Generation of different ranking using different methods

The case studies and the examples used in previous chapters indicated that using different methods for a problem may generate different final ranking. To explain why this has been occurred, it is necessary to review the characteristics of these methods.

6.2.1. Characteristics of AHP method

Although AHP can generate a ranking of alternatives and it has been used for thousands of selection problems (Forman and Gass, 2001) but it cannot be used without other techniques to generate a feasible ranking in the presence of resource limitation (Schniederjans and Wilson, 1991; Schniederjans and Garvin, 1997; Badri, 1999). Not only the tangible resource limitation such as avoiding spending more than a specified budget cannot be considered, but also there are always some intangible constraints that decision maker wants to satisfy them, such as obtaining the minimum level of safety. In other words, AHP uses both tangible and intangible criteria to make a ranking without taking into account the satisfaction of each criterion or sub-criterion. To obtain a ranking for alternatives, AHP uses synthesising procedure which combines just the relative importance of lower level criteria and upper level criteria in a hierarchy without taking into account whether a criterion has been fulfilled. The consequence of ignoring these resource limitations when AHP is used alone is to provide different ranking when it is combined with other methods.

Moreover, AHP also does not have any device to aggregate the different outcomes of multiple stakeholders who developed different hierarchies for a problem with different criteria and sub-criteria (such as customers' hierarchy and managers' hierarchy). Therefore, when aggregation between the stakeholders is required, AHP cannot be used.

6.2.2. Characteristics of AHP and heuristic methods

The methodology used two heuristic methods to aggregate different rankings generated by multiple stakeholders. The combination of AHP and heuristic methods carry the same shortcoming of AHP because these combinations use the same information derived by AHP. In other words, the main problems of using AHP alone remain but these heuristics methods help the stakeholders to aggregate their preferences. The first method used the final weights of AHP while the second method used its detailed (global and partial) weights. The characteristics of applying these two methods are explained in next section.

6.2.2.1. Characteristics of AHP and final weights heuristic method

The combination of AHP and final weights heuristic method used the final weights of AHP as a guide to generate a distance index for modified ranking. This method is especially useful when the stakeholders developed different hierarchies with different criteria and sub-criteria. The method helps the stakeholders to compromise on an alternative based on the distance index. The distance index included two parts; perpendicular distance between alternatives' points (cumulative weights) and ideal line and the distance between the alternatives' points and the origin of coordination system. The former measured the inconsistencies between stakeholders, while the latter measured how far an alternative' point is from the origin of coordinate system. The duty of latter part is to prevent selection of the worst alternative from all of the stakeholders' viewpoints. In other words, the summation of these two distances not only minimise the inconsistencies but also it tries to compromise on an alternative which is nearer to the origin of the coordinate system.

6.2.2.2. Characteristics of AHP and detailed weights heuristic method

This method is a useful approach for aggregation of preferences between the stakeholders when they developed the same hierarchy for a problem with the same criteria and sub-criteria, but establishing different judgements for them. The method uses a distance index again as a measure for compromising on an alternative. The method measures the relative effect of each criterion or sub-criterion for choosing an especial alternative from point of view of each individual stakeholder. The philosophy of this method is based on this reality, if the relative effect of each criterion or sub-criterion for choosing an especial alternative is the same for different stakeholders, and therefore the ranking of the criteria or sub-criteria for different stakeholders is the same for selecting that alternative, then that alternative is a preferable one because all the stakeholders ranking for its criteria or sub-criteria was the same. For example assume there are three criteria (C_1, C_2, and C_3), two alternatives (A and B), and two stakeholders (X and Y). From the point of view of stakeholder X, the relative effect (weights) of these criteria for choosing the alternative A is 0.30, 0.45, and 0.25, while this effect for stakeholder Y is 0.20, 0.70, and 0.10, respectively. In this situation, both stakeholders have the same ranking of the criteria for choosing alternative A. The most important criteria for choosing alternative A from the viewpoints of both stakeholders are C_2, C_1, and C_3. Although the weights of criteria are different for the stakeholders but the ranking is the same. Therefore, they will select alternative A as the preferable alternative because they have already compromised on the elements of that alternative.

If the ranking of criteria or sub-criteria is not the same for selecting an especial alternative from point of view of each individual stakeholder, then the situation of each criterion or sub-criterion point on the coordination system (which now are measured by their cumulative weights) is not the same. In this situation, the distance index can measure the difference of all the criteria or sub-criteria between the stakeholders. In fact, the distance index minimise the discrepancies between the criteria or sub-criteria. The minimum the distance, the better is the alternative.

6.2.2.3. Characteristics of AHP-ZOGP individual models

The most important feature of AHP-ZOGP is taking into account the concept of desirable and undesirable achievement of a criterion or sub-criterion via its objective function with the help of partial weights of AHP which enable us to consider not only tangible constraints but also intangible ones. In the AHP alone, each criterion or sub-criterion has a relative importance weight. AHP as said before, combine these weights to generate a final weight for each alternative. When choosing an alternative, a criterion (such as safety) may be satisfied with that selection. For example choosing alternative A *is* an excellent choice with regard to safety criterion while the decision maker wants to choose an alternative which the safety criterion performs very good not excellent. In this case, selection of alternative A is a desirable achievement with regard to safety criterion and so its effect should not be considered if the objective function is as a minimisation of undesirable deviation variables. In other words, with minimisation objective function, those effects should be taken into accounts which have undesirable effect such as exceeding the budget limitation. In fact, AHP-ZOGP not only can consider the effect of desirable and undesirable achievement of criteria or sub-criteria depends on the type of the objective function but also it is able to ignore the effect of desirable or undesirable criteria through assigning zero to those relevant deviation variables in its objective function. Generally, AHP-ZOGP models can consider those neglected parts of AHP alone.

6.2.2.4. Characteristics of AHP-ZOGP for aggregation

AHP-ZOGP for aggregation of different outcomes obtained by individual AHP-ZOGP models has this ability to take into account the non-obligatory constraints (tangible and intangible) of all stakeholders. The importance of each criterion or sub-criterion is determined by its relevant weights in the aggregated objective function which can be as weighted linear or MINIMAX concept. The procedure of minimising the undesirable deviation variables tries to minimise those deviation variables of stakeholders which has the greatest coefficient (weight of a criterion or sub-criterion) in the objective function. This method can measure how far a final selected alternative is from the point of view of each criterion or sub-criterion of each individual stakeholder. In addition, this method with the additive weighted objective function generates a single outcome with assigning different arbitrary weights to individual part of the aggregated AHP-ZOGP objective function (the objective function of aggregated model has different parts, each part includes the minimisation of undesirable variables of each individual stakeholder ZOGP's model) to indicate the relative importance of additive undesirable deviation variables for each individual stakeholder. In fact, with changing the weights of each individual stakeholder in the objective function, a decision maker can be provided with a range for each part of the aggregated ZOGP's objective function to keep the final outcome unchanged. MINIMAX concept can also be used to provide confidence of selected alternative if this method generates the same ranking of alternatives.

When heuristic methods were used to aggregate the outcomes of each individual stakeholder, the methods used the weights of criteria or sub-criteria in an absolute fashion, neglecting some of criteria or sub-criteria have already reached to their expected desirables. Using AHP weights with developed heuristics methods for aggregation had the lack of using all of the criteria or sub-criteria desirable and undesirable concepts. The AHP-ZOGP model for aggregation solves this problem with considering the undesirable deviation variables in its objective function.

6.3. Relevant theorems

6.3.1. Arrow's impossibility theorem

One famous theorem which may affect the approach is the Arrow's impossibility theorem (Scott and Antonsson, 1999) because of its aggregation procedures. Arrow's theorem states that there can be no consistent, equitable aggregation method for social choice.

Although the problem of MCDM-MSDM seems similar to the problem of social choice, in which the ranking of several alternatives by individuals are to be combined into a single ranking but there are some differences which make it non-applicable for the proposed approach.

1- The basic aim of social choice problems is to combine separate weak orders into a single social order, while the approach violates this assumption because design decisions are made by explicit comparison of degrees of preferences based on ratio scale.

2- In social choice problems, each weak order corresponds to the wishes of an autonomous individual; in MCDM-MSDM decision, each order corresponds to a single criterion (Scott and Antonsson, 1999). In design problems, there may be many people involved, but decisions depend upon the aggregation of engineering criteria. In other words, in engineering design decisions, rather than social choice problems, attributes, not people, must be reconciled.

3- In social choice problems, all orderings are accorded equal worth. In the MCDM-MSDM problems, different weights are assigned to different criteria based on their effects on the problem. While it is natural to accord all human voters equal worth, the equal weights of different criteria in engineering design problems are meaningless.

4- In social choice problems, individuals are free to rank the alternatives as they want, while in a design situation, there are always some tangible criteria that prevent us from ranking them freely.

5- Engineering design problems have constraints that differ from social choice problems and therefore Arrow's theorem cannot be applied (Scott and Antonsson, 1999). For example, government regulations must be fulfilled or there is a limitation of available budget to launch a new design to market.

6.3.2. Game theory

The proposed approach can have multiple stakeholders who may have their own perception of a problem. Because game theory deals with decision situations in which two or more intelligent opponents have conflicting objectives (Taha, 1997) so one may ask why this theory has not been used.

Game theory cannot be used because of three reasons. First, the stakeholders may choose their most appropriate alternative based on considering the viewpoints of other stakeholders such as what happened in a peristaltic pump case study. The marketing department stakeholder considered the viewpoints of customers as a criterion. In other words, the stakeholders may not choose their alternatives solely, without a pure view on their sights, a key assumption of game theory (Hillier and Lieberman, 1995). Second, in game theory, the parties involved in a problem are competing with each other that mean if a player loses a game, the other will win the game, while in the design selection problem, the stakeholders act supplementary to each other. In other words, the stakeholders want to help each other to make an enhanced decision. Third, a key element in game theory is the nature of playing a game repeatedly (Rogers, 2002). That means a game should be repeated several times to reach a steady state situation. This element cannot be applied for the design decisions because in this kind of decision, unlike everyday decisions such as the decisions between the employees and management, the situation of decision making may be long standing. Constructing or non-constructing a dam in a particular place or transferring or not transferring an advanced manufacturing technology are examples of these kinds of decisions.

6.4. Aggregation methods

6.4.1. Heuristic distance method based on AHP's final weights

The approach used a heuristic distance method for aggregation of outcomes based on final AHP's weights when the stakeholders make different hierarchies. This method used the perpendicular distance and distance from origin of coordinate system as an index to choose the final alternative. One may claim that Moshiri's method (1998) based on calculating the perpendicular distance between the alternatives' points and ideal line can be used as an index when distance from the origin of coordinate system is added to perpendicular distance.

Although considering the distance from origin of coordinate system prevents the selection of the worst alternative, it does not take into account the weights of alternatives. The weights are important because between alternatives, it is possible that two alternatives have had very close weights. For example, assume there are three alternatives with the weights of 0.50, 0.48, and 0.02. Placing the orders based on these weights on the coordinate system will cause an inaccurate distance. While the actual difference between the first two alternatives is 0.02 (0.50 - 0.48 = 0.02), when they are placed in the axis of coordinate system, this difference will be 1 (2 – 1 = 1). Therefore the result distance based on the order of alternatives cannot reflect the real situation. Although this approach removes the distance problem disadvantages of Moshiri's method, but it has the problem of insignificant differences of alternative's weights. It is worth noting that using the cumulative weights of alternatives and calculating just the perpendicular distance is also insufficient because it is possible the worst alternative from all stakeholders' viewpoints will be placed in the ideal line.

The above discussion described that the orders of alternatives' points for providing an index for aggregating the outcomes created by individual stakeholders are inadequate even with considering the distance from origin of coordinate system.

6.4.2. Nash bargaining

The aggregation function can be as a modified version of what was suggested by Nash as $Min \sum_i |(x_i - x_i^*)(y_i - y_i^*)|$ between two stakeholders, in which x_i and y_i indicate the preference of *ith* criterion from viewpoint of stakeholder x and y respectively, while x_i^* and y_i^* represent their best outcome of *ith* criterion (Binmore and Davies, 2001).

Although the aim of this function is to decrease the dispersions between different stakeholders, this method has two main problems:

1- To use this function, stakeholders' decomposition elements should be the same. In other words, different stakeholders cannot develop different hierarchies with different criteria or sub-criteria.

2- When a stakeholder obtains its best value for a criterion, the dispersions will be set to zero without the consideration of values of other stakeholders for the same criterion or sub-criterion.

A simple example is used to clarify the second problem. Assume that there are three alternatives as A, B, and C, two stakeholders as X and Y and a number of criteria that one of them is flexibility. Assume that the most appropriate alternative from point of view of stakeholders X and Y considering all of the criteria is A and B, respectively. Assume that the relative importance of each alternative when they are compared with flexibility criterion is as in table 43.

Table 43 An example to clarify the problems of Nash aggregation function

Stakeholders	Alternatives		
	A	B	C
X	0.40	0.50	0.10
Y	0.25	0.35	0.40

Using the function for flexibility criterion, we obtain:

For alternative A: |(0.40-0.50)(0.25-0.40)| = 0.015

For alternative B: |(0.50-0.50)(0.35-0.40)| = 0.000

For alternative C: |(0.10-0.50)(0.40-0.40)| = 0.000

In this case, both alternatives B and C created the same index, while alternative B is obviously better than C. This problem occurred because the significant difference of 0.10-0.50 was offset when it multiplied by zero.

Therefore, using this function for aggregating the outcomes provided by individual stakeholders cannot convey the true and guaranteed index for achieving an aggregated single outcome.

6.5. An efficient approach for sensitivity analysis of ZOGP models

The presence of integer variables in the ZOGP models makes sensitivity analysis a complex task. However, the sensitivity analysis was made with changes of some important coefficients and parameters of the models, and the method was not straightforward. In other words, each problem had the special situation and sensitivity analysis was made based on the situation of the problem. To facilitate the sensitivity analysis, it is necessary to remove somehow the nature of integer variables in the models to convert the models into linear programming with well-defined sensitivity analysis procedure.

Cutting plane method can be used to resolve the problem (Taha, 1997). In this method, the integer binary variables are removed from the set of constraints and replaced with new constraints as $x_j \leq 1 (j = 1,2,\cdots)$. If the outcome of the model is integer, then there is no further action and sensitivity analysis can be made easily to obtain the range of each coefficient of the objective function and target values of constraints in order to retain the current outcome optimal. Otherwise, a new constraint is added successively to the problem based on fractional units of non-integer variables in order to modify the feasible space. The added new constraints should not eliminate any of the original feasible points of the problem. The procedure continues to reach an integer outcome for all variables.

It is interesting that the elimination of integer variables for most of the constructed ZOGP models for case studies will not change the outcomes. For others, it is necessary to add new constraints to convert the non-integer outcome to integer ones. Using the cutting plane method can be used to facilitate the sensitivity analysis procedure because this method converts the problem into a linear programming model with a well-defined manner of sensitivity analysis. However, for some problems, addition of new constraints may be repeated several times to generate an integer outcome (Taha, 1997).

6.6. Validation

Validation is the process of determining the degree to which a theory, an approach or a model is a "good enough" representation of the reality from the perspective of the intended uses of the theory, the approach or the model (Anderson and Bates, 2001; Gass 1993; Landry and Oral, 1993). Validation is a complex process because the concept of "good enough" includes subjective judgements of what constitutes a reasonable degree of a "good enough" and it differs from the points of view of different individuals. Subjective judgements prevent making a general validation approach of theories, approaches, or models. Therefore, absolute validation is philosophically impossible because it requires not only to eliminate the effects of subjective judgements, which are impossible, but also it needs an infinite number of tests (Anderson and Bates, 2001).

Scientific theories cannot be proven; they can only be tested through observations. An agreement of observations with predictions does not validate the theory, but once an exception is observed, the theory is judged to be invalid (Babuska and Oden, 2004). Thus, a theory, a methodology, an approach or a mathematical model can never be proven to be valid; rather, we can say that there are not enough evidences to reject them. Therefore, as long as a methodology or an approach does not have sufficient evidences to reject it, we can accept it.

Validation relative to a specific series of tests may be perfectly legitimate as a basis for making decisions (Babuska and Oden, 2004). In these situations, the relative validation can be possible when validation involves comparison of observed events with those predicted by methods. In addition, if an approach or a model has the ability to produce more information that would be of value to the decision maker, then the approach or the model is good enough to predict the outcomes of an event (Gass, 1993). Although there are no universal criteria for validation because any validity judgement involves beliefs which are different from one stakeholder to another (Landry and Oral, 1993) but Gass (1993) suggested the validation can be made by theoretical validity basis, input data validity, and operational validity criteria. However, simplicity, transparency, flexibility, and some sort of criteria that measures the degree of conformity of the model to empirical facts are other types of criteria (Dery et al. 1993).

The validation in this research deals with three subjects: validation of methodology, validation of methods or mathematical models, and validation of outcomes of methods used to obtain the ranking of alternatives.

6.6.1. Methodology validation

Validation of a methodology can be measured by the criteria which Gass (1993) has suggested. If a methodology has a valid theoretical, valid input data, and valid consecutive operational activities between the stages of a methodology, there is no evidence to invalidate it. The proposed methodology has these characteristics because:

1- The methodology is based on well-defined AHP and ZOGP methods (chapters 2, 3, and 4).

2- The methodology uses the tangible data and intangible data which are obtained from real sources and subjective judgements of experts, respectively.

3- There are logical activities between the stages of the methodology which make it operational for use. These activities include: elimination of those subjective data from which their real values can be obtained, the combination of the AHP and ZOGP method to improve the level of information for better decision making, relationship between AHP and heuristics methods, relationships for making sensitivity analysis, and etc.

In addition, the methodology has simplicity with accuracy, transparency and flexibility. When it is said that, for example, the methodology is flexible, it means that the methodology is measured with available methods such as weighted objective method, controlled convergence method, or MAUT.

The methodology is simple, easy to use and accurate because:

- It uses AHP to elicit the judgements to determine the relative importance of criteria or sub-criteria with its simple pairwise comparisons and ratio scale. Although one can claim that the methods such as weighted objective method or controlled convergence method are much easier than the methodology, but it should be mentioned that these methods use ordinal scale which is not as accurate as ration scale. It should be noted that for the case studies discussed earlier, no one had the problem to complete the questionnaires. On the other hand, there were no any further activity to construct the models because the coefficients of the models are the weights obtained by AHP.

- If it is accepted that the distance from alternatives' points to ideal line for different stakeholders is a suitable index to measure the inconsistencies between different stakeholders, then the heuristic methods provide the good results if the underachievement or overachievement of criteria or sub-criteria are measured altogether without separating them into desirable or undesirable achievement. Heuristic methods for aggregation use a simple distance function to generate the indexes for selection of most appropriate alternative when different stakeholders have chosen different outcomes using AHP alone.
- The AHP's global weights are used to construct the coefficients of ZOGP's objective functions. In addition, AHP's partial weights for intangible criteria are used to construct the parameters of ZOGP's constraints. In other words, the parameters of ZOGP models have already been identified.
- It uses linear additive function (or MINIMAX concept) to construct the aggregated ZOGP's model objective function. In other words, the outcome of the ZOGP models can be obtained easily.

The approach is transparent because:

- The instructions of each part of the methodology are traceable. For example, the inconsistency ratio can detect which pairwise comparison has not been judged precisely or which member of the group in the group decision making created the pairwise inconsistencies.
- It can measure the undesirable distance discrepancies (with its overachievement or underachievement concept of the criteria or sub-criteria) between the stakeholders and tries to minimise these discrepancies via AHP-ZOGP method for aggregation.
- Each part of the methodology has a logical link not only with its previous and next stage which makes it operational but also to other stages which make it understandable for users.

The methodology is also flexible because:

- It can be used for single and multiple stakeholders.
- It can be used for single or group decision making.

- It can include tangible and intangible criteria.
- It can be applied to elicit the different judgements within and between the stakeholders.
- It can be used to aggregate different outcomes obtained by individual stakeholders.

Therefore, from the point of view of the methodology, there is no reason to invalidate it. In addition, the approach produces more information when it is compared with current approaches. The information includes:

1- The underachievement or overachievement of criteria in a straightforward way. That means without any other activities, this information is available via the deviation variables of ZOGP models.

2- The total undesirable deviations for each individual stakeholder (the value of individual ZOGP's objective functions).

3- The total undesirable deviations when multiple stakeholders are considered (the value of aggregated ZOGP's objective function).

4- The range of each parameter in the objective function or target values of criteria that retain the current outcome unchanged via sensitivity analysis of ZOGP models.

5- The relative importance of each individual stakeholder that can change the current outcome of the aggregated model.

6.6.2. Models Validation

Model validity checks whether or not the proposed model does what it is supposed to do. In other words, validity checks whether the model has the ability to provide a reasonable prediction of the behaviour of the system under study (Taha, 1997). Approximations and simplification are basic assumptions for constructing a model because it is an abstract idealisation of the problem (Hilier and Lieberman, 1995). Therefore, for models validation, one should note that all models are approximations of the reality and so they cannot, and we do not expect to, be fully validated. Therefore, care must be taken to ensure that the model remains a valid representation of the problem.

One way to validate a model is to compare its output with historical output data when it is possible (Taha, 1997; Hilier and lieberman, 1995). The model is valid if, under similar input conditions, it reproduces past performance. However, there is no assurance that future performance will continue to duplicate past behaviour. Because models are usually based on examination of past data, the proposed comparison should be favourable. For the models applied in this thesis, the models could not be checked through historical data because there were no available data for the current situation.

Another way to validate a model is to consider the components of the model (Anderson and Bates, 2001). The components of a mathematical model are parameters (input data), variables (outputs), and the relationship structure between mathematical expressions. Thus, to validate a model, its components must be checked. The parameters of a model is falling into three categories: parameters that are known and measured, parameters that can be estimated based on judgements (e.g. based on prior experience judgement), and guesswork. All models involve informed judgement and typically a bit of guesswork as well. Wherever subjective judgements or guesswork are required, systematic errors can occur (Anderson and Bates, 2001). On the other hand, the model developer should be convinced that the output of the model does not contain "surprises" (Taha, 1997). In other words, the outcome should make sense and the results should be intuitively acceptable. Finally, the relationship structure between mathematical expressions should reflect the characteristics of the problem, such as binary nature of main variables and existence of constraints in a problem.

Additional insight into the validity of the model can sometimes be obtained by varying the parameters and/or the decision variables and checking to see whether the output from the model behaves in a plausible manner (Taha, 1997; Hilier and lieberman, 1995). This is often especially revealing when the parameters or variables are assigned extreme values near their maxima or minima. The validity of models can also be checked by constructing more than one model (Anderson and Bates, 2001). Construction of more than one model of a problem with different views at the problem can reveal potential errors in a single model.

The validity of the models used in this thesis, was checked by: 1) the parameters (inputs) of the models, 2) the output of the models, 3) relationship structure between mathematical expressions, 4) examining the extreme values 5) sensitivity analysis through adding new constraints to the model, and 6) generation of several models.

First, the parameters of the models used in this thesis were real values for tangible criteria and were obtained by AHP for intangible criteria. As mentioned earlier, AHP has the ability to generate true or approximation weights which were used to construct the objective function coefficients and intangible constraints parameters. So, it can be said that the input data are relatively reliable. Second, the output of the models, the value of main variables and deviational variables, could be justified individually and by making sensitivity analysis. The output of the models did not include surprises. Third, the mathematical expressions could represent the nature of the problem, considering tangible and intangible constraints, binary selection of main variables, and minimisation of undesirable deviation variables. Fourth, putting extreme values in both sides of the best and worst values for coefficients in the objective function and target values of criteria (right-hand sides of the constraints), revealed the best and worst alternatives, respectively. Fifth, adding new constraints such as selection of two alternatives, or selection of at least one alternative did not change the result of initial outcome. Sixth, construction of more than one model, such as two models with different objective functions for aggregated model, did not change the final outcome.

6.6.3. Validation of outcomes of the methods

Using different methods to obtain the ranking of alternatives generate different outcomes. The problem here is which of these outcomes and which of these methods are preferable. As discussed earlier in section 6.2., it depends on what source of information is available and how a problem is constructed.

1- If a problem is constructed without involving multiple stakeholders and the relative importance of criteria and sub-criteria are important for decision making in its absolute manner (i.e. without considering the desirable or undesirable concept of achieving or non-achieving to a criterion or sub-criterion), then AHP ranking can be accepted.

2- If for the same problem as above, the said concept is important, then a decision maker can use the AHP-ZOGP model to generate a better outcome. In this case, just the undesirable deviation variables (undesirable distances from target values) are minimised and desirable distances are not considered.

3- If there are multiple stakeholders who developed different hierarchies for a problem and the relative importance of criteria and sub-criteria are important for stakeholders to make a final decision in its absolute manner (i.e. without considering the desirable or undesirable concept of achieving or non-achieving to a criterion or sub-criterion), and the outcome is different ranking for alternatives from the point of view of different stakeholders, then AHP and final weights heuristic method can be used. This method uses the final weights of alternatives, neglecting how important is a criterion or sub-criterion

4- If the same problem as above exist with this difference that different stakeholders construct the same hierarchy with different judgments about pairwise comparison, AHP with detail weights can generate a better ranking because that method uses the detail weights of criteria or sub-criteria not the final weights of alternatives. This method uses the relative importance of criteria or sub-criteria which carry more information about the relative importance of each criterion or sub-criterion, not just the weights of alternatives.

5- If there is a decision maker and the concept of underachievement or overachievement of a criteria or sub-criteria to their target values is important, then AHP-ZOGP can be used. This method takes into account the undesirable distance concept via minimising the total discrepancies which will be available if all the criteria or sub-criteria did not perform as the best for final selected alternative.

6- For the same problem as above with multiple stakeholders, AHP-ZOGP aggregation is more preferable because this method has the ability of providing more information in comparison with other methods. Not only this method aggregates different ranking obtained by individual stakeholders using the underachievement or overachievement concept, but also the new information about how important are one stakeholder to another (which can be obtained by sensitivity analysis of relative importance of each individual stakeholder) helps the stakeholders to modify their initial understanding of the problem and make some modification to obtain a better result. Moreover, using both types of objective function (weighted linear method and MINIMAX) which obtained the same result, increase the confidential use of this method.

In addition of above discussion to see how good of ranking are, we can consider a few groups to use different methods for a problem. It is worth noting that the problem should have the characteristics of the methods that this methodology intends to support. Therefore, it is necessary to distinguish between the problems by the number of stakeholders and the hierarchies involved in the process of decision making. If a problem have a single stakeholder (like as manufacturing department), then the methods of aggregation cannot be applied. If there is more than one stakeholder with different hierarchies (like as selection of vehicle manufacturing technology), then the method of AHP with detailed weights cannot be used. In other words, to compare the outcomes, it is necessary to see the groups will solve a problem which is relevant to them. For example, a group cannot have multiple stakeholders (between stakeholders concept) and wants to use controlled convergence method because this method cannot support the decision in the environment of multiple stakeholders between the stakeholders.

To propose a method for evaluating the performance of a ranking, assume a selection problem is given to three groups. The selection problem has one stakeholder with different individuals (manufacturing stakeholder contains some individuals inside it such as employees, mangers and so on). One group can use controlled convergence method, the second can use MAUT, and third one can use the AHP-ZOGP model. If the outcomes of these methods are the same, then the ranking of the alternatives can be reliable because those methods generate the same ranking. If the outcomes are different, then it is necessary to discuss why this has been occurred. In this case, it should be said that the control convergence method use the equal preference of all the criteria or sub-criteria. For MAUT, it can be discussed that the individuals cannot develop the utility function exactly because of its non-reality situation to asking the lottery type questions. The ranking of AHP-ZOGP method can be accepted because this method removes the aforementioned drawbacks of the controlled convergence method and the MAUT.

The same procedure can be used for a problem with different stakeholders (such as manufacturing department, design department and customers) and different hierarchies. In this case, two groups can use AHP and heuristic method using final weights of alternatives obtained by AHP and AHP-ZOGP method. If there are different ranking of alternatives using these methods, then the reasons for that should be discussed. One reason of accepting the AHP-ZOGP method can be that this method distinguishes between the overachievement and underachievement of the criteria or sub-criteria, while the other method does not. The same procedure with the more or less discussion can be applied for a problem with multiple stakeholders and the same hierarchies developed by individual stakeholders.

Generally, because available methods for selecting the most preferable alternative cannot cover the aggregation of multiple stakeholders between the stakeholders, so the evaluation of how good the ranking are is impossible. Proviso on impossibility of validation by direct test only one will be selected. However, some discussion can be made as mentioned in this section.

6.7. Concluding remarks

The discussion of several points indicates that there are some theories and other issues which may affect the proposed approach. However, it was shown that:

1- Arrow's impossibility theorem cannot affect the design selection problems.

2- Although game theory was designed for overcoming the problems of conflicting objectives between stakeholders, but it cannot be used because of non-malevolent nature of stakeholders, the complementary nature of stakeholders and non-repeatability nature of design problems.

3- Other heuristic aggregation methods based on orders of final alternatives is insufficient to make a sound decision.

4- Nash function cannot be used for different stakeholders with different hierarchies or elements. In addition, the effect of a great dispersion cannot be taken into account when another stakeholder can satisfy fully its objective.

5- The sensitivity analysis can be made in a more efficient way through using cutting plane method.

6- Pure validation is not possible. The validation can be made by introduction of some criteria such as theoretical, input data, operational, simplicity, transparency, and flexibility criteria. The approach was examined through these criteria. In addition, the approach could create some additional information which is not available in current approaches.

7- The models were checked not only through their maxima and minima values for the parameters of the models but also through adding new constraints to the model and constructing more than one model for a problem in hand.

8- The outcome of the methods can be evaluated by considering some groups to solve a problem with different methods suggested in this thesis. If all the groups generate the same ranking of the alternatives, the outcome can be accepted without any further activities. Otherwise, it is necessary to discuss why different rankings are emerged and discuss why the methods of this thesis generate different ranking.

CHAPTER 7
CONCLUSION AND FUTURE RESEARCH

7.1. Overview

The aim of this chapter is to provide a summary of the approach. Then the limitations of the approach, contributions to knowledge, and the future researches are discussed and finally a conclusion is reached.

7.2. Summary of the proposed approach

This thesis proposed an approach for selecting design alternatives based on two routes: using AHP as a stand-alone methodology and the combination of AHP with ZOGP. The first route used AHP as a stand-alone methodology to obtain the final weights of alternatives from each stakeholder viewpoint because of its ability to provide consistent weights (Badri, 2001). The weights were then aggregated through heuristic distance methods to achieve a single outcome. If there were different hierarchies from point of view of different stakeholders, AHP's final weights were used to aggregate the outcomes using a distance function. This function measured the perpendicular distance between each individual alternative point and the ideal line beside the distance between each alternative point and the origin of the coordinate system. The coordination of each alternative's point was identified by its cumulative order final weights.

If there were similar hierarchies for stakeholders, then AHP's detailed weights including partial and global weights could also be used alternatively to provide the single outcome based on the effect of each single criterion or sub-criterion to choose a specific alternative. This effect was obtained by multiplying the partial weights of alternatives and global weights of each criterion or sub-criterion from the viewpoint of all stakeholders. If these effects for all stakeholders to choose an alternative were same, then there was no difference between the stakeholders to choose that alternative. In other words, when the orders of criteria or sub-criteria for choosing an alternative were same, that means all the stakeholders had the same idea about the alternative and the effect of criteria or sub-criteria. Otherwise it was necessary to measure the difference between the effects of criteria or sub-criteria for all the stakeholders. This difference could be obtained by calculating the perpendicular distance between orders' cumulative weights of criteria or sub-criteria for all the stakeholders. A method of calculating the difference was discussed in chapters 4 and 5.

When using AHP as a stand-alone methodology, what were not taken into account were resource limitations in a straightforward manner, non-considering the target values of criteria or their lower and upper limit, and discrepancies between the final selected alternative with the alternative which was best from the point of view of a criterion or sub-criterion.

The second route initially used the combination of AHP and ZOGP in order to find the most appropriate alternative from each stakeholder viewpoint. In this route, it was assumed that each individual criterion acts as a single goal in a ZOGP model, so each criterion could have two variables, desirable and undesirable, which were related to desirable distances and undesirable distances, respectively. These variables can exist in both types of criteria, tangible and intangible. In other words, in addition to having tangible goals (such as avoiding over utilising maximum available budget), there are intangible goals which were related to intangible criteria such as avoiding having less quality when alternatives are compared regarding quality criterion. One of the main purposes of combining AHP and ZOGP is to minimise the undesirable tangible and intangible distances. In addition, using ZOGP allowed for tradeoffs in information that permits the decision maker(s) to see these tradeoffs in terms of underachieving or overachieving.

This route used AHP's weights to construct the ZOGP's objective function and its constraints from each stakeholder viewpoint. The approach used the global weights of criteria, obtained by AHP, as the coefficients of undesirable variables in the ZOGP objective function. The global weight of each criterion which expresses the contribution of that criterion into the overall goal of a problem reflects the importance of each criterion with regard to all criteria when they are compared against each other. The greater the coefficient of an undesirable variable in the objective function, the smaller the chance to get value for that undesirable variable related to that criterion because a minimisation procedure tries to set undesirable variables to be zero. In other words, undesirable variables which have greater coefficient will be minimised sooner than others. Using global weights as coefficients of the weighted objective function will solve the problem of assigning arbitrary values to represent the importance of each goal for solving the problem. In fact, using global weights is a systematic way to provide meaningful and logical weights for taking into account the importance of each criterion or sub-criterion in the objective function.

On the other hand, partial weights, the relative importance of alternatives with regard to a criterion or sub-criterion, obtained by AHP with regard to intangible criteria were used to construct the intangible constraints. However, these constraints are not real ones, but they are important because when they are put into the model as constraints, their duties are to take into account the distances between final selected alternative and ideal alternative from point of view of criteria. Although, the target value of intangible constraints could be set as any normalised number, they were initially chosen to have the best relative importance of a criterion when alternatives were compared with regard to that criterion. The greatest value was selected because choosing the best alternative from all criteria was the incentive of the decision maker in an ideal situation. However, the target value can be changed to other values in the sensitivity analysis to see the effect of these changes in the final outcome. To construct the tangible constraints, the available data for tangible criteria or sub-criteria were normalised to make sure the deviation variables could be added in the objective function. The target value of tangible constraints was the available resources after normalisation procedure.

Constructing another ZOGP model helped the decision maker to aggregate the individual ZOGP models which were constructed for each stakeholder involved in the problem and therefore, to aggregate their outcomes. The advantage of this ZOGP model was that it could produce a single outcome for all stakeholders involved in the decision. The aggregated ZOGP model not only measures the discrepancies between ideal alternative when alternatives are compared with regard to a criterion or sub-criterion and final selected alternative, but also it could includes tangible and intangible constraints which existed for different stakeholders.

The aggregated ZOGP's objective function tries to minimise: 1) the sum of weighted undesirable variables for stakeholders, and 2) the maximum linear sum of individual stakeholders in order to achieve a single outcome. In the former case, sum of ZOGPs' individual objective functions are minimised while in the latter case, in fact, more importance is given to the stakeholder who created more deviations from their target values and then it was minimised. In this situation, the problem is in advance, we do not know which stakeholder create more deviations from their target values.

The constraints of aggregated ZOGP model were the constraints of individual ZOGP models for each stakeholder which would be put consecutively in the new model. The duty of these constraints was to measure the differences between the final selected alternative and ideal alternative from the point of view of each criterion or sub-criterion and each stakeholder.

The individual or aggregated ZOGP's models attempts to minimise the undesirable intangible and tangible deviation variables related to criteria whereas previous works have only considered the minimisation of undesirable tangible criteria and tangible constraints. The previous researches did not suggest any method of assigning the priorities to the objective function of ZOGP models and finally they have taken into account just one stakeholder.

7.3. Contributions to knowledge

The contribution to knowledge with regard to this research can be summarised as follows. The details of each part can be found in other chapters of this thesis.

1- Developing a decision support method to facilitate the design decision problems in MCDM-MSDM environment.

2- Combining the AHP and ZOGP in a rational way to include tangible and intangible criteria in the decision making process using relevant information obtained by AHP.

3- Combining the AHP and ZOGP for considering the distance concept neglected by AHP when it is used alone.

4- Developing two heuristic methods for aggregation the outcomes obtained by individual stakeholders when AHP is applied as a stand-alone methodology.

5- Developing a method based on ZOGP model for aggregation of outcomes obtained by individual stakeholder ZOGP's model.

6- Combining AHP and ZOGP in order to find the most preferable alternative from individual stakeholders for the following cases:

- Selection of a vehicle manufacturing technology.
- Selection of a peristaltic pump.
- Selection of a swivel joint design alternatives.
- Selection of an advanced manufacturing system.
- Using developed heuristic distance methods for aggregation of stakeholders' outcomes for the selection problems mentioned above.
- Using ZOGP for aggregation of outcomes obtained by individual models in order to reach a single outcome for problems mentioned in part 6 excluding the fourth problem.

7.4. Limitation of proposed approach

The success of implementing the proposed approach in this thesis may appear limited by:

1- **The pairwise comparisons time consuming:** when the number of levels in the hierarchy and the number of criteria and sub-criteria are increased, then there is a disadvantage if all redundant pairwise comparisons need to be made. However, this disadvantage can be removed by using the method of incomplete judgement matrix.

2- **Heuristic aggregation methods:** although there are simple instructions for using these methods and they are understandable for users, they need to be examined with other applications.

3- **Aggregation methods by combination of AHP and ZOGP:** using an additive objective function is the simple one which may not be realistic. However, it may be considered as the first approximation. It also can be improved by considering other objective functions, as it was made by considering MINIMAX concept and modified Nash function.

4- **Usual modelling efforts:** the nature of the design selection problem minimises the limitations of data collection and modelling effort. For example, the number of alternatives must not exceed twenty for weighting (Saaty, 1980). In addition, the fairly small size of the ZOGP models should pose no formulation problem.

5- **Deterministic concept:** the approach does not involve uncertainty concept. Both AHP and ZOGP models are the deterministic approaches. All data and parameters in the AHP and ZOGP models are set up to be known. In the AHP, the pairwise comparisons between elements of the hierarchy are judged using the deterministic values. However, this drawback can be removed by considering the problem as different scenarios. The scenarios can include having different hierarchies, removing the insignificant criteria, changing the pairwise comparison, changing the 1 to 9 scale to other scales or using the problem in a group decision making environment. In fact this shortcoming can be removed by considering several scenarios which the decision maker(s) wants to treat them with. However, the fuzzy AHP can be developed to consider the uncertainty. This shortcoming for ZOGP models can also be resolved again by taking into account several scenarios and by careful consideration of sensitivity analysis of the models, especially simultaneous sensitivity analysis on AHP and ZOGP models.

7.5. Future research

Making a selection decision is a complex task because of several factors such as uncertainty nature and intangible criteria involving these decisions. The proposed approach looked at the problem in a deterministic way which can be improved by considering stochastic features. This research used the combination of concept-specification and concept-concept features to improve the design decision making. To combine these two features, the approach applied two techniques, each of them from its relevant feature. The approach used AHP and AHP-ZOGP for making the decision. Therefore, future research can be conducted in the following areas.

1- Using combination of other techniques from different features. These combinations may include MAUT-ZOGP, or fuzzy ZOGP. To enhance the approach, fuzzy method can be incorporated in the approach in the pairwise comparison stage or for estimating the target values of criteria.

2- The use of additive weighted objective function or using MINIMAX concept for aggregating the different outcomes obtained by each individual stakeholder ZOGP models may be developed by considering other objective functions such as multiplication or quadratic form of individual objective functions. In addition, the constraints of the aggregated model may be improved by combining individual constraints of single ZOGP models.

3- Other aggregation methods can be developed either when AHP is used alone or when aggregation is constructed through ZOGP model.

4- The fuzzy logic concept can also be developed for including the ambiguous goals in ZOGP models.

5- To obtain a representative value of pairwise comparison for the questions of AHP in the group decision making using geometric mean, the number of respondents is a matter for question. For example, how many people should be asked to answer a specific question in a marketing research for a pairwise comparison that it would be enough? In other words, how many people would be enough to create a reasonable representative outcome?

7.6. Concluding remarks

This thesis proposes an approach that, when making a design selection decision involving different stakeholders with a diverse range of conflicting tangible and intangible criteria could be a useful decision support tool because of its ability to create more information compared to available tools. The approach uses the AHP as an intermediate tool to improve the decision making process. Combination of AHP and ZOGP as a tool not only improves the decision making process for a single stakeholder but also enhance the situations involving multiple stakeholders because of its ability to aggregate the outcomes through aggregation of individual models.

The combined AHP-ZOGP method offers not only a systematic, easy to use approach for design selection decision problems for each stakeholder but also it offers an approach for aggregating the outcomes obtained by individual models. It extends previous research by incorporating a comprehensive prioritisation system, considering limitation on resources and considering intangible constraints as well as tangibles. Because of the synergy in the combined AHP-ZOGP approach, the approach not only is an excellent alternative to previous methodologies in design selection problems when there is a single stakeholder but also it is a new approach to aggregate different outcomes in the presence of multiple stakeholders, specially for "between the stakeholders".

In addition, the approach suggests two different methods to aggregate the outcomes of different stakeholders when AHP is used as a stand-alone methodology. The advantage of using these methods is their simplicity and understandablity for people involved in the decision.

The case studies, which involved vehicle manufacturing technology selection, choosing peristaltic pump, selection of a swivel joint design, and the justification of advanced manufacturing systems, possessed the characteristics of the type of problems this approach is intended to support. These characteristics include the the number of stakeholders involved with conflicting criteria, the resource limitations, and the presence of both tangible and intangible criteria. The case studies showed how it is possible to consider many criteria from different stakeholders to yield a single outcome that covers the requirements of the stakeholders. The case studies demonstrated that not only the use of AHP alone for design selection problems is insufficient, but also using famous methods such as controlled convergence method cannot validate the outcome. However, the information about relative importance obtained by AHP and outcomes obtained by AHP-ZOGP helps the decision maker(s) to find out how a criterion or sub-criterion can affect the outcome of a problem.

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Appendix A

A.1. Questionnaires for vehicle manufacturing technology selection

Two questionnaires based on two stakeholders, managers and customers viewpoints, were designed to elicit the relative importance between the criteria, sub-criteria and alternatives.

A.1.1. Managers' viewpoints

Questionnaire

(Managers' viewpoints)

Dear replier,

In today's world, an important part of economic development in each country is related to industry development of that country. In this regard, the huge industry, such as car manufacturing industries, has special places, because of its investment and making the job vacancies. In this process, the selection of appropriate technology is a great role.

Evaluation and making the priority of criteria that influence the selection of technology and also, making the priority of technologies' alternatives based on those criteria, is a complex process. It is necessary to consider the diverse stakeholders of decision-makers to ensure that the selected technology will be in direction of the goals of national development.

The aim of designing this questionnaire is to prioritise the efficient criteria for selection of technology from stakeholder of managers. It is obvious that the success depends on collaborate of managers and specialists who fill in this questionnaire. With your help, you will give me the chance to complete the project.

Please pay attention to the following notes before completing the questionnaire.

1- Since your name and personal details will not be written, thus you do not have any limitation to answer the questions. In this regard you will be free from any responsibility.

2- This questionnaire has been designed to use the =, >, and < symbols besides some numerical (verbal) description that make it easy to apply.

3- Please try to answer all of the questions if possible. If you could not answer any question, please leave it blank.

4- The manner of answering the questions in this questionnaire is so that in each question just two criteria (alternatives) will be compared to each other. When you compare these two criteria or alternatives, please do not pay attention to other criteria and just consider the two given criteria. Do not put more than one number in the pre-determined space and do not mark more than one on the specified locations. (There is an example in the next pages. Please read it for better understanding.)

5- Please pay attention to the following definitions that have been used in the questions.

- **Net profit** is the difference between the cost of a product and the selling price in the market.
- **Added value** is the monetary value difference between two consecutive work in progress stages of producing a product. Sometimes the meaning of added value is being applied instead of pure benefit. It should be noted that they are entirely different. For instance, it may be possible a product has had a high added value and low pure benefit, and vice versa. An obvious example is the cars that their entire components import from outside a country and assembled inside. These cars have low added value, while they may have high pure benefits. Note that the high added value in a country indicates the high technical and technological potentiality.
- **Price of technology** is that price that should be paid by a company to buy machineries, equipments, concession licence, softwares, management systems, etc.
- **Export possibility** is the ability to export the products to other countries.
- **National market share** is the ability of obtaining market share inside a country.
- **International market share** is the ability of obtaining market share outside a country.
- **Manufacturing technology** is the method of products manufacturing, stages and process of manufacturing, control methods, etc. Manufacturing technology can be manual, automatic, or combination of

manual and automatic. Whatever the machineries and equipments in a manufacturing system increase, the technology will be newer and will need more funds rather than manual systems.

- **Know-how** is an entire set of methods, technical maps, documents, softwares, preventive and repairing systems, technical characteristic, etc.
- **Flexibility** means the ability to use the same machineries, processes, moulds, jigs, fixtures, etc. to produce a new product(s) with the reasonable time and cost. If the products of a class can use the parts and components of other products from the same class, then the technology is flexible.
- **Quality of technology** is the quality of stages and process of manufacturing technology.
- **National supports** is a set of related and complement chains of after-sale services, repairing centres, distribution networks, parts and components producers, skilled labours (repairers, sellers, professional parts producers, etc.).
- **International supports** is the level of services that the seller can give the buyer of technology to ensure that these services will continue in the long life of a technology, helping on accommodating of the technology in the normal time, helping in expanding the technology to international markets, etc.
- **National make ability** means that we have permission to make the parts and components inside the country.
- **Government supports** is the supports that the government can provide for companies based on political, social and economical limitations.
- **Customers' styles** are the consistency with customers' requirements.
- **National trust** is a criterion to measure how much a technology can acquire the people' trusts.
- **Suitability with consumption pattern** is the consistency with consumption pattern which can be predicted in a long-term plan of a country.

General qualifications of replier:

1- Level of education:

2- Type of specialty:

3- Type of position:

4- How long have you been related to car industry?

5- Your company:

An example

Suppose that for buying a house four criteria have been considered as:

- number of bedrooms,
- closeness to urban services,
- social environment,
- silence of area.

It is obvious that the importance of these criteria is not identical for everybody. For example, it can be quite possible that the closeness of the house to urban services may be preferred against silence of area from one person, and for another person, it may be vice versa. Sometimes the preference of one criterion against another criterion can be neuter that means two criteria do not have any preference against each other.

Please pay attention to the following table.

Criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	A O B	□
Closeness to urban services	Silence of area		

In order to compare each criterion against another criterion, we will use the mathematical operators (=, >, <). If one prefer A criterion (closeness to urban services) against B criterion (silence of area), ">" will be put inside the circle. If B criterion is preferred, then "<" will be put inside the circle. If the preference of criteria is identical to each other, then "=" will be put inside the circle. The next stage is identifying how much a criterion is preferred to another one. To do this, we will use the numerical judgement. These numbers are 1 to 9 that are defined as following table.

Verbal Judgement	Numerical Judgement
Extremely preferred	9
Very strongly to Extremely preferred	8
Very strongly Preferred	7
Strongly to very strongly preferred	6
Strongly preferred	5
Moderately to strongly preferred	4
Moderately preferred	3
Equally to moderately preferred	2
Equally preferred	1

The number then will be put in the square. With this process, while two criteria or alternative are compared with each other, in the meantime the degree of preferences also will have been identified.

Now suppose one wants to select a house between two alternatives (A and B) using one of the four criteria. In order to select a house, it is clear that one should compare the alternatives with regard o each of the aforementioned criteria.

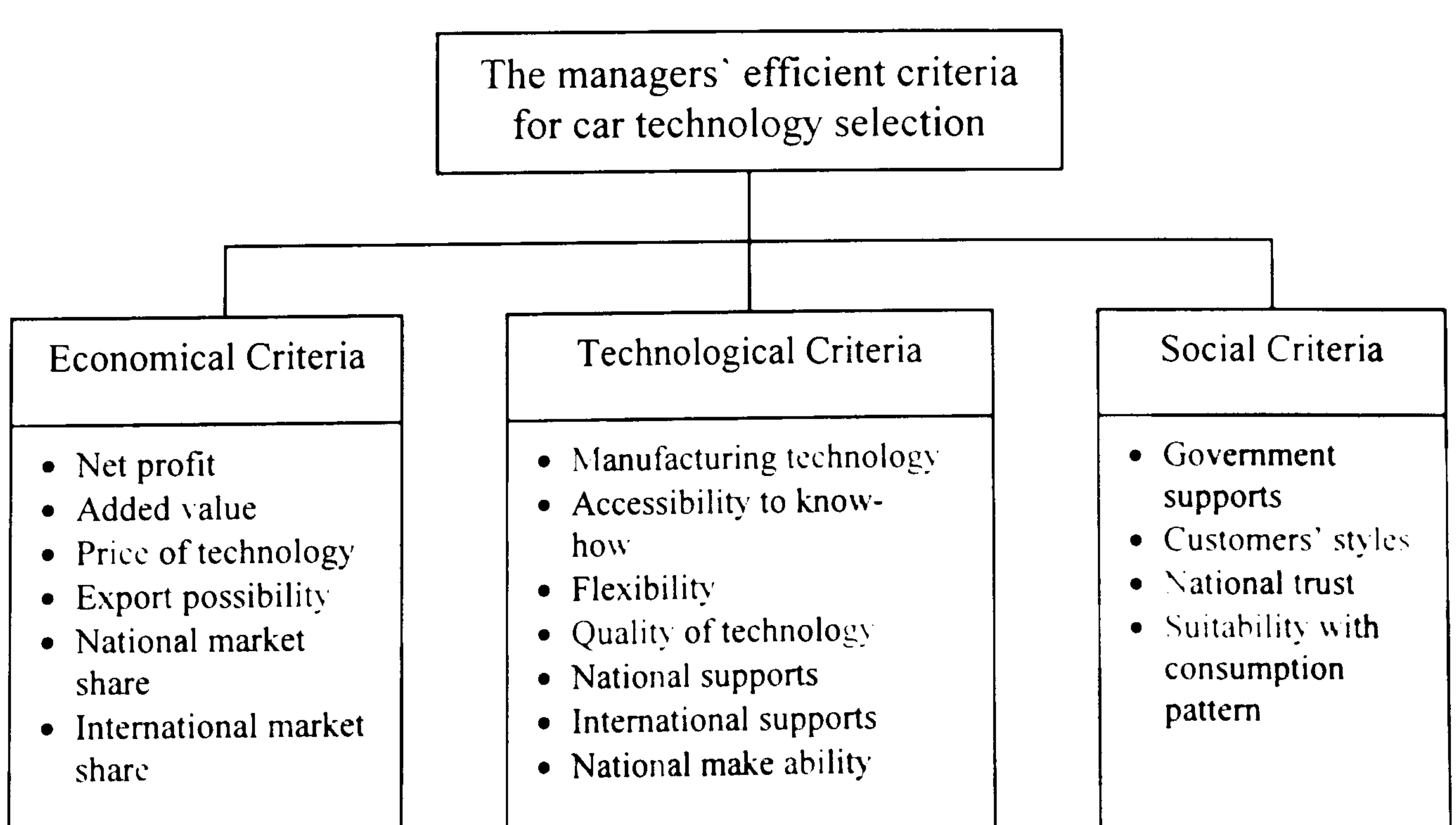
Please pay attention to the following table.

Criteria: silence of area		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
House		A O B	□
A	B		

If one prefers house A against house B regard to that criterion (silence of area), then he should put ">" in the circle. If he prefers house B compared with house A, then he should put "<" in the circle. If the preference of house A and B be identical, then he put "=" in the circle. For example, suppose one prefer house A against house B. in this case, he should put ">" in the circle. Then he should answer how much he has preferred house A against B. suppose he moderately prefers A against B. Then, he should put number 3 in the square.

The base of this questionnaire is identical to the above example. You always compare two alternatives regard to a specified criterion or compare criteria against each other. It should be noted again when you compare two criteria, you should concentrate only on those two criteria and do not attention to other criteria. Since all of the criteria will compare to each other pairwisely, the final result encompasses the all of the criteria in the decision-making process.

Please fill in the questionnaire based on below figure



Comparison tables for criteria

In your opinion, when you want to evaluate a proposal to select a car technology, which of the economical, technological, and social criteria are more important? Please put the appropriate symbol (=, >, <) in the specific place (the column which has been identified by AOB). Then identify how much one criterion is more important to another one by putting the number 1 to 9 in the specific place (the column which has been identified by square).

> Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
> **1**: Equally Preferred **2**: Equally to Moderately Preferred **3**: Moderately Preferred
> **4**: Moderately to Strongly Preferred **5**: Strongly Preferred
> **6**: Strongly to Very Strongly Preferred **7**: Very Strongly Preferred
> **8**: Very Strongly to Extremely Preferred **9**: Extremely Preferred

Criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	AOB	□
Economical	Technological		
Economical	Social		
Technological	Social		

Comparison tables for economical sub-criteria

In the following table, the sub-criteria of economical criteria will be compared to each other. Please fill it in.

> Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
> **1**: Equally Preferred **2**: Equally to Moderately Preferred **3**: Moderately Preferred
> **4**: Moderately to Strongly Preferred **5**: Strongly Preferred
> **6**: Strongly to Very Strongly Preferred **7**: Very Strongly Preferred
> **8**: Very Strongly to Extremely Preferred **9**: Extremely Preferred

Economical Sub-criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	AOB	□
Net profit	Added value		
Net profit	Price of technology		
Net profit	Export possibility		
Net profit	National market share		
Net profit	International market share		
Added value	Price of technology		
Added value	Export possibility		
Added value	National market share		
Added value	International market share		
Price of technology	Export possibility		
Price of technology	National market share		
Price of technology	International market share		
Export possibility	National market share		
Export possibility	International market share		
National market share	International market share		

Comparison tables for technological sub-criteria

In the following table, the sub-criteria of technological criteria will be compared to each other. Please fill it in.

Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
1: Equally Preferred **2**: Equally to Moderately Preferred **3**: Moderately Preferred
4: Moderately to Strongly Preferred **5**: Strongly Preferred
6: Strongly to Very Strongly Preferred **7**: Very Strongly Preferred
8: Very Strongly to Extremely Preferred **9**: Extremely Preferred

Technological Sub-criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	AOB	□
Manufacturing technology	Accessibility to know-how		
Manufacturing technology	Flexibility		
Manufacturing technology	Quality of technology		
Manufacturing technology	National supports		
Manufacturing technology	International supports		
Manufacturing technology	National make ability		
Accessibility to know-how	Flexibility		
Accessibility to know-how	Quality of technology		
Accessibility to know-how	National supports		
Accessibility to know-how	International supports		
Accessibility to know-how	National make ability		
Flexibility	Quality of technology		
Flexibility	National supports		
Flexibility	International supports		
Flexibility	National make ability		
Quality of technology	National supports		
Quality of technology	International supports		
Quality of technology	National make ability		
National supports	International supports		
National supports	National make ability		
International supports	National make ability		

Comparison tables for social sub-criteria

In the following table, the sub-criteria of social criteria will be compared to each other. Please fill it in.

Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
1: Equally Preferred **2**: Equally to Moderately Preferred **3**: Moderately Preferred
4: Moderately to Strongly Preferred **5**: Strongly Preferred
6: Strongly to Very Strongly Preferred **7**: Very Strongly Preferred
8: Very Strongly to Extremely Preferred **9**: Extremely Preferred

Social Sub-criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	AOB	□
Government supports	Customers' style		
Government supports	National trust		
Government supports	Suitability with consumption pattern		
Customers' style	National trust		
Customers' style	Suitability with consumption pattern		
National trust	Suitability with consumption pattern		

Comparison tables for alternatives regard to all of the sub-criteria

In these tables, the alternatives will be compared to each other regard to all of the sub-criteria (economical, technological, and social sub-criteria). When you fill in the table, please notice that the technology is important not the products that technology can produce.

Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
1: Equally Preferred **2:** Equally to Moderately Preferred **3:** Moderately Preferred **4:** Moderately to Strongly Preferred **5:** Strongly Preferred
6: Strongly to Very Strongly Preferred **7:** Very Strongly Preferred **8:** Very Strongly to Extremely Preferred **9:** Extremely Preferred

Economical criteria		Net profit (Sub-criteria)		Added value (Sub-criteria)		Price of technology (Sub-criteria)		Export possibility (Sub-criteria)		National market share (Sub-criteria)		International market Share (sub-criteria)	
A	B	AOB	□	AOB	□	AOB	□	AOB	□	AOB	□	AOB	□
Fiat	Honda												
Fiat	Hyundai												
Fiat	Toyota												
Fiat	VolksWagen												
Honda	Hyundai												
Honda	Toyota												
Honda	VolksWagen												
Hyundai	Toyota												
Hyundai	VolksWagen												
Toyota	VolksWagen												

Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
1: Equally Preferred **2:** Equally to Moderately Preferred **3:** Moderately Preferred **4:** Moderately to Strongly Preferred **5:** Strongly Preferred
6: Strongly to Very Strongly Preferred **7:** Very Strongly Preferred **8:** Very Strongly to Extremely Preferred **9:** Extremely Preferred

Technological criteria		Manufacturing technology (Sub-criteria)		Accesibility to know-how (Sub-criteria)		Flexibility (Sub-criteria)		Quality of technology (Sub-criteria)		National supports (Sub-criteria)		International supports (Sub-criteria)		National make ability (Sub-criteria)	
A	B	AOB	□	AOB	□	AOB	□	AOB	□	AOB	□	AOB	□	AOB	□
Fiat	Honda														
Fiat	Hyundai														
Fiat	Toyota														
Fiat	VolksWagen														
Honda	Hyundai														
Honda	Toyota														
Honda	VolksWagen														
Hyundai	Toyota														
Hyundai	VolksWagen														
Toyota	VolksWagen														

Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
1: Equally Preferred **2**: Equally to Moderately Preferred **3**: Moderately Preferred **4**: Moderately to Strongly Preferred **5**: Strongly Preferred **6**: Strongly to Very Strongly Preferred **7**: Very Strongly Preferred **8**: Very Strongly to Extremely Preferred **9**: Extremely Preferred

Social criteria		Government supports (Sub-criteria)		Customers' style (Sub-criteria)		National trust (Sub-criteria)		Suitability with Consumption Pattern (Sub-criteria)	
A	B	AOB	□	AOB	□	AOB	□	AOB	□
Fiat	Honda								
Fiat	Hyundai								
Fiat	Toyota								
Fiat	VolksWagen								
Honda	Hyundai								
Honda	Toyota								
Honda	VolksWagen								
Hyundai	Toyota								
Hyundai	VolksWagen								
Toyota	VolksWagen								

A.1.2. Customers' viewpoints

Questionnaire

(Customers' viewpoints)

Dear replier,

This questionnaire has been designed to evaluate the priority of each car manufacturing technology based on several effective factors. Since the production of goods and services in a competitive economical environment is affected by consumers' style, therefore with knowing your style, the manufacturers will be able to manufacture the products that satisfy your needs and can be competitive in the worldwide.

Evaluation and making the priority of criteria that influence the selection of car technology and also, making the priority of technologies' alternatives based on those criteria, is a complex process. It is necessary to consider the diverse viewpoints of decision-makers to ensure that the selected technology will be in direction of the goals of national development.

The aim of designing this questionnaire is to prioritise the efficient criteria for selection of car manufacturing technology from viewpoints of customers. It is obvious that the success depends on collaborate of customers who fill in this questionnaire. With your help, you will give me the chance to complete the project.

Please pay attention to the following notes before completing the questionnaire.

1- Since your name and personal details will not be written, thus you do not have any limitation to answer the questions. In this regard you will be free from any responsibility.

2- If you are living with other adults, you can answer the questions with consult with others.

3- This questionnaire has been designed to use the =, >, and < symbols besides some numerical (verbal) description that make it easy to apply.

4- Please try to answer all of the questions if possible. If you could not answer any question, please leave it blank.

5- The manner of answering the questions in this questionnaire is so that in each question just two criteria (alternatives) will be compared to each other. When you compare these two criteria or alternatives, please do not pay attention to other criteria and just consider the two given criteria or alternatives. Do not put more than one number in the pre-determined space and do not mark more than one on the specified locations. (There is an example in the next pages. Please read it for better understanding.)

6- Filling in the questionnaire may be taken some time. If you are feeling tired, please fill it in separate by separate in several turns.

7- Please pay attention to the following definitions that have been used in the questions.

- **Comfort** is the state of being from suffering, pain or anxiety when one sitting in the car for driving.
- **Elegant** is concerned with beauty of a car.
- **Type** is the class of cars, such as Fiat, Honda, and Toyota.
- **Dimension and shape** is the size and outer form or appearance of a car.
- **Modern equipment** is the ability of having electrical equipment and having air conditioner.
- **Price** is the price that one should pay for buying a car.
- **Fuel Consumption** is the consumption of fuel in a given measurement such as mile per gallon or in 100 kilometres.
- **Repairing cost** is the average cost one should pay for repairing a breakdown of a car.
- **Easy to sell second hand** means the ability or how easy one can sell his used car to market.
- **Safety** is the measure of not being dangerous or in danger.
- **Durability** is a measure of useful life.
- **Horsepower** is a unit for measuring the power of engines` cars.
- **Easy to repair** means the ability or how easy a repairman can repair a car.

8- The following table provides the data for alternatives regard to tangible criteria.

Model	Price		Fuel Consumption			Power @ 1000 rpm	
	(S)	Normal	(MPG)	(LPM)	Normal	(H)	Normal
Punto (Fiat)	15000	0.181	37	0.123	0.141	11.8	0.102
Civic (Honda)	18000	0.217	26	0.175	0.201	24.6	0.213
Elantra (Hyundai)	14000	0.168	24	0.189	0.217	22.5	0.195
Celica (Toyota)	16000	0.193	27	0.168	0.193	21.9	0.190
GTI VR6 (Volks Wagen)	20000	0.241	21	0.216	0.248	34.5	0.300

General questions of replier:

1- Your age:

2- Male or female:

3- Your job:

4- Your annual salary:

5- Your degree:

6- Had or have you had any cars?

7- How many times have you changed your car?

8- How many times have you bought a brand new car?

9- How much time have you used your previous car and then have changed it?

10- What type of car do you have at the present?

11- How many persons have contributed to fill in this questionnaire?

12- If you intend to buy a brand new car, what is your maximum budget?

An example

Suppose that for buying a pair of shoes four criteria have been considered as:

- Price,
- Durability,
- Comfort,
- Elegance.

It is obvious that the importance of these criteria is not identical for everybody. For example, it can be quite possible that the price of shoes may be preferred against comfort from one viewpoint, and for another person, it may be vice versa. Sometimes the preference of one criterion against another criterion can be neuter that means two criteria do not have any preference against each other.

Please pay attention to the following table.

Criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	A O B	□
Price	Elegance		

In order to compare each criterion against another criterion, we will use the mathematical operators (=, >, <). If one prefer A criterion (price) against B criterion (elegance), ">" will be put inside the circle. If B criterion is preferred, then "<" will be put inside the circle. If the preference of criteria is identical to each other, then "=" will be put inside the circle. The next stage is identifying how much a criterion is preferred to another one. To do this, we will use the numerical judgement. These numbers are 1 to 9 that are defined as following table.

Verbal Judgement	Numerical Judgement
Extremely preferred	9
Very strongly to Extremely preferred	8
Very strongly Preferred	7
Strongly to very strongly preferred	6
Strongly preferred	5
Moderately to strongly preferred	4
Moderately preferred	3
Equally to moderately preferred	2
Equally preferred	1

The number then will be put in the square. With this process, while two criteria or alternative are compared with each other, in the meantime the degree of preferences also will have been identified.

Now suppose one wants to select a pair of shoes between two alternatives (A and B) using one of the four criteria. In order to select a pair of shoes, it is clear that one should compare the alternatives with regard to each of the aforementioned criteria.

Please pay attention to the following table.

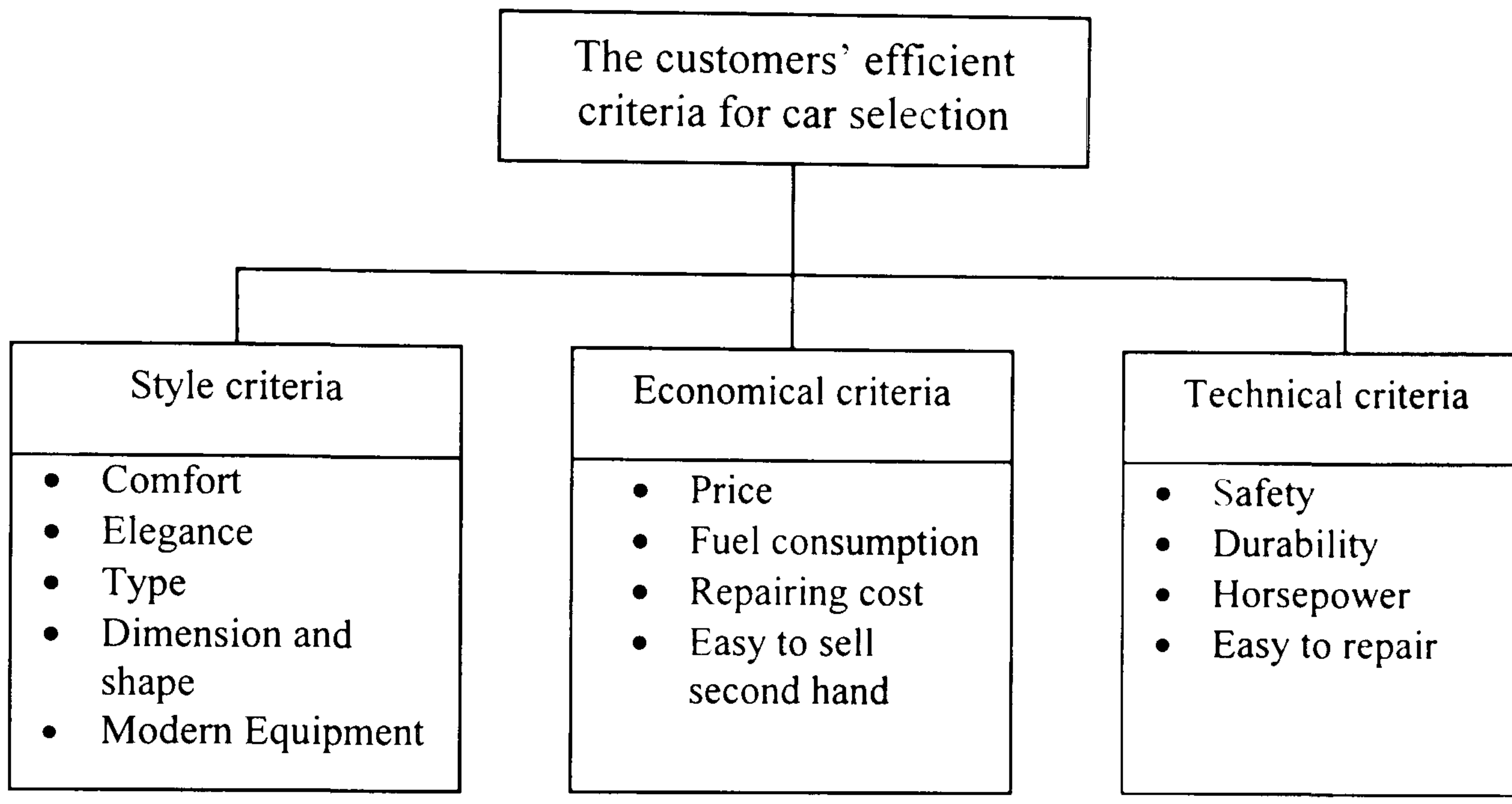
Criteria: Elegance		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
Pair of shoes		A O B	□
A	B		

If one prefers shoes A against shoes B regard to that criterion (elegance), then he should put ">" in the circle. If he prefers shoes B compared with shoes A, then he should put "<" in the circle. If the preference of house A and B be identical, then he put "=" in the circle. For example, suppose one prefer shoes A against shoes B. In this case, he should put ">" in the circle. Then he should answer how much he has preferred shoes A against B. suppose he moderately prefers A against B. Then, he should put number 3 in the square.

The base of this questionnaire is identical to the above example. You always compare two alternatives regard to a specified criterion or compare criteria against each other. It should be noted again when you compare two criteria, you should concentrate only on those two criteria and do not attention to other criteria. Since all of the criteria will compare to each other pairwisely. the final result encompasses the all of the criteria in the decision-making process.

When you fill in the questionnaire, please notice to the left hand top corner criteria in those table that alternatives will be compared to that criteria.

Please fill in the questionnaire based on below figure



Comparison tables for criteria

In your opinion, when you want to buy a car, which of the style, economical, and technical criteria are more important? Please put the appropriate symbol (>, <, =) in the specific place (the column which has been identified by AOB). Then identify how much one criterion is more important to another one by putting the number 1 to 9 in the specific place (the column which has been identified by square).

> Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
> **1**: Equally Preferred **2**: Equally to Moderately Preferred **3**: Moderately Preferred
> **4**: Moderately to Strongly Preferred **5**: Strongly Preferred
> **6**: Strongly to Very Strongly Preferred **7**: Very Strongly Preferred **8**: Very Strongly to Extremely Preferred **9**: Extremely Preferred

Criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	AOB	□
Style	Economical		
Style	Technical		
Economical	Technical		

Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
1: Equally Preferred **2**: Equally to Moderately Preferred **3**: Moderately Preferred
4: Moderately to Strongly Preferred **5**: Strongly Preferred
6: Strongly to Very Strongly Preferred **7**: Very Strongly Preferred **8**: Very Strongly to Extremely Preferred **9**: Extremely Preferred

Style Sub-criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	AOB	□
Comfort	Elegance		
Comfort	Type		
Comfort	Dimension and shape		
Comfort	Modern equipments		
Elegance	Type		
Elegance	Dimension and shape		
Elegance	Modern equipments		
Type	Dimension and shape		
Type	Modern equipments		
Dimension and shape	Modern equipments		

Comparison tables for economical sub-criteria

In the following table, the sub-criteria of economical criteria will be compared to each other. Please fill it in.

Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
1: Equally Preferred **2**: Equally to Moderately Preferred **3**: Moderately Preferred
4: Moderately to Strongly Preferred **5**: Strongly Preferred
6: Strongly to Very Strongly Preferred **7**: Very Strongly Preferred **8**: Very Strongly to Extremely Preferred **9**: Extremely Preferred

Economical Sub-criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	AOB	□
Price	Fuel consumption		
Price	Repairing costs		
Price	Easy to sell second hand		
Fuel consumption	Repairing costs		
Fuel consumption	Easy to sell second hand		
Repairing costs	Easy to sell second hand		

Comparison tables for technical sub-criteria

In the following table, the sub-criteria of technical criteria will be compared to each other. Please fill it in.

Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
1: Equally Preferred **2:** Equally to Moderately Preferred **3:** Moderately Preferred
4: Moderately to Strongly Preferred **5:** Strongly Preferred
6: Strongly to Very Strongly Preferred **7:** Very Strongly Preferred **8:** Very Strongly to Extremely Preferred **9:** Extremely Preferred

Technical sub-criteria		Type of preference (=, >, <)	How much is it preferred? (1,2,3,4,5,6,7,8,9)
A	B	AOB	□
Safety	Durability		
Safety	Horsepower		
Safety	Easy to repair		
Durability	Horsepower		
Durability	Easy to repair		
Horsepower	Easy to repair		

Comparison tables for alternatives regard to all of the sub-criteria

In this stage, the alternatives will be compared to each other regard to all of the sub-criteria (style, economical, and technical sub-criteria). When you fill in the table, please notice that the technology of car is important not the type of products that technology can produce (for example, the Peugeot technology can produce several types of cars, such as 206, 307, 405, 406, and etc.).

Please put one of the =, >, or < in the column **AOB** for type of preference. Please put the numbers 1 to 9 regard to following definition in the column □.
1: Equally Preferred **2:** Equally to Moderately Preferred **3:** Moderately Preferred
4: Moderately to Strongly Preferred **5:** Strongly Preferred
6: Strongly to Very Strongly Preferred **7:** Very Strongly Preferred **8:** Very Strongly to Extremely Preferred **9:** Extremely Preferred

Technical criteria		**Safety (Sub-criteria)**		**Durability (Sub-criteria)**		**Horsepower (Sub-criteria)**		**Easy to repair (Sub-criteria)**	
A	B	AOB	□	AOB	□	AOB	□	AOB	□
Fiat	Honda								
Fiat	Hyundai								
Fiat	Toyota								
Fiat	Volks Wagen								
Honda	Hyundai								
Honda	Toyota								
Honda	Volks Wagen								
Hyundai	Toyota								
Hyundai	Volks Wagen								
Toyota	Volks Wagen								

Please put **one** of **the** =, >, **or** < **in the column AOB for** type of preference. **Please put the numbers** 1 **to** 9 **regard to** following definition **in the column** □.
1: Equally Preferred **2:** Equally to Moderately Preferred **3:** Moderately Preferred **4**: Moderately to Strongly Preferred
5: Strongly Preferred **6:** Strongly to Very Strongly Preferred **7:** Very Strongly Preferred
8: Very Strongly to Extremely Preferred **9:** Extremely Preferred

Style **criteria**		**Comfort (Sub-criteria)**		**Elegance (Sub-criteria)**		**Type (Sub-criteria)**		**Dimension and shape (Sub-criteria)**		**Modern equipments (Sub-criteria)**	
A	B	AOB	□	AOB	□	AOB	□	AOB	□	AOB	□
Fiat	Honda										
Fiat	Hyundai										
Fiat	Toyota										
Fiat	Volks Wagen										
Honda	Hyundai										
Honda	Toyota										
Honda	Volks Wagen										
Hyundai	Toyota										
Hyundai	Volks Wagen										
Toyota	Volks Wagen										

Please put **one** of the =, >, or < in the column **AOB for type of preference**. Please **put the numbers** 1 **to** 9 regard **to** following definition in the **column** □.
1: Equally Preferred **2: Equally** to Moderately **Preferred 3: Moderately** Preferred
4: Moderately to Strongly **Preferred 5**: Strongly **Preferred 6: Strongly to Very Strongly** Preferred
7: Very Strongly Preferred **8: Very Strongly** to Extremely Preferred **9:** Extremely Preferred

Economical criteria		Price (Sub-criteria)		Fuel consumption (Sub-criteria)		**Repairing costs (Sub-criteria)**		Easy to sell second hand (Sub-criteria)	
A	B	AOB	□	AOB	□	AOB	□	AOB	□
Fiat	Honda								
Fiat	Hyundai								
Fiat	Toyota								
Fiat	Volks Wagen								
Honda	Hyundai								
Honda	Toyota								
Honda	Volks Wagen								
Hyundai	Toyota								
Hyundai	Volks Wagen								
Toyota	Volks Wagen								

Appendix B

Questionnaires for peristaltic pump case study

Dear participant,

The aim of designing this questionnaire is to prioritise and weightings the criteria or sub-criteria for selection of pump design alternatives from viewpoints of manufacturing department, customers and marketing department. Evaluation and making the priority of criteria that influence the selection of pump alternative designs, is a complex process. It is necessary to consider the diverse levels of criteria and sub-criteria to ensure that the selected alternative will be in direction of the predetermined goals. It is obvious that the success depends on collaborate of participants who fill in this questionnaire. With your help, you will give me the chance to complete the project.

There are some notes in the following paragraph that helps you to fill in the questionnaire. In addition, an example has been provided to clarify the manner of filling in the questionnaire, as well.

The manner of answering the questions in this questionnaire is so that in each question just two criteria (alternatives) will be compared to each other. When you compare these two criteria or alternatives, please do not pay attention to other factors and just concentrate on the two given criteria or alternatives.

Please try to answer all of the questions if possible. If you are not able to answer any question, please leave it blank.

An example

Suppose that for buying a pair of shoes four criteria have been considered as:

- Price,
- Durability,
- Comfort,
- Elegance.

It is obvious that the importance of these criteria is not identical for everybody. For example, it can be quite possible that the price of shoes may be preferred against comfort from one viewpoint, and for another viewpoint, it may be vice versa.

Sometimes the preference of one criterion against another criterion can be neuter that means two criteria do not have any preference against each other.

Please pay attention to the following table. In this table the criteria are compared with each other. If price of product is more important than durability of product, then you should write **X** in the Preference column because price is in the **X** column. If the importance degree of price of product is as same as comfort of product, then you should put **E** in the pertinent cell. If elegant of product is more important than durability of product, then write **Y** in the related cell because now elegance is in the **Y** column.

Criteria		Preference X, Y, or E (Equal)?	How much? (1 to 9)
X	**Y**		
Price	Durability	X	5
Price	Comfort	E	1
Durability	Elegance	Y	3

The next stage is assigning the numeric to verbal judgements in the pairwise comparisons. Assume that price of product is strongly preferred by you against the durability. In this case, based on the below table, put the number **5** in the "How much?" column. Because price and Comfort has not got any preference to each other, then number **1** should be placed at pertinent cell in the "How much?" column. Finally assume that elegance is moderately preferred against durability. In this case, again based on the below table, you should write number **3** in the cell.

Assignment of numbers to verbal judgements

Verbal Judgement	Numerical Judgement
Extremely preferred	9
Very strongly to Extremely preferred	8
Very strongly Preferred	7
Strongly to very strongly preferred	6
Strongly preferred	5
Moderately to strongly preferred	4
Moderately preferred	3
Equally to moderately preferred	2
Equally preferred	1

The next step is to compare each alternative regard to each criterion. Assume that three buying shoes alternative is available (A, B, and C). In this step, we compare the alternatives with each other regard to criteria such as price and comfort. The previous procedure is repeated in order to evaluate the relative importance of each alternative regard to each criterion and to assign the numbers to relative importance. Assume that the price of alternative B is preferred to C and price of alternative C is preferred to A. In this case that is obvious that the price of alternative

B is preferred to alternative A. Then we should put **Y**, **Y**, and **X**, respectively in the column of Price (X, Y, or E). After that, it is necessary to assign numbers to those have been compared. Again, it can be done using the numbers in the table. For example we can assign **3**, **6**, and **2** to those pairwised comparisons in the pertinent column. The same procedure is repeated to the column of Comfort.

Alternatives		Price		Comfort	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
A	B	Y	3		
A	C	Y	6		
B	C	X	2		

The base of this questionnaire is identical to the above example. You always compare two criteria, sub-criteria and alternatives regard to a specified criterion or compare criteria against each other. It should be noted again when you compare two criteria, you should concentrate only on those two criteria and do not attention to other criteria. Since all of the criteria will compare to each other pairwisely, the final result encompasses the all of the criteria in the decision-making process.

Please fill in the questionnaire based on figures B.1 to B.3

Based on below figures, please fill it the following questionnaire based on physical, operational, physical and operational and market view. When you try to fill it in, three situations may be occurred:

I) Criterion **X** is preferred to criterion **Y**,

II) Criterion **X** is equally preferred to criterion **Y**,

III) Criterion **Y** is preferred to criterion **X**.

When one of the cases of I and III have been occurred, you should determine which criterion is preferred. In this case, please write one of the letters **X**, **Y**, or **E**, in the determined cell. If you write the **X** in the determined cell means the criterion on the **X** column is preferred to the criterion in the **Y** column and vice versa. If you write the **E** in the predetermined cell, means that from your viewpoint, two criteria in the **X** and **Y** column has the equal preference. If you write X or Y in the predetermined cell, means that you preferred one of them against another one, you should determine in this stage, how much one criterion is preferred to another one. The number for assigning how much is one criterion is preferred to another one, are listed below. If case II is happened (the criteria have not got any preferences to each other), just put the number **1** in the specified place or leave it blank.

First, the criteria in the level 2 of figures are compared with each other. Then the sub-criteria will be compared with each other, and finally the sub-criteria regard to each design alternative will be compared.

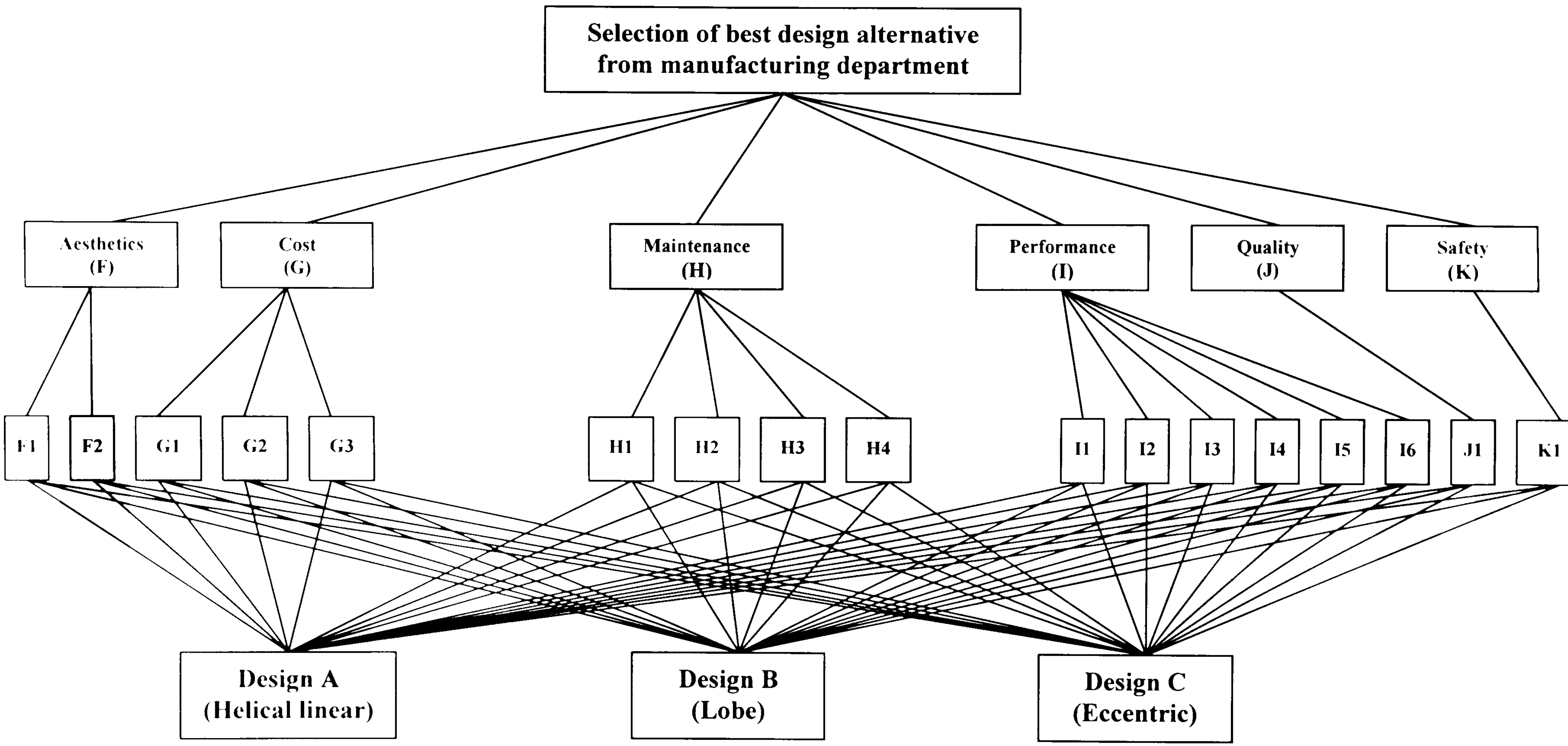


Figure B.1 The hierarchy from manufacturing department

Pairwise comparison of Criteria (level 1) for manufacturing department

Criteria		Preference X, Y, or E (Equal)?	How much? (1 to 9)
X	Y		
Aesthetics (F)	Cost (G)		
Aesthetics (F)	Maintenance (H)		
Aesthetics (F)	Performance (I)		
Aesthetics (F)	Quality (J)		
Aesthetics (F)	Safety (K)		
Cost (G)	Maintenance (H)		
Cost (G)	Performance (I)		
Cost (G)	Quality (J)		
Cost (G)	Safety (K)		
Maintenance (H)	Performance (I)		
Maintenance (H)	Quality (J)		
Maintenance (H)	Safety (K)		
Performance (I)	Quality (J)		
Performance (I)	Safety (K)		
Quality (J)	Safety (K)		

Pairwise comparison of Sub-Criteria (level 2) for manufacturing department

Criteria		Preference X, Y, or E (Equal)?	How much? (1 to 9)
X	Y		
Conveys elements of Verder & Verderflex branding **(F1)**	Conveys recommendations made from affective design study **(F2)**		
GMU purchase cost **(G1)**	Manufacturing process cost **(G2)**		
GMU purchase cost **(G1)**	Material cost **(G3)**		
Manufacturing process cost **(G2)**	Material cost **(G3)**		
Hose replacement time **(H1)**	Bearing replacement time **(H2)**		
Hose replacement time **(H1)**	Hose burst bearing protection **(H3)**		
Hose replacement time **(H1)**	GMU replacement time **(H4)**		
Bearing replacement time **(H2)**	Hose burst bearing protection **(H3)**		
Bearing replacement time **(H2)**	GMU replacement time **(H4)**		
Hose burst bearing protection **(H3)**	GMU replacement time **(H4)**		
May be cleaned / sterilised by CIP / SIP **(I1)**	Inlet / discharge **(I2)**		
May be cleaned / sterilised by CIP / SIP **(I1)**	Fluid path **(I3)**		
May be cleaned / sterilised by CIP / SIP **(I1)**	Load support **(I4)**		
May be cleaned / sterilised by CIP / SIP **(I1)**	Hose support **(I5)**		
May be cleaned / sterilised by CIP / SIP **(I1)**	Zero cross contamination **(I6)**		
Inlet / discharge **(I2)**	Fluid path **(I3)**		
Inlet / discharge **(I2)**	Load support **(I4)**		
Inlet / discharge **(I2)**	Hose support **(I5)**		
Inlet / discharge **(I2)**	Zero cross contamination **(I6)**		
Fluid path **(I3)**	Load support **(I4)**		
Fluid path **(I3)**	Hose support **(I5)**		
Fluid path **(I3)**	Zero cross contamination **(I6)**		
Load support **(I4)**	Hose support **(I5)**		
Load support **(I4)**	Zero cross contamination **(I6)**		
Hose support **(I5)**	Zero cross contamination **(I6)**		

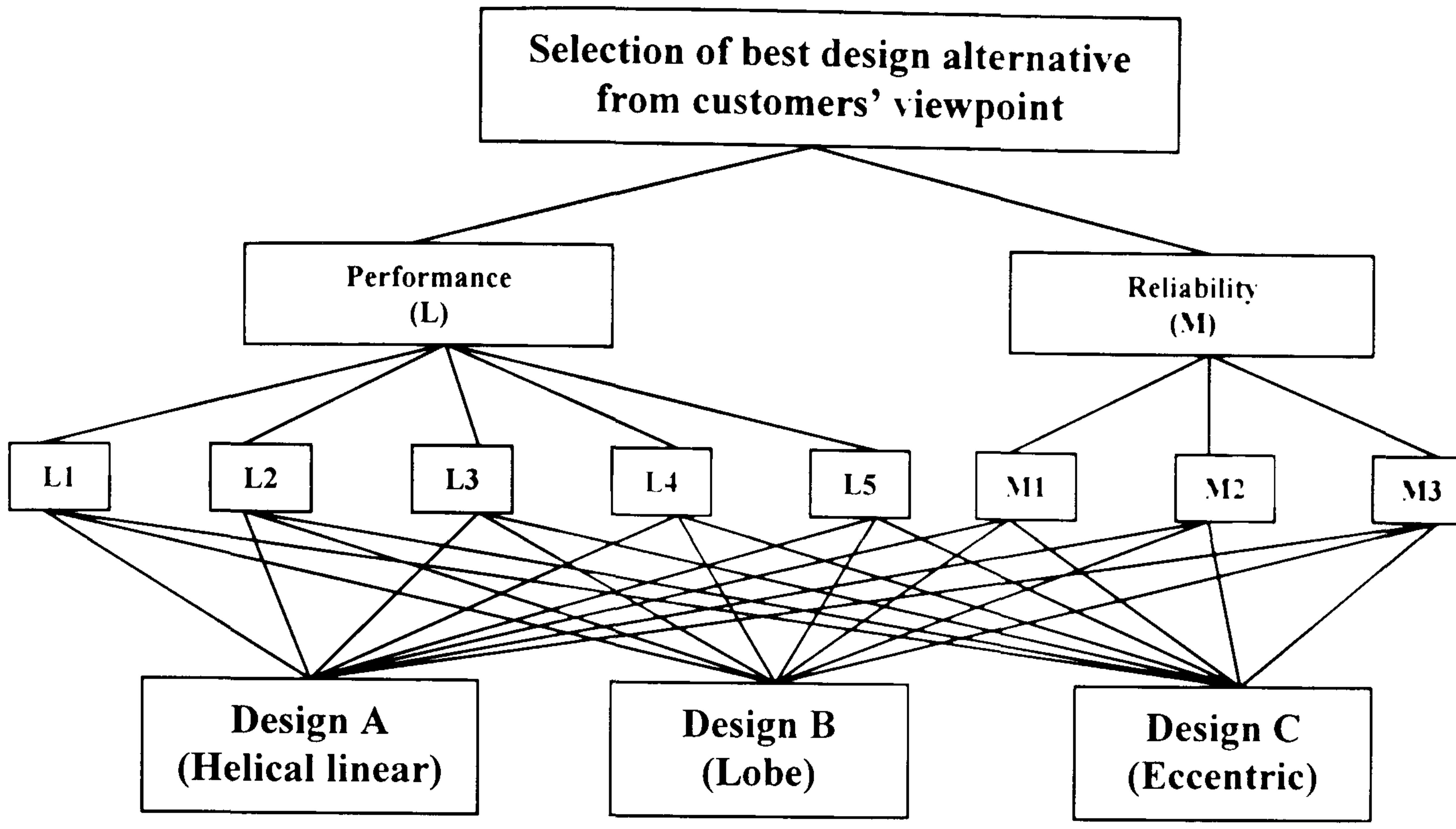


Figure B.2 The hierarchy from customers' viewpoint

Pairwise comparison of Criteria (level 1) for customers' viewpoint

Criteria X	Criteria Y	Preference X, Y, or E (Equal)?	How much? (1 to 9)
Performance (L)	Reliability (M)		

Pairwise comparison of Sub-Criteria (level 2) for customers' viewpoint

Sub-Criteria X	Sub-Criteria Y	Preference X, Y, or E (Equal)?	How much? (1 to 9)
Continuous max flow (L1)	Flow repeatability (L2)		
Continuous max flow (L1)	Load dynamics (L3)		
Continuous max flow (L1)	Efficiency (L4)		
Continuous max flow (L1)	Discharge pressure (L5)		
Flow repeatability (L2)	Load dynamics (L3)		
Flow repeatability (L2)	Efficiency (L4)		
Flow repeatability (L2)	Discharge pressure (L5)		
Load dynamics (L3)	Efficiency (L4)		
Load dynamics (L3)	Discharge pressure (L5)		
Efficiency (L4)	Discharge pressure (L5)		
Pump head reliability (M1)	GMU reliability (M2)		
Pump head reliability (M1)	Hose life (M3)		
GLU reliability (M2)	Hose life (M3)		

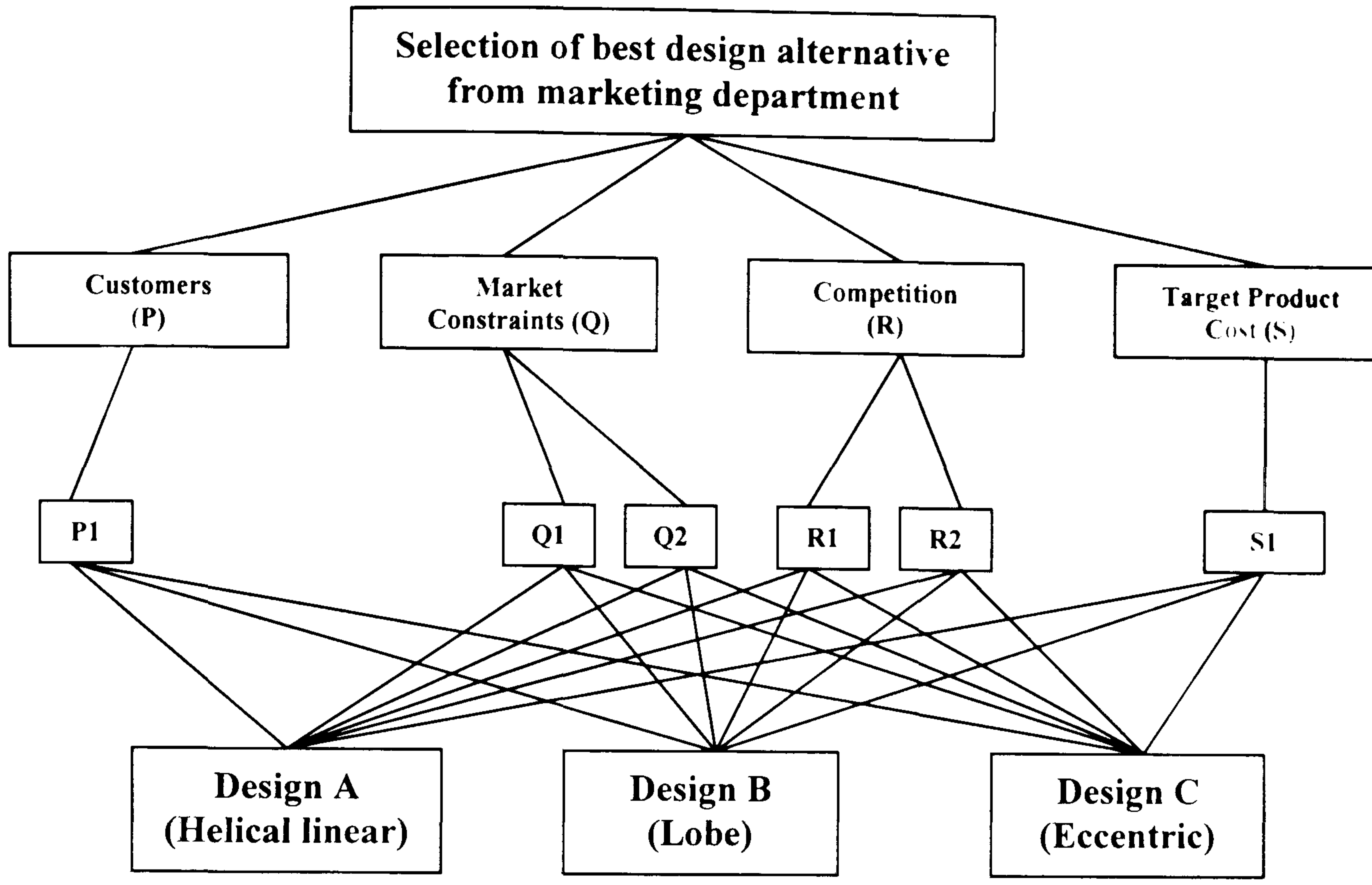


Figure B.3 The hierarchy from marketing department

Pairwise comparison of Criteria (level 1) for marketing department

Sub-Criteria		Preference X, Y, or E (Equal)?	How much? (1 to 9)
X	Y		
Customer **(P)**	Market constraints **(Q)**		
Customer **(P)**	Competition **(R)**		
Customer **(P)**	Target product cost **(S)**		
Market constraints **(Q)**	Competition **(R)**		
Market constraints **(Q)**	Target product cost (S)		
Competition **(R)**	Target product cost (S)		

Pairwise comparison of Sub-Criteria (level 2) for marketing department

Sub-Criteria		Preference X, Y, or E (Equal)?	How much? (1 to 9)
X	Y		
Market acceptance due to aesthetics **(Q1)**	Posesses traditional 'hallmarks' of High quality **(Q2)**		
Performance against direct competition such as Bredel, Abaque and Delasco **(R1)**	Performance against indirect competition such as AOD and PC pumps **(R2)**		

Pairwise comparisons of Sub-Criteria in manufacturing department regard to design alternatives

Manufacturing department		Aesthetic (F)				Cost (G)					
		Conveys elements of Verder & Verderflex branding (F1)		Conveys recommendations made from affective design study (F2)		GMU purchase cost (G1)		Manufacturing process cost (G2)		Material cost (G3)	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
Helical Linear (A)	Lobe (B)										
Helical Linear (A)	Eccentric (C)										
Lobe (B)	Eccentric (C)										

Pairwise comparisons of Sub-Criteria in manufacturing department (level 2) regard to design alternatives

Manufacturing department		Maintenance (H)							
		Hose replacement time (H1)		Bearing replacement time (H2)		Hose burst bearing protection (H3)		GMU replacement time (H4)	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
Helical Linear (A)	Lobe (B)								
Helical Linear (A)	Eccentric (C)								
Lobe (B)	Eccentric (C)								

Pairwise comparisons of Sub-Criteria in manufacturing department (level 2) regard to design alternatives

Manufacturing department		Performance (I)					
		May be cleaned / sterilised by CIP / SIP (I1)		Inlet / discharge (I2)		Fluid path (I3)	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
Helical Linear (A)	Lobe (B)						
Helical Linear (A)	Eccentric (C)						
Lobe (B)	Eccentric (C)						

Pairwise comparisons of Sub-Criteria in manufacturing (level 2) regard to design alternatives

Manufacturing department		Performance (I)					
		Load support (I4)		Hose support (I5)		Zero cross Contamination (I6)	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
Helical Linear (A)	Lobe (B)						
Helical Linear (A)	Eccentric (C)						
Lobe (B)	Eccentric (C)						

Pairwise comparisons of Sub-Criteria in manufacturing department (level 2) regard to design alternatives

		Quality (J)		Safety (K)	
Manufacturing department		Quality (J1)		Safety (K1)	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
Helical Linear (A)	Lobe (B)				
Helical Linear (A)	Eccentric (C)				
Lobe (B)	Eccentric (C)				

Pairwise comparisons of Sub-Criteria in customers' viewpoint (level 2) regard to design alternatives

		Performance (L)									
Customers' viewpoint		Continuous max flow (L1)		Flow repeatability (L2)		Load dynamics (L3)		Efficiency (L4)		Discharge pressure (L5)	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
Helical Linear (A)	Lobe (B)										
Helical Linear (A)	Eccentric (C)										
Lobe (B)	Eccentric (C)										

Pairwise comparisons of Sub-Criteria in customers' viewpoint (level 2) regard to design alternatives

		Reliability (M)					
Customers' viewpoint		Pump head reliability (M1)		GMU reliability (M2)		Hose life (M3)	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
Helical Linear (A)	Lobe (B)						
Helical Linear (A)	Eccentric (C)						
Lobe (B)	Eccentric (C)						

Pairwise comparisons of Sub-Criteria in marketing department (level 2) regard to design alternatives

		Customer (P)		Market constraints (Q)			
Marketing department		Applicable to key functions: dosing/metering, filtering and general fluid transfer (P1)		Market acceptance due to aesthetics (Q1)		Posesses traditional 'hallmarks' of High quality (Q2)	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
Helical Linear (A)	Lobe (B)						
Helical Linear (A)	Eccentric (C)						
Lobe (B)	Eccentric (C)						

Pairwise comparisons of Sub-Criteria in marketing department (level 2) regard to design alternatives

		Competition (R)				Target product cost (S)	
Marketing department		Performance against direct competition such as Bredel, Abaque and Delasco **(R1)**		Performance against indirect competition such as AOD and PC pumps **(R2)**		Target product cost (S1)	
X	Y	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)	X, Y, or E (Equal)?	How much? (1 to 9)
Helical Linear (A)	Lobe (B)						
Helical Linear (A)	Eccentric (C)						
Lobe (B)	Eccentric (C)						

Appendix C

Table 44 Summary of managers' results

Criteria A	Criteria B	Geometric Average	Number of Respondent
Economical	Technological	2.7080	12
Economical	Social	3.5269	12
Technological	Social	1.9318	12
Economical Sub-criteria		Geometric Average	Number of Respondent
A	**B**		
Net profit	Added value	1.2046	12
Net profit	Price of technology	3.5043	12
Net profit	Export possibility	1.1725	12
Net profit	National market share	2.9676	12
Net profit	International market share	1.2095	12
Added value	Price of technology	2.2091	12
Added value	Export possibility	1.0699	12
Added value	National market share	2.7673	11
Added value	International market share	1.1508	12
Price of technology	Export possibility	0.8158	12
Price of technology	National market share	0.9797	12
Price of technology	International market share	0.7043	11
Export possibility	National market share	2.9584	11
Export possibility	International market share	1.0828	11
National market share	International market share	0.3429	11
Technological Sub-criteria		Geometric Average	Number of Respondent
A	**B**		
Manufacturing technology	Accessibility to know-how	0.8028	10
Manufacturing technology	Flexibility	1.0265	11
Manufacturing technology	Quality of technology	1.2329	11
Manufacturing technology	National supports	1.2130	11
Manufacturing technology	International supports	0.6300	12
Manufacturing technology	National make ability	1.8393	12
Accessibility to know-how	Flexibility	1.5014	12
Accessibility to know-how	Quality of technology	1.2169	12
Accessibility to know-how	National supports	1.9888	12
Accessibility to know-how	International supports	1.5415	12
Accessibility to know-how	National make ability	2.0060	12
Flexibility	Quality of technology	0.6041	11
Flexibility	National supports	1.1508	11
Flexibility	International supports	0.9289	11
Flexibility	National make ability	1.2962	11
Quality of technology	National supports	1.7955	11
Quality of technology	International supports	1.1018	12
Quality of technology	National make ability	1.2791	11
National supports	International supports	0.6186	11
National supports	National make ability	0.7510	11
International supports	National make ability	1.4250	11
Social Sub-criteria		Geometric Average	Number of Respondent
A	**B**		
Government supports	Customers' style	1.3775	12
Government supports	National trust	0.9193	12
Government supports	Suitability with consumption pattern	1.5015	12
Customers' style	National trust	0.4159	12
Customers' style	Suitability with consumption pattern	0.8869	12
National trust	Suitability with consumption pattern	1.5244	12

Table 44 Summary of managers' results (Continued)

Economical criteria		Net profit (Sub-criteria)		Added value (Sub-criteria)		Price of technology (Sub-criteria)		Export possibility (Sub-criteria)		National market share (Sub-criteria)		International market Share (sub-criteria)	
A	B	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number
Fiat	Honda	0.9346	6	0.6934	6	0.8909	6	0.4338	6	0.3219	6	0.7419	6
Fiat	Hyundai	0.2794	6	0.2489	6	0.2932	6	2.1822	6	1.8860	6	1.4422	6
Fiat	Toyota	0.5054	6	0.5503	6	0.8327	6	0.7418	6	0.2308	6	0.8909	6
Fiat	VolksWagen	0.5363	6	0.6934	6	1.0379	6	0.5673	6	0.3061	6	0.6933	6
Honda	Hyundai	0.2772	6	0.2472	6	0.3376	6	3.5115	6	3.0143	6	1.6189	6
Honda	Toyota	1.0000	6	0.7418	6	0.8327	6	1.2010	6	0.7418	6	1.2599	6
Honda	VolksWagen	0.5054	6	0.8909	6	1.1230	6	0.9346	6	1.2599	6	0.8326	6
Hyundai	Toyota	3.3089	6	3.0389	6	2.6387	6	0.4724	6	0.2763	6	0.5673	6
Hyundai	VolksWagen	3.7141	6	3.5115	6	3.4065	6	0.2473	6	0.3062	6	0.4869	6
Toyota	VolksWagen	0.9532	6	1.5131	6	1.5131	6	0.6933	6	1.8172	6	0.8326	6

Table 44 Summary of managers' results (Continued)

Technological criteria		Manufacturing technology (Sub-criteria)		Accessibility to know - how (Sub-criteria)		Flexibility (Sub-criteria)		Quality of technology (Sub-criteria)		National Supports (Sub-criteria)		International supports (Sub-criteria)		National market ability (Sub-criteria)	
A	B	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number
Fiat	Honda	0.5888	6	1.0700	6	0.4283	6	0.5503	6	0.5143	6	0.8116	6	0.4209	6
Fiat	Hyundai	2.4495	6	0.2545	6	1.3480	6	0.5673	6	0.5868	6	0.5259	6	0.6368	6
Fiat	Toyota	.0.3029	6	0.5302	6	0.5503	6	0.3400	6	0.4903	6	0.6177	6	0.4082	6
Fiat	VolksWagen	0.4724	6	0.5673	6	0.6813	6	0.3865	6	0.4338	6	0.7647	6	0.7937	6
Honda	Hyundai	2.6207	6	0.3328	6	2.0397	6	0.5673	6	0.4801	6	0.4778	6	1.7963	6
Honda	Toyota	0.7418	6	0.7647	6	0.6609	6	0.7418	6	0.8326	6	0.8326	6	0.7937	6
Honda	VolksWagen	0.5774	6	0.5673	6	0.7418	6	0.6299	6	0.7418	6	0.7418	6	1.2009	6
Hyundai	Toyota	0.2371	6	3.7141	6	0.4582	6	0.3240	6	1.1301	6	2.1720	6	0.4338	6
Hyundai	VolksWagen	0.2371	6	3.9468	6	0.3376	6	0.2918	6	1.7042	6	1.5255	6	0.8182	6
Toyota	VolksWagen	1.2009	6	1.6189	6	1.2599	6	0.8326	6	1.5131	6	1.0000	6	1.6984	6

Table 44 Summary of managers' results (Continued)

Social criteria		Government supports (Sub-criteria)		Customers' style (Sub-criteria)		National trust (Sub-criteria)		Suitability with Consumption Pattern (Sub-criteria)	
A	B	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number
Fiat	Honda	0.6934	6	0.8736	6	0.4808	6	1.1225	6
Fiat	Hyundai	0.2692	6	0.9346	6	1.8172	6	0.4902	6
Fiat	Toyota	0.5503	6	0.7147	6	0.4724	6	0.6609	6
Fiat	VolksWagen	0.6177	6	1.1225	6	0.5246	6	0.8584	6
Honda	Hyundai	0.2692	6	2.0801	6	2.1170	6	0.9346	6
Honda	Toyota	1.0000	6	0.8909	6	0.8909	6	1.0000	6
Honda	VolksWagen	0.8326	6	1.0700	6	1.1225	6	1.0000	6
Hyundai	Toyota	3.1881	6	0.4082	6	0.3219	6	0.7937	6
Hyundai	VolksWagen	3.3879	6	0.6070	6	0.2763	6	0.7783	6
Toyota	VolksWagen	1.2599	6	1.2599	6	1.0000	6	1.1225	6

Table 45 Summary of customers' results

Criteria		Geometric Average	Number Of Respondent
A	**B**		
Style	Economical	0.4050	28
Style	Technical	0.5727	29
Economical	Technical	1.4158	30
Style Sub-criteria		Geometric Average	Number Of Respondent
A	**B**		
Comfort	Elegance	1.7464	28
Comfort	Type	1.6806	30
Comfort	Dimension and shape	1.5951	28
Comfort	Modern equipments	1.3707	27
Elegance	Type	0.9453	27
Elegance	Dimension and shape	1.4501	28
Elegance	Modern equipments	0.9261	31
Type	Dimension and shape	1.1555	29
Type	Modern equipments	1.4751	28
Dimension and shape	Modern equipments	0.9672	29
Economical Sub-criteria		Geometric Average	Number Of Respondent
A	**B**		
Price	Fuel consumption	2.0150	30
Price	Repairing costs	1.3409	30
Price	Easy to sell second hand	0.8888	30
Fuel consumption	Repairing costs	0.5192	29
Fuel consumption	Easy to sell second hand	0.6388	30
Repairing costs	Easy to sell second hand	1.1342	30
Technical Sub-criteria		Geometric Average	Number Of Respondent
A	**B**		
Safety	Durability	1.5590	30
Safety	Horsepower	2.5569	31
Safety	Easy to repair	1.9480	29
Durability	Horsepower	2.9657	29
Durability	Easy to repair	1.4202	30
Horsepower	Easy to repair	0.7884	29

Table 45 Summary of customers' results (Continued)

Style criteria		**Comfort (Sub-criteria)**		**Elegance (Sub-criteria)**		**Type (Sub-criteria)**		**Dimension and shape (Sub-criteria)**		**Modern equipments (Sub-criteria)**	
A	**B**	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number
Fiat	Honda	0.2369	29	0.2681	30	0.2484	26	0.3105	26	0.2852	27
Fiat	Hyundai	0.6596	25	0.7392	29	0.7952	25	0.7918	26	0.6976	26
Fiat	Toyota	0.1907	30	0.2701	31	0.2372	27	0.2380	27	0.2816	27
Fiat	Volks Wagen	0.3658	28	0.4835	28	0.3608	24	0.3282	26	0.3627	24
Honda	Hyundai	3.9573	28	3.4469	30	3.3500	27	2.1860	29	2.2181	27
Honda	Toyota	0.5369	27	0.5073	29	0.4975	26	0.5953	27	0.6761	27
Honda	Volks Wagen	1.4331	27	1.6933	28	1.2193	24	1.2208	28	1.6599	25
Hyundai	Toyota	0.2463	29	0.3001	30	0.2289	26	0.3187	29	0.2930	28
Hyundai	Volks Wagen	0.4122	27	0.5953	28	0.5276	23	0.4114	28	0.7554	26
Toyota	Volks Wagen	1.4161	27	2.0583	27	1.6663	22	1.4282	27	1.7606	26

Table 45 Summary of customers' results (Continued)

Table 45 Summary of customers' results (Continued)

Economical criteria		Price (Sub-criteria)		Fuel consumption (Sub-criteria)		Repairing costs (Sub-criteria)		Easy to sell second hand (Sub-criteria)	
A	B	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number
Fiat	Honda	1.2849	29	1.5575	26	0.6167	25	0.3662	28
Fiat	Hyundai	0.6815	28	1.5605	26	0.4746	25	0.8405	27
Fiat	Toyota	1.6697	29	2.5536	27	0.4715	25	0.3279	28
Fiat	Volks Wagen	1.7206	27	1.1652	25	1.0138	23	0.3628	25
Honda	Hyundai	0.7211	28	1.3946	25	0.7861	24	2.3385	27
Honda	Toyota	0.8464	28	0.5973	26	0.7554	24	0.5359	27
Honda	Volks Wagen	1.1033	26	1.5100	27	1.3405	25	1.2115	27
Hyundai	Toyota	2.0068	29	0.7269	28	0.7950	24	0.3320	27
Hyundai	Volks Wagen	1.4743	28	1.1141	26	1.6663	25	0.6530	26
Toyota	Volks Wagen	1.7410	27	1.9149	26	2.2890	25	1.9786	27

Table 45 Summary of customers' results (Continued)

Technical criteria		Safety (Sub-criteria)		Durability (Sub-criteria)		Horsepower (Sub-criteria)		Easy to repair (Sub-criteria)	
A	B	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number	Geometric Average	Number
Fiat	Honda	0.2927	27	0.3549	27	0.3988	27	0.6494	22
Fiat	Hyundai	0.9732	26	1.4297	28	0.9021	27	0.6263	22
Fiat	Toyota	0.2546	27	0.2585	27	0.3512	27	0.4245	23
Fiat	Volks Wagen	0.3321	25	0.2884	26	0.4332	26	0.7669	21
Honda	Hyundai	3.4267	27	3.6849	26	2.8493	27	1.1948	23
Honda	Toyota	0.7272	25	0.5998	25	1.4611	26	0.6274	20
Honda	Volks Wagen	0.8647	27	0.5746	25	0.9595	25	1.1591	21
Hyundai	Toyota	0.2615	28	0.2640	26	3.0921	27	0.4523	22
Hyundai	Volks Wagen	0.3756	27	0.3141	26	0.5085	26	1.1460	21
Toyota	Volks Wagen	1.2943	25	0.7965	26	1.2295	25	1.8045	21