Making Infrastructure Legible

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This thesis is dedicated to the hackers, kludgers and jugaadists of the world: the truest ingenuity is found not in those who make, but in those who must make do.

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Abstract

This thesis represents the development and pilot application of a novel methodology for the speculative qualitative assessment (or "prototyping") of new infrastructural systems. Its core aim and guiding principle is to *make infrastructure legible*: to reveal and narrate its role in everyday life from a more human perspective than that of the paradigmatic technology-focussed approach. Or, more simply, the project aims to understand how infrastructures develop, how they evolve and entangle over time.

The methodology is centred on a novel model of sociotechnical change, known as the infrastructural trialectic. The trialectic makes a unique relational distinction between infrastructural systems and the technologies through which infrastructural functions are accessed, traces vectors of influence between focal actors in the model, and provides a framework for mapping the articulatory institutions which are enrolled in the formation and mutation of infrastructural assemblages.

The methodology has two modes of application: the historical mode, and the speculative. In the historical mode, the trialectic model becomes the lens of a situated longue duree analysis which explores the historical dynamics of sociotechnical change in the assemblages underpinning a particular everyday practice.

In the speculative mode, the findings from the historical mode are used as the basis for an extrapolative and speculative analysis of a novel technological intervention into the practice previously analysed. Drawing on techniques from strategic foresight and critical design, the prospective technology is "prototyped" against the context of a suite of four divergent near-future scenarios, so as to "stress test" the plausibility of its deployment under difficult circumstances.

This thesis presents and applies a novel model of sociotechnical change, and in doing so demonstrates that the shortcomings of paradigmatic models of change might be addressed through such an approach. It further demonstrates a unique hybrid method for the assessment and critique of new technologies and practices alike, which provides a more human perspective upon infrastructure (and indeed upon change itself) than prevailing approaches to assessment.

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Chapter 1

Introduction

1.1 *Everyday magic*: the ubiquity of infrastructure

For the vast majority of the citizens of the United Kingdom, infrastructure is an effectively ubiquitous presence in everyday life, enabling or otherwise underpinning countless actions and activities, from the technical to the mundane.

Take, for example, the making of a cup of tea—what could be more simple? But as most often performed, even this deceptively domestic act involves significant infrastructural support. Turn the tap to fill your kettle, and you marshal the resources of a catchment-wide network of reservoirs, pumps, pipes and treatment works, with little more thought or effort than opening a cupboard. Switch on the kettle, and an increasingly international network of generation and distribution springs into action, boiling your freshly provided potable water at no more complex or demanding a signal than a snap of your fingers. And that's without even beginning to consider the global logistical networks which brought tea, coffee, sugar and much, much more to the kitchen tables of a country in which none of those crops are native...

Making a cup of tea is simplicity itself by comparison to a truly contemporary action, such as reading the news on a smartphone. With the touch of a finger on capacitive glass, you send and summon data from locations scattered all across the globe, linked by a latticework of copper cables and glass fibres, and suspended in a sea of electromagnetic signals. The routers and data centres and backbones and base-stations of that network are all by necessity connected to their local energy networks, which may themselves in turn be managed, in part or in whole, by means of flows of data passing through the communications systems for which they provide the power. When you touch the screen of a smartphone, you are making a request of what is unarguably the largest and most complex machine known to humankind—but you do so for a reason most mundane, and with the simplest of gestures.

Infrastructure is ubiquitous, then—but it is also illegible.

1.2 *Everyday illusion*: the illegibility of infrastructure

It's not that we do not see infrastructure—though much of it is hidden from sight, and quite purposefully so—but that, like fragments of a much larger manuscript, those pieces which we do see are insufficient to convey the meaning of the whole. The mechanism of this illegibility is a form of self-effacement: when performing as it should, infrastructure literally fades into the background or melts into the walls, manifest only in the ongoing possibility of certain forms of action.

We may turn to science fiction for a metaphor that lets us get a little closer to infrastructural illegibility, in the form of the third of Arthur C Clarke's "laws", which states:

> "Any sufficiently advanced technology is indistinguishable from magic." (Clarke, 1973)

Note that, counter to some contemporary readings—whether journalistic (Dormehl, 2018; Matthews, 2018) or academic (Feied, Handler, Gillam, & Smith, 2009)—Clarke is not conflating his categories. He's not claiming that magic and technology are the same thing, only that those uninitiated to either paradigm would have no basis upon which to distinguish them.

Likewise, infrastructure is not magic—but then magic isn't really magic either: it's illusion, prestidigitation, sleight of hand. And supporting the illusion of consumerism is exactly what infrastructure does: while you watch the illusionist's white gloved hand (your tap, your kettle, your smartphone screen), infrastructure is busy behind the illusionist's back (or yours), propping up his patter, setting up the trick without showing you the workings.

Infrastructure puts the rabbit in the hat. It doesn't merely provide; it also provides the illusion of effortless and immediate provision *ex nihilo*. This illusion produces the illegibility of infrastructure with which this project is concerned.

1.3 *Heavy weather*: three challenges to illegible infrastructure

Why, then, is this a problem? Should we not consider the nigh-magical affordances of modern infrastructure as both the crowning achievement and just reward of technoscientific endeavour? Why need infrastructure be legible to anyone other than those organisations and institutions whose duty is to build and/or manage it? Isn't this rather blissful form of ignorance the proof and product of specialisation as a civilisational strategy? Or, more bluntly: isn't this the sort of problem best left to domain experts?

This attitude to infrastructure has arguably served us well enough to date, but its efficacy is fading fast in the face of three mutually entangled external challenges which, considered together, demand that we develop a more comprehensive and systemic appreciation of these systems of ubiquitous provision.

The first challenge is that of a changing climate, and it's double-edged—because not only will infrastructures have to adapt to changes in climate (which will impact in all sorts of ways upon their operational parameters, and upon patterns of usage and demand), but they must also play a vital role in its mitigation, given that they are utterly complicit in its (re)production (Raven, 2017a). Or, more simply: given climate change is in significant part the outcome of human resource extraction and consumption as amplified and extended by infrastructural systems, any attempt to address climate change which doesn't appreciate the role of infrastructure is doomed to failure. (Note that resource depletion and pollution are significant elements of climate change in which infrastructure is also complicit, and should be treated as being of equal importance to the "headline" phenomena of temperature change, sea-level rise etc, if not as being causal of them; see e.g. Steer, 2014, .)

The second challenge is demography. Population growth may be slowing, but populations are still growing overall, and it's not just a matter of numbers: climate change and conflict are generating migration and internal displacement, while economic factors are driving rapid urbanisation, in the process exacerbating soaring inequalities between different sections of society (Behrens & Robert-Nicoud, 2014), which are manifest in the increasingly fevered contestation of scarce natural resources. Given infrastructure's role in the extraction, processing and distribution of resources (see again Raven, 2017a), a deeper appreciation of these functions and their (re)production is a prerequisite to meeting this looming socioeconomic crisis; this is not simply to see infrastructure, then, but to see infrastructure as a tool for social justice, if only potentially so.

The third challenge to infrastructural illegibility is political, in what is perhaps a more profound sense than that of the demographic challenge. For while infrastructure can be seen as the medium of economics—the board upon which the game of trade is played, if you like—it can also be seen as the medium of the media (or the metamedium), as the system-of-systems through which "the media" are themselves distributed and mediated. All discourse, all debate, however profound, however banal—absolutely *all* knowledge exchange with *anyone* other than your immediate neighbours is enabled and distributed by infrastructural systems. It therefore follows that infrastructure is also, in effect, the medium of democracy—and at time of writing, the last few years have provided a surfeit of examples of how access to or control over infrastructural systems might be used to pervert, frustrate and even undermine the democratic principle (Shackelford et al., 2017), in addition to creating more mundane and immediate forms of disruption. Therefore if we wish to preserve the practice of democracy, or perhaps even improve it, it behoves us to reveal and understand the systems which make it possible.

These three challenges—which are really just three aspects of a far broader existential crisis for humanity—would all be reduced by a solid understanding of the dynamics of infrastructural change over the long term. But given that infrastructure is costly, slow to build and long to last, the challenges further require the projection of that understanding into the troubled and uncertain times ahead. For most people, the ubiquity of infrastructure is only apparent at the moment in which it fails—which, even in the most low-stakes circumstances, is almost always too late.

1.4 *High stakes, long bets*: three constituencies for infrastructural legibility

As such, there are three major use-cases for infrastructural legibility, associated with three different constituencies of stakeholder. For civil engineers, system managers and the like, infrastructural legibility informs the ability to successfully manage and maintain extant systems in an ever-changing context.

For policymakers, planners and activists, infrastructural legibility underwrites the ability to effectively plan upgrades, expansions and reconfigurations of infrastructural provision which may take decades to deliver.

For citizens, perhaps most importantly of all, infrastructural legibility is a precondition of an infrastructural mandate, which we might describe as the political will to support (and pay for) infrastructural reconfigurations. New and/or upgraded systems will be costly and disruptive, and while citizens may (and often do) enthuse at the prospect of new or improved provision, the sacrifices necessary to make it happen may prove a hard sell in the absence of a clear argument for their necessity and utility (Damigos, Tourkolias, & Diakoulaki, 2009; Hensher, Shore, & Train, 2006). Or, more simply: it's hard to get people to pay more for their magic, or to accept a less magical service for the same cost as before.

Meeting these challenges for these consituencies necessitates an understanding of how the things people do coevolve with the systems they make use of in doing them. But it is clearly impossible to study change which has yet to occur—and therefore a deeper understanding of historic changes in infrastructural provision offers us the most likely source of precedents for navigating the necessary changes ahead.

With that said, while this project starts from an understanding that the reconfiguration of infrastructures (and of the actions for which we make use of infrastructures) is a pressing necessity, it does not seek normative conclusions: the question is not "how should infrastructure be changed?", but rather "how does infrastructure change (or not change)?" We begin with an assertion: it should be recognised that what little basis exists for normative claims on infrastructural futurity is alarmingly thin, and that systematic primary research is required in order to ground such investigations going forward. The project that follows represents the development and application of a methodology intended to fulfill that purpose.

A note on style

Before continuing with this thesis, some explanation may be necessary regarding the style and approach thereof. This PhD project was explicitly funded as an interdisciplinary enquiry, located somewhere between civil engineering on the one hand, and urban studies and planning on the other. Furthermore, due to its author's unusual career path, the resulting work also partakes in ideas and approaches from social theory, Science and Technology Studies, media theory and futures studies. As a result, the meta-challenge of the project was that of developing a novel conceptual language that could be parsed by scholars from both sides of the disciplinary divide defined by the funding—as well as, ideally, by scholars from a variety of other disciplines, for whom infrastructure is a *terra incognita* of increasing importance.

The conceptual language thus developed (as set out in the literature review and the methodological explorations to follow) is in turn supported by a style of analysis (and of writing) which is rather more "literary" in character than is traditional to civil engineering, the discipline under whose official aegis it was developed, and perhaps even unusually verbose by the standards of the more mainstream social sciences. Or, to be uncharacteristically blunt: it is wordy, and its structure is strongly influenced by narrative and historical approaches, rather than by the structured and quantitative rigours of the "hard" sciences.

This does not merit any apology—indeed, the rarity of similarly qualitative and narrative approaches to sociotechnical change remains, for the author at least, among the greatest of justifications for taking this approach. But it does perhaps merit a caveat for those more accustomed to a clear division between data and analysis, which are necessarily blended together in this project (particularly in chapters 5, 6 and 7). The necessity of writing the majority of this thesis in the so-called "passive voice" (avoiding the use of the first person, in other words—a practice which is more widely accepted in the social sciences, but still largely considered anathema among engineers) can serve to blur the distinction between data and analysis still further, as it may not be immediately apparent when the "I" of the researcher is interpreting on the reader's behalf, rather than the sources speaking to them directly. (The use of direct quotations from sources rather than paraphrasing represents one way, among many, which this more narrative style attempts to foreground the data/analysis distinction without unduly disrupting the flow of the narrative being delivered).

Furthermore, with regard to the linguistic style of the work, it bears noting that all disciplines are reliant upon words and concepts which are familiar to their initiates, but may be obscure, obtuse or arcane to outsiders; such a lexicon allows for both concision and precision, even as it demands much of the uninitiated reader. That the conceptual lexicon developed herein may be unfamiliar to many of its readers is regrettable, but also unavoidable: therein lies the difficulty of truly interdisciplinary work, in that it involves not so much the bridging of two disciplines as the creation of an entirely new one. Likewise for the lexicon more broadly: this thesis deploys words which are arcane, or at least unfamiliar to the context of common usage, but it does so for much the same reason that an engineer might deploy a complicated piece of calculus, or a technical term—which is to say, for the sake of brevity. This may seem an odd excuse, given that this is a long thesis even when measured by the standards of the social sciences. Nonetheless, it would have been far longer still if not for recourse to the precision and concision offered by particular choices of words.

In summary: because of what it was commissioned to achieve, and due to the particular methods deployed to achieve those ends, this thesis is neither a short read, nor a simple one. But nor is it impenetrable—and it is hoped that the ideas and narratives contained within it will prove a more than adequate reward for the reader's patience.

Chapter 2

Literature Review

Introduction

As suggested in the introduction, there are two main aspects to this project: an attempt to understand historical processes of change in infrastructure, and an attempt to speculate on potential future changes in infrastructure. While the methods and findings of the former must necessarily inform the latter, the processes are nonetheless distinct, and thus the relevant literatures are reviewed separately below.

2.1 Hindsight: studying historical change in infrastructures

To oversimplify more than a little, there are two basic approaches to studying technological change, distinguished by their primary focus: some look first at technology, while others look first at people.

2.1.1 Technology-centric approaches

In search of "infrastructure"

It first bears noting that there must be theories or understandings of infrastructural change within the broader literatures of the disciplines directly concerned with the construction, management and maintenance of specific infrastructures, even if they are not formally codified. There is a developmental history implicit in the self-conception of civil engineers, as there is in any field of human endeavour: an in-group understanding of how things got to be the way they are. Regrettably, but perhaps not surprisingly, these histories are extremely partial, in both senses of the term. Indeed, it would be no insult to describe them more properly as mythologies, the foundations of which may be found in such series as Samuel Smiles' *Lives of the Engineers* (Smiles, 1866)—a sequence of largely affectionate Great Man hagiographies which foreground the actions and talents of a few prominent individuals at the expense of their context, thus establishing the dubious narrative of civil engineering as an entirely rational and apolitical project whose success is as inevitable as it is unquestioned.

But as argued in the introduction, even were such disciplinary origin-stories factual, they would be of little use in the context of this project, which is oriented precisely toward inter- and transdisciplinary understandings; if we seek a model of infrastructural change that is rigorous and not specific to a particular technology or system, we must therefore look beyond the literatures of the civil engineers.

What, then, of literatures aimed at infrastructure more broadly? The greatest surprise here might be that such literatures are few and far between, though that claim deserves some qualification: the use of "infrastructure" as a key search term in academic search engines returns a great many results, but the vast majority of these are pertinent only to computer science and IT systems management, which use the term infrastructure as a catch-all label for the hardware aspect of their operations. Filtering for these leaves plenty of results, but the majority of those tend to be highly domain-specific—pertaining only to water infrastructures, for instance, or to the materiality of oil pipelines—and non-tautologous definitions of the term "infrastructure" are notable by their absence. This may have something to do with its comparatively recent rise to prominence in English usage, and the even more recent specificity of the notion of infrastructure as used in everyday discourse, whereby the term becomes concrete rather than relational (see e.g. Raven, 2017a).

Hansman, Magee, De Neufville, Robins, and Roos (2006) is perhaps the earliest paper of significance to argue specifically for the study of infrastructure as a multidisciplinary, multi-system topic, and sets out an ambitious research program to that end. However, even the journal in which the paper appeared has largely ignored that call: Critical Infrastructures, as both a journal and a discipline, is oriented primarily toward maintaining the resilience of specific extant infrastructures against wildcard threats (e.g. industrial sabotage, hacking, riots: see Lewis, 2014; Pederson, Dudenhoeffer, Hartley, & Permann, 2006), and avoiding so-called "cascading failure" (Ouyang, 2014). To be clear, these are important issues, but the way in which they are researched has little to tell us about how infrastructure changes over time. Or, to put it another way: Critical Infrastructures sees particular examples of infrastructural obduracy as a tactical goal to be sought, while this project is more interested in infrastructural obduracy (and plasticity) as a general phenomenon to be understood.

Systems: Large / Technical / Sociotechnical

Historically, infrastructures have often been studied through the lens of systems theory, which rose to prominence in the 1960s before metastasizing into the literatures of many other disciplines. Systems and complexity theory in the abstract will dealt with later in this section, after first focussing on what might be thought of as "applied" systems theory specific to the infrastructural domain.

The development of the Large Technical Systems paradigm, founded by Thomas P Hughes's study of the evolution of electricity networks in the United States (Hughes, 1993), represents what is perhaps the first specifically infrastructural theory of change, and has been applied to other infrastructures (as in Davies 1996, which looks at telecomms networks). Reviewing his work, Graham and Marvin observe that Hughes deployed "an explicitly sociological and historical perspective" in order to show how the combination of technical apparatuses into infrastructural systems "involved complex economic, political and social negotiations", with a focus on the entrepreneurial struggle to impose systemicity on the network under construction (Graham & Marvin, 2001, p180). As time passes, these systems become mutually entangled with one another, and with their societal context. Novel technologies or systems may result in substitutions of service provision (e.g. air travel replacing rail travel in the United States), but older systems rarely vanish entirely. Rather, observe Graham and Marvin, they become blackboxed: "taken for granted, ubiquitous, [and] standardised" (Graham & Marvin, 2001, p181); furthermore, "[b]ecause of the apparent permanence of black-boxed Large Technical Systems, infrastructure networks thus retain powerful images of stability" (Graham & Marvin, 2001, p182).

That stability is, as recent events have demonstrated, largely illusory: natural disasters, terrorism and hacking have all caused damage and downtime to crucial systems across the world in recent years, as have the slower, more systematic catastrophes of underfunding, mismanagement and corporate incompetence. As such, the black-boxing phenomenon which Graham and Marvin identify in LTS is reminiscent of Clarke's Third Law, as discussed in the introduction: vast systems which cannot slip from our sight, which nonetheless slip from our comprehension. So LTS is looking in the right direction—but as Graham and Marvin point out, the discipline's "supply-side focus" and its "overwhelming concern with 'system-builders"' betray a fundamentally managerial perspective (Graham & Marvin, 2001, p184). In aiming to guide system-builders toward the successful vanishing of an infrastructure—the operationalisation of Clarke's Third Law, in other words—LTS seeks to seal up black-boxed systems permanently. As such, it stands in opposition to the aim of this project, which is more interested in understanding the vanishing process than repeating the trick.

Being something of an evolution of LTS, Sociotechnical Systems is a predominantly managerial discipline aimed at shaping organisational development, which takes “the concepts and metaphors of general systems theory, in particular the notion of ’open systems’ [...] as a way of describing, analysing and designing systems with joint optimisation in mind” (Walker, Stanton, Salmon, & Jenkins, 2008, p5). In recent years, it has been applied to such infrastructural topics as smart electricity grids in Korea (Mah, van der Vleuten, Ip, & Hills, 2012) and rainwater harvesting systems in the UK (Ward, Barr, Butler, & Memon, 2012). The major distinction from LTS is that Sociotechnical Systems explicitly acknowledges that any large system has a social dimension as well as a technical dimension.

Sociotechnical Systems theory aims at the identification and reification of a maximised open system which is both optimal and efficient but, where LTS advocates system management through accretive growth, Sociotechnical Systems advocates the “design [of] organisations that exhibit open systems properties and can thus cope better with environmental complexity, dynamism, new technology and competition” (Walker et al., 2008, p5)—which is to say that, far from being interested in understanding the process of technological change, Sociotechnical Systems is in fact focussed on circumventing such dynamics in order to maintain an overall systemic stability. This focus on organisational design works against anything other than a highly instrumentalised conception of infrastructural systems: social factors outwith the organisation are relegated to acknowledged externalities, with the result that socipolitical issues are always ‘out there’ in the externalised world (where they can be safely ignored) while the system under development is ‘in here’. Furthermore, *a priori* values are embedded in the analysis in the form of the unquestioned primacy of optimal throughput: meaning and values, while pertinent within the organisational frame, remain utterly subordinate to highly quantitative conceptualisations of optimal function. Again, these are laudable goals in context, but they orient Sociotechnical Systems theory orthogonally to the aim of this project, which is not to avoid, exploit or adapt to sociotechnical change, but rather to understand its dynamics.

Innovation(s)

Stepping somewhat away from the systems paradigm, Innovation Diffusion theory attempts to understand the take-up of new ideas and/or technologies in terms of communications between groups and individuals. Rogers defines diffusion as "the process by which an innovation is communicated through certain channels over time among the members of a social system" (E. M. Rogers, 2010, p5-6), and "a kind of social change, defined as the process by which alteration occurs in the structure and function of a social system"(E. M. Rogers, 2010, p6); examples offered include the uptake of sanitation processes in Peruvian villages, the Royal Navy's (slow, and oddly grudging) adoption of citrus fruits as a prophylactic against scurvy, and—by way of illustrating a failed diffusion—the ongoing marginality of the DVORAK keyboard against the ubiquity of the now-redundant QWERTY layout.

Innovation is arguably a necessary concept, but also a slippery one: for example, there is little agreement (or even discussion) as to whether innovation is a noun (meaning that "an innovation" is a discrete and identifiable product or service whose uptake can be studied), or a verb (meaning that "innovation" is the diffuse process by which technologies change), or both at once; some scholars have even gone so far as to suggest that innovation is basically unmeasurable (Nelson, Earle, Howard-Grenville, Haack, & Young, 2014). Rogers's weak conceptualisations do the term no favours, either, and in developing distinctions between diffusion and dissemination (the former being spontaneous, the latter a process to be managed by professional "change agents") and between decentralised and centralised diffusions (ditto), he reveals Innovation Diffusion to be fundamentally oriented toward the goal of "diffusing" any given product or service across as wide a market as possible. This reading is supported by the enduring popularity of Innovation Diffusion theory in managerial and marketing-related disciplines (see e.g. Cho, Hwang, & Lee, 2012; Delre, Jager, Bijmolt, & Janssen, 2010; Kreindler & Young, 2014; Peres, Muller, & Mahajan, 2010), and by its frankly naive conceptualisations of the social system (described, with rather charming optimism, as "a set of interrelated units that are engaged in joint problem solving to accomplish a common goal", E. M. Rogers, 2010, p24). Much as with LTS and Sociotechnical Systems, Innovation Diffusion is entirely focussed on trying to engender and harness sociotechnical change; in their urgent desire to intervene, these frameworks overlook the multitudinous actions of others which necessarily contribute to the dynamics of the change they seek to steer.

Transitions and the Multi-Level Perspective

If popularity is any measure of success, then the reigning theory of sociotechnical change is surely Transitions, a considerable body of literature clustered around a model or framework known as the Multi-Level Perspective. The MLP "organises analysis into a socio-technical system that consists of niches, regimes and landscapes"—a terminology which "provides a language for organising a diverse array of considerations into narrative accounts of transitions"—and defines the goals of innovation policy as the "need to escape lock-in, deflect path dependencies and transform sociotechnical regimes" (Smith, Voß, & Grin, 2010, p441). Oriented toward achieving 'transitions' to more sustainable systems of provision than currently prevail, the MLP considers both novel technologies and extant "structural trends in the [...] exisiting regime" (Verbong & Geels, 2007, p1025) from a policy perspective, while also exploring the "perceptions, strategies and actions" of other actors with a stake in said regime, such as "firms, utilities, special-interest groups [and] consumers" (Verbong & Geels, 2007, p1025). As well as less obviously infrastructural technologies, the MLP has been used to analyse water distribution systems (Geels, 2005a), electricity networks (Verbong & Geels, 2007), road networks (Geels, 2007), as well as the 'transitions' from horse-drawn carriages to the automobile (Geels, 2005b), and from sailing ships to steamers (Geels, 2002); it is the *de facto* standard for infrastructural research, at least in the European context.

But it is not without its flaws, which appear to be endemic to technology-centric theories of change. Shove and Walker (2007), noting the rapid expansion of the Transitions literature (and enthusiasm for such) in both the Netherlands and the UK, observe that "studies of systems in transition are typically distanced, even voyeuristic" (Shove & Walker, 2007, p764), and that transitions research—along with the related literature on Transitions Management, which not only analyses sociotechnical change but proposes policy interventions aimed at steering it—is haunted by an implicit but otherwise unacknowledged managerial agency which is somehow supposedly 'outside' or 'above' the system it proposes to manage. Furthermore, "important types *and agents* of change" (Shove & Walker, 2007, p768; emphasis added) are conspicuous by their absence from the Transitions literature, such as "rampant" rogue innovations that block off potential pathways of change, the "trajectories of fossilisation and decay" caused by the abandonment and redundancy of legacy systems, and "fundamental transformations in the the ordinary routines of daily life" (Shove & Walker, 2007, p768). Much like Innovation Diffusion, the *a priori* orientation of Transitions toward active interventions actively precludes the objective understanding of sociotechnical change as a process.

Nonetheless, the MLP represents the current state of the art in technology-centric theories of change, and therefore offers a point of departure for future work. With that in mind, there follows a summary of three common critiques of the MLP and the concept of transition, as generously compiled and partially defended by its most enthusiastic proponent (Geels, 2011).

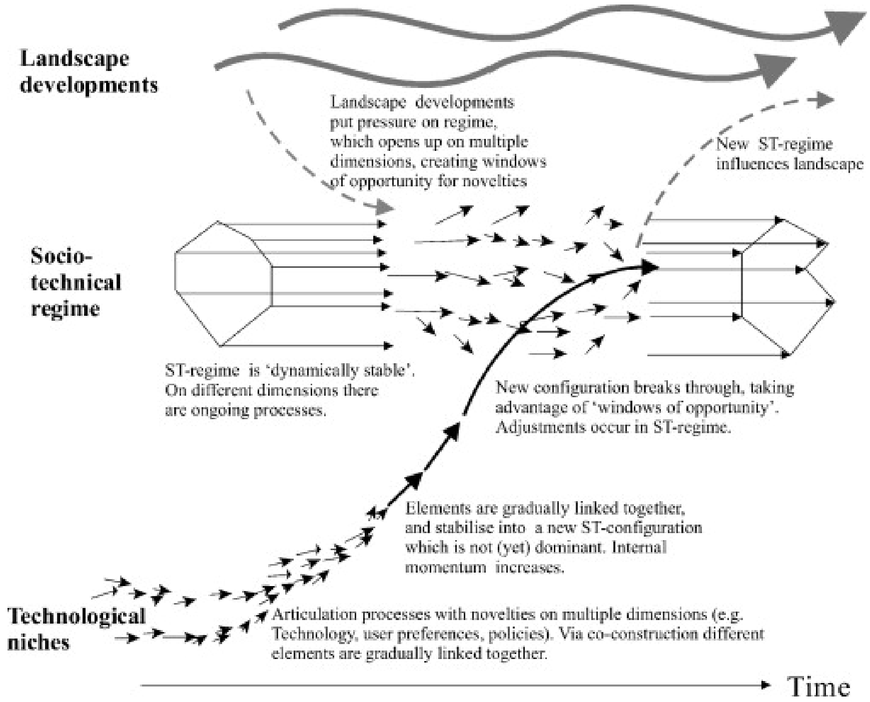

Figure 2.1: Schematic representation of transition dynamics (from Geels, 2004)

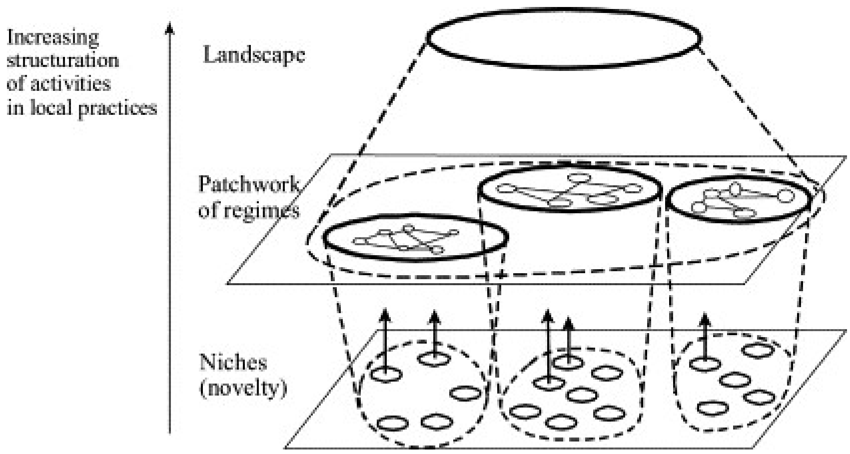

Figure 2.2: Structural framework of the Multi-Layered Perspective (from Geels, 2004)

Agency & Hierarchy This first objection contains two related criticisms: that the MLP underplays the role of agency, and that its hierarchical strata would be better replaced by what is known as a flat ontology—namely a model in which status and agency are emergent from changing networks of relationships between actors, rather than from arbitrary conceptual strata.

Geels (2011, p29) defends the MLP against the claim of underplaying agency by arguing that agency is effectively embedded in the structural concepts of niche, regime and landscape. While this is true, it addresses the letter of the critique rather than its spirit: agency is undoubtedly present in the MLP, where constructs such as "culture" and "markets" reconfigure their interrelationships amid a blizzard of arrows that appear to co-conceptualise actors, technologies, learning processes and influences as an undifferentiated flow of something happening (as in Figure 2.1 on page 13)—but the bearers of agency are nowhere to be seen.

With regard to the critique that the MLP is overly hierarchical, Geels notes that later iterations of the MLP have downplayed the necessity of a hierarchical relationship between niches, regimes and landscapes, which was originally intended to indicate differing degrees of structural stability between the layers. Nonetheless, it is hard to read the model (as shown in Figure 2.2 on page 13) as anything other than hierarchical: a higher order of structure or stability remains a higher order, even if one argues that "higher" structure or stability is not necessarily "better".

These two critiques can be seen as two sides of the same coin: agency is underplayed through its being embedded in (and thus obscured by) hierarchical conceptual strata. This abnegation of agency plays out in the accounts generated by MLP case-studies, wherein inventions and technologies propagate through a loosely-defined landscape, competing to be the most rational and economically viable option available. Choices are certainly being made in these accounts—but who is making them? They are made off-stage by characters we never meet, and as such the basis of those choices—which is to say, the rationale or motivation behind the selection of one technology over another—remains unclear.

The problem is compounded by the absence of a teleology of technology use: beyond an implicit assumption of something close to Rational Choice Theory, and another implicit assumption that a good technology is one that people decide to buy, the MLP has surprisingly little to say about *why* anyone would bother to develop a new technology, nor *why* anyone might choose to take it up—both of which are preconditions to its proliferation, and thus surely central to an understanding of the dynamics of sociotechnical change.

Placelessness & Holism Another related pair of criticisms of the MLP refer to "the operationalization and specification of regimes", and "the sociotechnical landscape as a residual category" (see again Geels, 2011, p31, p36). To paraphrase, the former critique focusses on the way in which the regime stratum is defined (which is to say very loosely, particularly as regards distinguishing a regime from a less specific system); the latter critique accuses the sociotechnical landscape stratum of acting as "a 'garbage can' concept that accounts for many kinds of contextual influences" (Geels, 2011, p36)—a convenient dumping-ground for messy and unquantifiable influences or externalities, such as climate and demography.

Like those bundled under Agency & Hierarchy above, these critiques are also engaged with the implicit hierarchical structure of the MLP, and with its insistence on creating abstract categories with which to think through the process of sociotechnical change. But there are two other aspects to these critiques worthy of closer consideration, namely placelessness and holism.

The root of the critique of placelessness can be found in the MLP's reliance on spatial metaphors—e.g. niche, regime, landscape—which give a false and self-contradictory impression of a spatialised understanding of change dynamics. Interestingly, Geels's (partial) abandonment of an explicit hierarchy for the strata in response to this critique actually makes the problem more obvious:

> "... most niches do not emerge within regimes, but often outside them (although niche actors are usually aware of regime structures). While the socio-technical landscape is an external context, the relation with regimes (and niches) is not necessarily hierarchical..." (Geels, 2011, p37-38)

In addition to the uncertainty as to whether a niche is "within" a regime or not, it is unclear whether that "within" refers to a conceptual relationship, a geographical relationship, or some combination of the two; likewise, if the sociotechnical landscape is "an external construct", is the regime therefore *conceptually* internal to it, or *geographically* internal, or some combination of the two? If a niche can emerge "outside" a regime, how does it get "inside"? On what conceptual plane is this movement taking place?

This is problematic because sociotechnical change is an inescapably spatial phenomenon. But as indicated by the critiques in question, the 'space' in which transition is played out is largely undefined in geographical terms: MLP-based studies tend to be spatially bounded by nation-state (see e.g. Belz, 2004; Geels, 2005b; Verbong & Geels, 2007), which doesn't seem entirely unreasonable when the nation-state in question is Switzerland, but rather stretches credibility when applied to the entirety of the United States of America.

This is not to say that the MLP assumes a homogeneity of possibility with regard to the adoption of a new technology; on the contrary, its hierarchical levels of organisation represent an attempt to systematise and understand the heterogeneity of possibility. But it does so through spatial terms which remain largely unanchored in actual geographical space, and then only through the use of fuzzy and contestable dichotomies (such as urban/rural, for instance). To discuss technology usage across a nation as sizable and populous as the United States is geographically simplistic at best, as regardless of intentions it implies a broad similarity of sociotechnical trajectory in every city at around the same time—which is barely credible in the context of a federal nation of fifty distinct states, let alone in the context of a nation whose geographically distributed inequalities are arguably its defining socioeconomic feature.

Transitions are also loosely bounded in the temporal sense. Their origins are fairly easily identified—simply locate and date the earliest prototypes of the technology in question—but their endings are vague, signalled only by the "dominance" of said technology in the marketplace by comparison to those other options which it has been assumed to supersede. For instance, Geels (2005b) marks the USian transition from the horse-drawn carriage to the automobile as effectively complete by 1930, but at no point quantifies that completion. Had *all* horse-drawn carriages disappeared by that point? 90% of them? 75%? 51%? Where were the first disappearances, and the last? Did the transition complete everywhere all at once?* Given the analysis of transition tends to be bounded by the nation-state, this is certainly implied, though perhaps not intentionally.

In summary, then, the critique of placelessness observes that, through its use of spatial metaphors, the MLP actively obscures the actual geography of sociotechnical change, and in doing so, weakens it own explanatory and narrative powers considerably.

The second critique in this bundle (which also applies to many theories and frameworks other than the MLP) is that it mistakes holistic thinking for systemic thinking. The distinction between a holistic approach and a systems approach is well illustrated in Latour's defence of James Lovelock's Gaia hypothesis against its misreading by earth systems scientist Toby Tyrell (Latour, 2017). In holistic thought, as used by Tyrell, the constituent elements or actors of a system magically combine to form an entity or actor of a higher order, which is implied to have a separate and superior agency and teleology to those of the actors comprising

*Geels argues convincingly that statistical approaches, such as aggregate logistical curves describing changing numbers of carriages and automobiles, would run the risk of obscuring the reasons behind the dynamics; nonetheless, some verifiable quantification of the omega point would make the overall concept of transition notably less sketchy.

it. Latour reads Lovelock's approach as being distinct from holism, as Lovelock's analysis steadfastly refuses to elevate the system conceptually above its constituent actors: as Latour's title puts it, Lovelock's Gaia is not "a god of totality". So when Tyrell paraphrases Lovelock, describing Gaia as "the idea that life moderates the global environment to make it more favourable to life", Latour observes that:

> "... Life is now written as if it were the agent lording over organisms, much like the spirit floating over the water. Whereas in Lovelock, there is nothing in the whole that is not in the parts—and this is precisely the novelty of *not* adding a superior [analytical] level. Tyrell falls straight into the trap, and imagines that Life acts as a Whole distinct from its parts [... and] shifts unwittingly to a classical distinction between parts and whole, borrowed straight out of social theories—which, in turn, have borrowed them off the shelf from theology." (Latour, 2017, p65)

The MLP makes a similar error in its creation of sociotechnical regimes and landscapes: like Tyrell's "Life", they're somehow more than the sum of that of which they are comprised, possessed of an organisational capacity or agency which acts on behalf of its member-actors.

To be fair to the MLP, this is a very easy elision to enact, which is why it is so commonplace. Language itself—producer and product of the subjectivity of consciousness—struggles to narrate systemic causality, because language is haunted by the infrastructures of old hierarchies (as Latour points out above); despite our best efforts, language cannot help but seek an alpha and an omega, a cause and an effect, a winner and a loser. The MLP's stated orientation toward causal explanations merely compounds the difficulty, because causality and systemicity are incompatible epistemologies: in contexts of complexity, then, causality plays a role akin to a "god of the gaps", an inexplicable agency invented out of narrative necessity, and the MLP's sociotechnical regime is the *machina* from which that particular *deus* can emerge at the appropriate analytical moment.

This is a philosophical distinction, admittedly, but it has considerable relevance to the study of sociotechnical change, which—just like earth systems science—tends to perpetuate an oppositional relationship between organisms and their environment. As Latour puts it, "on Lovelock's earth, no one is any longer in any position to 'mould' anybody else" (Latour, 2017, p67), while on Tyrell's, "the whole has been shifted onto another plane than the parts" (Latour, 2017, p72); in its desperation to identify a 'prime mover' in the innovation narrative, the MLP mirrors Tyrell's strategy, and so shuts off the possibility of a truly systemic understanding of sociotechnical change.

Generic Reproduction This third critique combines another pair of related criticisms of the MLP. The first of these refers to the MLP's "bias in favour of bottom-up change," (Geels, 2011, p32) which at first blush would seem rather contradicted by previously-discussed criticisms of its inherently hierarchical structure. The substance of the critique, however, is that MLP approaches "tend unduly to emphasize processes of regime change which begin within niches and work up, at the expense of those which directly address the various dimensions of the sociotechnical regime or those which operate 'downwards' from general features of the sociotechnical landscape" (Berkhout, Smith, & Stirling, 2004), which reads less as a complaint about a bias toward bottom-up change, and more as a complaint about a bias toward a particular and specific conceptualisation of sociotechnical transition—toward a particular generic narrative of change, in other words.

Indeed, this bias is seen as a feature rather than a bug, as revealed in Geels's responses to another criticism, namely that the MLP offers little more to scholarship on sociotechnical change than a heuristic device. Geels interprets this as a dig at the presumed non-rigour of qualitative/interpretive frameworks in general, which he rightly defends as being more useful than quantitative approaches to such broad, multidimensional topics:

> "Frameworks such as the MLP are not 'truth machines' that automatically produce the right answers once the analyst has entered the data. Instead, they are 'heuristic devices' that guide the analyst's attention to relevant questions and problems." (Geels, 2011, p34)

This seems reasonable, but is rather contradicted when Geels goes on to explain the MLP's employment of "process theory" as its "explanatory style": "process theories do not explain variance in the dependent variable as 'caused' by independent variables, but instead explain outcomes in terms of event sequences, and the timing and conjunctures of event-chains" (Geels, 2011, p34). Hence is justified the MLP's use of "narrative explanation"—although, confusingly, Geels goes on to claim that this is aimed at the production of "causal narratives", which in light of his earlier comments would seem to be a contradiction: if process theory doesn't profess to explain the causes of variance, it is unclear how it is nonetheless producing causal narratives. Contradictions aside, however, the real problem emerges when Geels states that in order "[t]o develop casual narratives, explanations therefore need to be guided by 'heuristic devices' such as *conceptual frameworks that specify a certain plot* [...] the MLP provides such a plot for the study of transitions" (Geels, 2011, p35, emphasis added).

To be clear, this project bears no principled objection to the use of heuristics. The particularity of the problem is best illustrated by further embracing Geels's literary metaphor of the plot: the MLP is, in effect, a generic story-form that relies on pre-established permutations of certain archetypal characters, settings and events. Much as with an airport thriller novel or superhero movie, you always end up with the same basic arc of story: in the case of the MLP, that generic story is known as "transition", and it follows the journey of a hopeful young innovation on its adventures through the sociotechnical landscape, struggling against the incumbent regime until it finally achieves the "market dominance" which was its destiny and birthright.*

That's not to say that the generic transition plot doesn't ever play out pretty much as specified by the MLP—transitions of this type can certainly be identified (although the spatiotemporal looseness of the transition concept means that it can be drawn in such a way as to maximise the chance of proving itself correct). The problem is the assumption that all transitions must follow a variant of this standard plot; a related critique of the MLP highlights its inability (or perhaps just its unwillingness) to deal with stories of innovation and change which don't follow a heroic arc, and in particular stories of the decline, suppression or failure of innovations (Shove & Walker, 2007).

Systems and network theory

The Transitions literature, much like the majority of the approaches discussed thus far, draws to some degree on network theory for its explanatory power. Originally a spur of graph theory, which is in turn descended from systems-theoretical approaches, network theory is foundational to disciplines such as information science and communication studies, but it is first and foremost a method for the abstraction and depiction of complex systems (Newman, 2010). As is also true for systems theory and the principles of cybernetics, the dominant role of network theory in infrastructural research is in the building and optimisation of model systems, be they communications networks (Shakkottai & Srikant, 2008), transport networks (Caramia & Dell'Olmo, 2008; Marinov & Viegas, 2011) or even multi-system networks (Varga et al., 2014)—for solutions-oriented short-term planning, in other words. But if a rigorously quantitative application of network theoretical principles can produce successful predictive models of complex systems over the short term, it is implicit that a more abstracted and qualitative understanding of those same principles should be able to contribute to a description of the dynamics of sociotechnical change over the longer term. Indeed, this is why concepts from

*The similarities between the MLP's account of an innovation's rise to market maturity and the so-called Hero's Journey, the archetypal story-form first identified by Joseph Campbell and relentlessly exploited by lazy writers ever since, certainly bear note; the dominance and phallocentrism of the Hero's Journey in technoscience is dealt with at length in Haraway (2016a).

network theory tend to be invoked within innovation narratives—but they are deployed in a rather shallow fashion, most often in the form of a brief genuflection toward the notional influence of "network effects" (see e.g. Markard & Truffer, 2008, p597), which has become a sort of shorthand or euphemism for the deliberate and directed diffusion sought by Rogers and his disciples (see section 2.1.1 above): another "god of the gaps" concept whose offhand invocation supposedly explains the uptake (or otherwise) of some novelty or another.

To be clear, network effects are very real phenomena, and of great relevance to infrastructural matters—for while the definition of the term "infrastructure" is contentious, it's plain to see that the vast majority of the systems we tag with that label are networks (Raven, 2017a), which we might therefore expect to behave largely as described by the theory of the same name. But the relationships between the various phenomena bundled under the term "network effects" and such qualities of a network as its density and topology (which is to say, its spatial distribution and connectivity, among other parameters) is subtle and contingent: network effects are ubiquitous to networks, but their actual expression is always a function of the topology of the network in that particular location. Or, more prosaically: while there are general rules or laws of network behaviour, individual networks (and subnetworks) work differently according to how they're connected—which means that looking closely at the spatial distribution and connectivity of networks may offer another useful parameter for the analysis of sociotechnical change in the long term.

Complexity theory

Before returning to the topic of spatial network topology, however, the concept and discipline of complexity bears some exploration. Defining complexity (and/or the complex systems which definitionally exhibit complexity) is inherently paradoxical, given the term refers to an essential property of unpredictability, and picking through the debates that characterise the early years of this (still young) discipline are well beyond the scope of this project. However, for our purposes here, the following definition of complexity theory is as good as any other available:

> "...one might proceed to define complexity theory tentatively as the study of non-linear phenomena and bottom-up processes of emergent self-organisation. Non-linear phenomena or systems are those that do not display proportionality between input and output and in which small influences can result in large effects." (Bousquet, 2012)

Two conceptual phenomena are considered characteristic of complex systems, namely self-organisation and emergence:

> "Self-organisation is the process by which the autonomous interaction of individual entities results in the bottom-up emergence of complex systems, systems composed of many parts that are coupled in a non-linear fashion. Here the notion of network is vital to describe the patterns of interaction that are constituted by the interplay of entities in a complex system [...] A key related concept is that of emergence, the process by which complex structures form on the basis of simple rules." (Bousquet, 2012)

It has been axiomatic in complexity scholarship that complex systems, particularly those which are "radically open and contextualised", are in effect impossible to successfully model using agent-based simulations; "radically open" systems are those where the analytical partition between the system and its "ambience" is impossible to sustain, while a contextualised system exhibits the following properties: "[it] includes one or more elements that also occur in a different system(s), or [...] it is itself a shared element between more than one system [...and in] this other system(s) the shared elements take part in causal processes different from those included in the original system" (Chu, Strand, & Fjelland, 2003). Much like the complex ecosystems with which these discussions were initially concerned, large sociotechnical systems—due to their reciprocal embeddedness with human societies, and with other sociotechnical systems—would thus seem to be beyond the possibility of being modelled.

However, that hasn't stopped people from trying, encouraged in no small part by the undeniably spectacular advances in computing power since complexity emerged as a discipline in the 1990s. The result is a highly reductionist and quantitative computational approach to complexity, whereby vast statistical aggregates of individual behaviours are revealed to follow "simple reproducible patterns" (see e.g. Gonzalez, Hidalgo, & Barabasi, 2008, wherein the journeys of hundreds of thousands of people are analysed by reference to their cell-phone location data). It is not for this project to attempt to gainsay the findings of physics and mathematics, but to observe that this sort of reductionism reveals its "simple reproducible patterns" at the expense of the agency, meanings and motivations of hundreds of thousands of people; the modellers have constructed a "closed" system, but in order to do so they had to shut out the social context (or "ambience") entirely.

This paradigm has come to a sort of fruition in the last decade or so, with Barabási (2011) announcing that irreducible complexity is in fact steadily giving way to network science in the age of "Big Data":

> "Computer science, fuelled by its poster progenies, such as Google or Facebook, is mounting a successful attack on complexity, fuelled by the conviction that a sufficiently fast algorithm can tackle any problem, no matter how complex." (Barabási, 2011)

While it may well transpire that "a sufficiently fast algorithm can tackle any problem", the question of whether the "solution" so provided will take any account of such fuzzy and hard-to-quantify notions such as social justice or human values is left unasked—not, to be clear, due to any conspiratorial malice on the part of network scientists, but as a result of the inevitable externalisation of unquantifiable social factors from the models they favour. The ethics of these data-driven epistemologies are increasingly subject to question (see e.g. Hauer, 2018; Mittelstadt, Allo, Taddeo, Wachter, & Floridi, 2016), but in the context of this project the real issue with the computer-scientific approach to complexity is its relentless reduction and/or exclusion of social factors, which are precisely what this project seeks to explore. Throwing ever more computing power at the challenge will not bring "the social" back in, but push it still further to the margins.

Complexity more broadly has many valuable pointers for the would-be scholar of sociotechnical change, however. For instance, Tainter (2006) takes a highly abstract view of complexity at the historical-civilisational scale, and frames it as an economic argument:

> "Complexity can be viewed as an economic function. Societies and institutions invest in problem solving, undertaking costs and expecting benefits in return. In any system of problem solving, early efforts tend to be simple and cost-effective. That is, they work and give high returns per unit of effort. [...] As the highest-return ways to produce resources, process information, and organize society are applied, continuing problems must be addressed in ways that are more costly and less cost-effective. *As the costs of solving problems grow, the point is reached where further investments in complexity do not give a proportionate return.* [...] A prolonged period of diminishing returns to complexity is a major part of what makes problem solving ineffective and societies or institutions unsustainable." (Tainter, 2006, emphasis added)

The difficulty here is that the problem-solving done with the aim of addressing the consequences of complexity also serve to make the overall system yet more complex:

> "Efforts at problem solving, as seen in the examples of producing resources and producing information, commonly evolve along a path

> of increasing complexity, higher costs, and declining marginal returns. Ultimately the problem solving effort may grow so cumbersome, costly, and ineffective that it is either terminated, collapses, or requires large subsidies." (Tainter, 2006)

If we view infrastructural systems as a "solution" to the complex socioeconomic problem of resource distribution, Tainter's argument suggests that successive additions to the "stack" of systems deployed to this end will be ever more expensive, ineffective in proportion to their expense, and difficult to deploy; furthermore, they represent seemingly exponential increases of complexity in a system-of-systems which is already extremely complex and interconnected. Among Tainter's set of seven "lessons" regarding sustainability, the fourth is as follows:

> "Complexity in problem solving does its damage subtly, unpredictably, and cumulatively over the long term. *Sustainability must therefore be a historical science*." (Tainter, 2006, emphasis added)

Given that sociotechnical change can be seen as a paradigmatic mode of problem-solving in developed societies (and that the evolution of freight distribution systems can thus be seen as an accumulation of path-dependent sociotechnical solutions to the problem of resource distribution) it follows that, like Tainter's conception of sustainability science, any study of sociotechnical change must necessarily also be a historical project, particularly if it is intended to support and inform transitions toward more environmentally sustainable reconfigurations.*

Tainter's theme is taken up in Urry (2016), wherein the author argues that complexity theory reveals the old social-scientific distinction between "the natural and social [aspects of] time" to be illusory, and "emphasises the importance of history, time and emergence", the latter of which "stems from interactions between people and the environment, humans being indissolubly part of nature" (Urry, 2016, p67). Urry also synthesizes numerous studies of networks, including those of Barabási (mentioned above), observing that most actual social networks (the relationships between human actors, rather than the commercial internet-based communication services which are referred to by the same name) follow a Gaussian distribution which is distinctly egalitarian by comparison to the "power law"

*This argument is made in greater detail in an earlier paper by Tainter: "We have today a great advantage over the societies of the past-and not just in our technical abilities. Our knowledge gives us the opportunity to become the first people in history to understand the phenomenon of evolving complexity, and to learn where we are in this process. [...] An important part of research into sustainability must therefore be historical research to refine our understanding of our position today in a system of evolving complexity." (Tainter, 1995) distribution of connectivity observed in networks of websites, wherein a few "exceptionally well-connected hubs" dominate; this "aristocratic order" is reflected in complex networked sociotechnical systems such as the global financial system, from (or rather between) which "innovations" tend to emerge (Urry, 2016, p70).

As shall be shown, contemporary research projects with an infrastructural focus tend to see complexity and inter-systemic interdependence as an opportunity to be exploited, but Urry shows this position to be, at best, rather optimistic and one-sided. As Tainter's work (discussed above) shows, complexity is indeed a pathway for problem-solving, but it's a path of diminishing returns that eventually ends in a cliff-edge: relying on emergence is a risky strategy, as a close reading of complexity theory shows that "systems are dynamic, processual and unpredictable", and "emphasize[s] the importance of positive feedbacks that move systems away from equilibrium [...] while systems can be stabilised for long periods through 'lock-ins', certain small causes can prompt or tip the emergence of new 'paths"' (Urry, 2016, p59). This phenomenon of "metastability" is strongly (though not exclusively) social in its origins, and contributes to what we might characterise as the obduracy of sociotechnical systems (which is, of course, merely the negative framing of what in other circumstances is described as resilience):

> "Such lock-ins mean that the 'surrounding' social institutions matter a great deal in how systems develop over the long term, once they have been set onto a particular path [...] Systems can endure even though there are strong forces that 'should' undermine their irreversible, locked-in character." (Urry, 2016, p60)

Again, this is not to gainsay those who see complexity as providing potential opportunities for transformative change; it is rather to point out that the nature of the change that results is inherently resistant to forecasting or prediction, and that while positive feedback may indeed foster the rapid diffusion of new practices, the change that ends up diffusing may not always be the practices that are supported and nurtured by "change agents" or "transition managers"—who, despite their epistemological assumptions to the contrary, are very much subject to (and cogs captive within) the very systems which they claim to observe and intervene in from an objective external point-of-view. Furthermore, even in such circumstances as herding behaviour is successfully transformative in the short term, it "magnifies the the probability of system failure" (Urry, 2016, p62), as could be observed in the global financial collapse of 2008: because of the tightly coupled nature of modern systems-of-systems, such errors propagate too quickly to be corrected. "These complexity effects mean that one cannot read off, predict or produce a clear and knowable account of the future" (Urry, 2016, p63); models and algorithms can only ever extrapolate an approximation of the future in which no serious discontinuity disrupts the assumptions embedded in them.

Turning his attention to the role of complexity in "innovation", Urry observes that "it is not a foregone conclusion that the best innovation will be the one that ultimately shapes the future. Innovation involves processes that are different from the the linear notions often spoken about and promoted by policy-makers [... namely] a top-down process developed and implemented by hierarchical actors" (Urry, 2016, p74). On the contrary, the emergence of a new systemic configuration "involves the co-evolution of numerous interrelated elements; there are changes in both demand and supply sides; many agents are involved; long-term processes occur over decades; and the innovation is not caused by a single 'policy' or 'object'..." (Urry, 2016, p74). Urry concludes that "t[h]is combinatory character of innovation makes it hard to say exactly when an innovation process begins" (Urry, 2016, p75), but this could also be interpreted more ambitiously as evidence that "innovation" is in fact merely an artefact of an analytical attempt to tie down to one particular place and time (or object, or actor) an always-ongoing process which is in fact an emergent property of complex systems, and thus distributed (albeit unevenly) throughout the timespace of said systems. While serving to destabilise not only the innovation concept but also the notion of "transition" (see earlier in this chapter), this further underlines the necessity for the study of sociotechnical change to be historical and geographical in nature: to have any hope of understanding where and when change might manifest in the future, it is necessary to first understand where and when it manifested in the past, as the obdurate systems of the status quo were slowly taking shape.

Finally, Urry notes the sometimes surprising system-transformative effects produced by what initially seem to be very minor or "small" technologies. He cites as an example the stirrup, whose invention was a necessary prerequisite to first the success of the Jin dynasty of China, and subsequently the global propagation of military systems based on cavalry, and of societies wherein equestrian mobility was the primary mode of non-pedestrian transportation; "[t]his dependency upon small technologies shows the power of mundane objects in future system change." (Urry, 2016, p82-3)

Spatial network science

Network theory and graph theory are by their very nature abstract analytical approaches, and even when applied to the study of actually-existing systems there is a tendency to limit the analysis to the pure realm of statistics. But actually-existing systems and networks are not purely abstract statistical phenomena: they have a concrete existence in space and time, which is to say that their topology has a geography (and also, as such, a sociology). In recent years, the "spatial sciences"—which is to say, the more quantitative wing of geography, physical and human—have taken steps to integrate network science into their discipline. Barthélemy (2011) makes the argument that infrastructural systems (among other forms of complex network) "are all examples where space is relevant and where topology alone does not contain all the information", but nonetheless sticks to the mathematical modelling paradigm so as to focus on quantitative questions, such as identifying the "shortest route" between any two nodes in a large network, for instance; this bias can be seen throughout the analysis in Ducruet and Beauguitte (2014) of an evolving relationship between network science and the spatial sciences, which has proved fruitful for both sides.

However, it is nonetheless apparent that when it comes to network-theoretical and graph-theoretical approaches, one either studies concrete networks of infrastructure(s) as objects in their own right, or one studies social interactions as networked phenomena; no one seems to be using such approaches for analysing the interaction of social agents with infrastructures as a unified object of study. This isn't entirely surprising, given the sorts of behaviours and interactions that underpin sociotechnical change are subtle, multi-factoral and highly resistant (and/or of little interest) to quantitative analytics; while it may turn out to be possible to quantify and model such sociotechnical phenomena (frameworks for such a project have been suggested, such as that found in Tsiotas & Polyzos, 2018, but the resulting model-of-the-model is a significantly and dauntingly complex network in its own right), any such approach will unavoidably provide a supply-side perspective informed by economic understandings of behaviour, due to the epistemological assumptions embedded in the disciplines involved in developing them. By way of example, Cats (2017) describes a longitudinal investigation of spatial network topology in a railway system, and reveals some interesting dynamics (such as periodicities of development that correlate to planning interventions in the wider urban fabric), but it cannot tell us anything about how "densification" and other such network phenomena affect (and are in turn affected by) the day to day behaviours of citizens except in strictly quantitative terms (e.g number of journeys taken, miles travelled etc.).

Such system-level findings are valuable, of course, but they get us no closer to the question of how sociotechnical change actually happens as a result of people doing things; to invert a very old aphorism, they can't see the trees for the forest. Which is not to say that we don't need to understand the forest (the supply-side perspective); quite to the contrary. But we need to understand the trees (the demand-side perspective) as well—and to do that, we must turn to more people-centric approaches to the study of sociotechnical change.

2.1.2 People-centric approaches

What have heretofore been called people-centric approaches to the study of technological change might be more properly called anthropologies; they give equal weight to the social and technical dimensions of the systems under study, whereas the methodologies outlined above have a demonstrable tendency to privilege the technical over the social.

Two of these theoretical frameworks or positions—namely Actor-Network Theory and Cyborg Anthropology—are associated with the rather broad discipline of Science & Technology Studies; the third, Social Practice Theory, shares many assumptions with the other two, but leavens their insistence on a flat ontology through its focussing on the site of action as the starting point of analysis. All three can be seen as the qualitative and counter-hierarchical equalivalents to the network-theoretical approaches already discussed.

Science & Technology Studies

Actor-Network Theory and "sociologies of translation" Primarily concerned with "the mechanics of power" (Law, 1992, p380), A-NT is intended as a framework through which the world might be studied as "a series of interactions and negotiations, differences, chains of translation, trials of strength and compromises" (Dolwick, 2009, p39). A-NT explicitly places individuals and institutions on an equal footing alongside objects and knowledges, and attempts to trace the network(s) of interactions between them. According to (Callon, 1990, p134), agency inheres in the interactions between actors, rather than in the actors—human or otherwise—themselves. As such, A-NT's approach to innovation or change is to produce a narrative account of "how actors become interconnected, or [...] fall apart and become disconnected" (Dolwick, 2009, p39).

Latour's study of a failed Parisian personal rapid transit project (Latour & Porter, 1996) is arguably the canonical example of A-NT in an infrastructural context, wherein he observes that the realisation of such a project depends on its ability to "recruit new allies and at the same time make sure that their recruitment is assured" (Latour & Porter, 1996, p71); these acts of recruitment are referred to as "enrolment", and are achieved by the deployment of intermediaries: texts, speech acts or media "sent out" into the world and empowered to act on the network's behalf. The process is far from automatic: some entities may resist enrolment, or seek interactions with alternative actors (Callon, 2007, p71). However, dominant or powerfully-placed actors can reduce the likelihood of their enrolment attempts being rejected by engaging in a process of centering-through-translation, or "establishing themselves an obligatory passage point in the network of relationships they [are] building" (Callon, 2007, p69). In this manner, agency accretes more around certain central nodes in the network—actors who are able to reformulate the interests of other actors in a way that insists they be enrolled if they wish to achieve their own goals; in other words, it is the actor or node "who is able to translate others' interests into his own language [who] carries the day" (Latour, 1983, p144).

When this centering-through-translation is successful, the network "can be assimilated to a black box whose behaviour is known and predicted independently of its context" (Law, 1992, p152); having achieved this unity of action, the network effectively disappears from view, "to be replaced by the action itself and the seemingly simple author of that action" (Law, 1992, p385). So, phrased another way, A-NT is a tool for prising open black boxes and studying their inner workings; per (Jolivet & Heiskanen, 2010, p6748), A-NT is ideally suited to exploring "the kind of hybrid problems that we encounter today in an increasingly connected world where the global and local, the human and the technical, interact constantly".

Some critics, such as Amsterdamska (1990), have accused A-NT's accounts of being description rather than analysis, and lament A-NT's dissipation of causal agency and flows of power across the network; enthusiasts for the theory would counter that the distinction between description and analysis is highly contested, and that A-NT's dissipation of agency and power across networks of actors is what makes it so useful. Graham and Marvin concur, drawing on Latour's theories to describe infrastructure networks as "vast collectivities of social and technical actors blended together as sociotechnical hybrids that support the construction of multiple materialities and space-times" (Graham & Marvin, 2001, p185), noting that constant work is required to maintain such complex arrays of social and technical actors over long distances, and that A-NT "undermines the notion that we can simply and unproblematically generalise a single 'thing' called an infrastructure network" any more than we can do the same for a city (Graham & Marvin, 2001, p186). They observe also that A-NT dissolves one more dichotomy specific to infrastructure networks, namely that between the global and the local: a given network is not bigger than another, only "longer and more intensely connected", and "[i]n this sense a network must always remain continuously local, as it inevitably touches down in particular places" (Graham & Marvin, 2001, p189).

Cyborg Anthropology Cyborg Anthropology is an anthropological approach which emerged from the feminist writings of Donna J Haraway, with her Cyborg Manifesto (Haraway, 1991) considered to be the founding text. Haraway positions the Cyborg Manifesto as "an ironic political myth faithful to feminism, socialism and materialism", in which the cyborg is the central figure of faith; a cyborg is "a cybernetic organism, a hybrid of machine and organism, a creature of social reality as well as a creature of fiction" (Haraway, 1991, p149). Haraway uses the metaphor of the cyborg to construct a collective subjectivity for the body as suspended in the global web of technoscientific production.

The central idea is that contemporary humans are all cyborgs, in a fundamental way: the organic basis of our body is surrounded, supported and interpenetrated by the networks and systems of technoscience. Cyborg anthropology is distinguished from broader anthropological practice by this ontological position, rather than by any methodological differences. Much cyborg anthropology, in keeping with its parent field of Science & Technology Studies, has specialised in looking at medical technologies, and the way in which they (re/de)construct their subjects (see e.g. Dumit, 1997; Rapp, 1997).

While there are no studies of infrastructural change specifically informed by cyborg anthropology, there is a significant current in urban political ecology that uses Haraway's cyborg as a way to talk about cities as systems-of-systems. This tradition begins with Swyngedouw's argument for the city-as-hybrid, wherein he states his desire to narrate "the city in a cup of water":

> "The rhizome of underground and surface water flows, of streams, pipes and veins that come together in urban water gushing from the stand-pipe is a powerful metaphor for the socio-ecological processes that produce the city and become embodied in city life." (Swyngedouw, 1996, p66-7)

Further publications have stayed close to the question of urban water provision (e.g. Swyngedouw, 2006; Swyngedouw, Kaika, & Castro, 2002), while others have moved more toward a more general interpretation of the city as system-of-systems (e.g. Gandy, 2005; Swyngedouw et al., 2002), but such studies tend rather toward the theoretical and the conceptual. However, Haraway has provided supplementary methodological advice which seems particularly pertinent to the more empirical study of infrastructural change, namely her advocacy of situated knowledges:

> "Situated knowledges are about communities, not about isolated individuals. [...] The science question in feminism is about objectivity as positioned rationality. Its images are not the products of escape and

> the transcendence of limits (the view from above) but the joining of partial views and halting voices into a collective subject position that promises a vision of the means of ongoing finite embodiment, of living within limits and contradictions—of views of somewhere." (Haraway, 1988, p590)

The "view from above" Haraway mentions—which she also calls "the god trick"—is the voyeuristic and managerial perspective previously identified in the Transitions literature: it is a doubling down on placelessness, whereby not only is the "transition manager" or "change agent" granted an omniscient objective outsider's perspective on the system under study, but the situatedness of the system itself—its position in geographical space, for starters, but also its position in geographical space *in relation to other actors*—is largely overlooked, also (such as with the MLP's geographically incoherent treatment of the American transition from horse-drawn buggies to automobiles, described above). Haraway's insistence on situatedness and "positioned rationality" can be seen as a reiteration of the way in which Graham and Marvin claim that A-NT is able to reconcile the local with the systemic (see above), and suggests that grounding studies on infrastructural change in specific sites may, counterintuitively, be the best route toward generalisable conclusions: as she says, "[t]he only way to find a larger vision is to be somewhere in particular" (Haraway, 1988, p590).

Social Practice Theory

Social Practice Theory is a comparatively young social theory rooted, much like A-NT, in a flat ontology—which is to say that it admits of no hierarchical strata in its model of behaviour. It is distinguished from other social theories by its focus on practices as the unit of analysis. There are various aspects to the conceptualisation of practices, some of which are contested, but there are two stable and broadly accepted elements which are of particular relevance to this project.

Aspects of the practice: beyond Rational Choice The first relevant element is behavioural. Staunch advocates of SPT such as Shove (2010) have argued that dominant models of sociotechnical change, particularly the MLP, are rooted in crude and discredited models of human behaviour (such as so-called Rational Choice Theory), and that SPT can provide a superior model which addresses these shortcomings. A popular formulation of such a model presents the practice as an essentially tripartite entity, comprising a combination of *meanings*, *competencies* and *materials*—or, more simplistically, the model argues that the things people do are a function of their abilities to do them, their reasons for doing them, and the things with which they work to get them done (Spurling, McMeekin, Southerton, Shove, & Welch, 2013).

Again, this conceptualisation of action and change is not dissimilar to that which informs A-NT and Cyborg Anthropology, in that action is seen as emerging from networks of actors, whether human, non-human or hybrid. But the concept of the practice provides what we might describe as a manageable front-end heuristic through which the complexity of networks might be entered and explored: in short, the concept of the practice gives the analyst a clear site at the human scale from which to begin the process of tracing connections and relationships.

SPT has come under fire for what seems to some to be a fetish for paying attention to the small, the mundane and the domestic (see e.g. Geels, 2011), but it is notable that this granular demand-side perspective successfully does without the plethora of hierarchical strata and imaginary entities that populate so-called "mid-level" theories such as the MLP. And in avoiding such clutter by approaching the practice directly and working outward from there, SPT offers the possibility of a deeper understanding of the human desires and decisions that result in sociotechnical change.

Aspects of the practice: entity / performance The second important element of the practice concept is the distinction between the practice-as-entity and the practice-as-performance, which is not a simple either/or. Paraphrasing the theorist Ted Schatzki, it is explained in Shove, Watson, Hand, and Ingram (2007) that the practice-as-entity can be considered as a sort of constellation of all the meanings, competencies and materials which are, were or might yet be associated with the fulfilment of a particular teleological goal, while the practice-as-performance is:

> "[...] the active process of doing through which a practice-as-entity is sustained, reproduced and potentially changed. A practice-as-entity has a relatively enduring existence across actual and potential performances, yet its existence depends upon recurrent performance by real-life practitioners. Accordingly, practices cannot be reduced to just what people do. Equally there is no such thing as 'just' doing. Instead, doings are performances, shaped by and constitutive of the complex relations—of materials, knowledges, norms, meanings and so on—which comprise the practice-as-entity." (Shove et al., 2007, p13)

As such, were one engaged in analysing practices of personal hygiene, for example, the practice-as-entity would comprise all the possible ways of washing oneself, all the possible reasons to wash oneself (or not), and all the material things which might be used in the course of washing oneself. Specific performances of the practice of personal hygiene, however, are therefore comprised of a specific sub-set of the elements comprising the entity, due to the unique contextual and individual circumstances in which any given practice takes place: there are thousands of ways to wash in the practice-as-entity, but in a specific performance, *this* person washes in *this* way using *these* things for *these* reasons.

For this project, which is concerned with the legibility of infrastructure, the utility of SPT lies in its engagement with obduracy and path-dependency not as goals to be sought, but as emergent systemic phenomena to be understood. For example, in a canonical analysis Shove (2004, p101-116) shows how contemporary trends in bathroom design and furnishing are normalising or 'locking in' a daily showering practice while 'locking out' the practice of taking baths less regularly, which—when scaled up across regional populations—results in changed patterns of demand on water infrastructures. Let us consider *[daily showers]* and *[non-daily baths]* as two potential performances of the personal hygiene practice-as-entity: we can see that not only do we have a model of sociotechnical change wherein the teleological goal of the practice-as-entity (getting clean) which is currently being fulfilled by one particular practice-as-performance (daily showers) might instead be fulfilled by another performance consisting of a different set of elements entirely (non-daily baths), but we also have a model of sociotechnical change which explicitly connects people and the things they do to the technological systems with which they do them, and (crucially) vice versa.

Indeed, many other consumptive behaviours—which is to say everyday practices which draw or otherwise rely upon the provident capacities of infrastructures—have been studied through the lens of SPT (see e.g. Watson, 2012, transportation practices; Browne, Pullinger, Medd, & Anderson, 2014, domestic water-consuming practices; Gram-Hanssen, 2010, energy consumption in domestic devices with a stand-by mode; see Spaargaren, 2011 and Sahakian & Wilhite, 2014 for applications to the more broad notion of "sustainable consumption"). This suggests that SPT's explicitly materialist demand-side focus is the best available counter to the supply-side holism of dominant models of sociotechnical change.

2.2 Foresight: speculating on future change in infrastructures

The preceding sections of this chapter have explored a variety of approaches to the analysis of sociotechnical change occuring in the past and/or the present. In this section, we turn to the question of analysing and exploring potential sociotechnical change in the future—change which has yet to (and might never) happen, in other words, meaning that any such analysis is inherently speculative.

It first bears noting that civil engineers and planners have many established techniques for analysing and assessing newly proposed infrastructure projects: predominantly (and understandably) quantitative, they include the Environmental Impact Assessment (see Glasson and Therivel 2013 for an introduction to EIA, and Morgan 2012 for a critical assessment of its utility) and Cost-Benefit Analysis (see Boardman, Greenberg, Vining, and Weimer 2017 for an overview of CBA in practice, and Masur and Posner 2011 on the limitations of CBA, particularly with regard to political questions and "contested normative issues"). These processes are concerned primarily with the viability of the proposal as an engineering project (and, more often than not, as an investment vehicle). They are also important and necessary—but they are nonetheless insufficient for a full exploratory assessment of a future infrastructure. For while quantitative models of this sort can speak clearly to the *feasibility* of the project, they cannot speak to its *plausibility*—which is to say that quantitative studies can tell you whether a thing might be buildable, but it cannot tell you what might nonetheless impede or prevent you from building it; all externalities remain resolutely externalised. Furthermore, quantitative models routinely submerge the assumptions and heuristics which inform their outputs beneath a veneer of mathematical objectivity which is largely unearned (Porter, 1992). As such, while it would be foolish to suggest that quantitative planning and assessment techniques are useless or irrelevant, it nonetheless seems clear that they cannot provide an accessible, human perspective on their subjects; more qualitative and imaginative approaches are necessary. (Some exemplary contemporary projects concerned with infrastructure futures will be explored in greater detail at the end of this section.)

This is not to claim that there is a dearth of infrastructural visions, however. To the contrary, such visions are proliferating, whether they originate from governments (such as the leaflet campaign, ongoing at time of writing, promoting the HS2 rail project in the UK), consultancies and corporations (whose current preferred genre is the "smart city" prospectus website—in spite of, or perhaps due to, the nigh-complete lack of a rigorous definition of that concept in the academy or elsewhere; see e.g. Cavada, Hunt, and Rogers 2014), or indeed from hotshot entrepreneurs with little expertise or knowledge about infrastructure, but rather more familiarity with the speculative marketing strategies of venture-funded technology start-ups. Sometimes derided as "infrastructure fictions" (Raven, 2013), the *sine qua non* of the genre is surely tech billionaire Elon Musk's much mocked (but nonetheless popular) Hyperloop mass-transit concept, which hand-waves away the political practicalities (and an assortment of problematic laws of physics) with all the blithe facility of a science fiction author (R. Bradley, 2016). However, less obviously crazy examples, such as a Chinese project based around a traffic-straddling super-bus concept, are smaller in profile, more commonplace, and more successful at attracting inward investment—if frequently unsuccessful at delivering on their promises; the Chinese super-bus project collapsed, revealing what appears to be an investment scam; see Hincks (2017). Such infrastructural visions can be useful, but the genre tends toward blithe assumptions, quick estimates, and an almost total lack of reflexivity or critical thinking. They are speculative pitch documents, trial balloons—raw bait for the investment sharkpool. They are adverts, first and foremost—and it is exactly these uncritical (if not outright deceitful) narratives of infrastructural futurity which must be pushed back against.

2.2.1 Futures and scenarios

When it comes to more systematic approaches to to infrastructural foresight, the majority of established techniques and frameworks for medium- to long-term planning fall under the broad disciplinary umbrella of futures studies (see Bradfield, Wright, Burt, Cairns, & Van Der Heijden, 2005). This field grew out of the post-ww2 "operational research" paradigm founded by the RAND Corporation, and as Yanow (1993) has shown, futures studies in general retains many of the positivist and managerial epistemologies intrinsic to the Pentagon's particular take on systems theory; furthermore, the field remains sorely undertheorised in academic terms (Curry, 2013), which reflects its bias toward the needs of consultant practitioners. Which is to say that futures studies is predominantly oriented toward using closed-system models to support the development of business strategies, meaning that it is a poor fit with the multi-systemic, open-system challenges of infrastructural deployment; there is a mismatch not only of scale (the average infrastructural system outscales the average firm by several orders of magnitude as regards complexity), but also of teleology, of *purpose*. That said, the tools of futures studies are increasingly being brought to bear at the infrastructural scale, whether working with existing systems (Elliott, 2000, renewable energy; Lake & Bond, 2007, water) or more nakedly speculative assemblages (e.g. McDowall & Eames, 2006, "the hydrogen economy"), as the need for strategic thinking at an existential level becomes increasingly apparent.

Among the most popular futures methodologies is scenario-building (Lindgren & Bandhold, 2003), a process wherein a number of potential future situations (known as scenarios) are developed in order to support strategic decision-making in under uncertainty. In the echt application of the method, one creates a 2x2 matrix based on two axes which represnt the entanglement of two potentially divergent contextual trends, which in turn is used to generate a suite of four futures, each of which has different contextual circumstances; one quadrant (typically the upper right) comes to represent the organisation's "preferred future", and the others represent futures best avoided if at all possible, an the exercise serves to point the way ahead for the client (which, particularly in consulting contexts, is tantamount to endorsing strategic choices which have already been made, but which lack justification or a mandate among the workforce or shareholders). In other words, scenario development tends to be a highly normative practice, designed to pick winners ahead of time (or to "predict" them, which amounts to the same thing).

2.2.2 No maps for these territories: back-casting

Scenario generation processes are sometimes combined with a technique known as "back-casting", a name chosen for its deliberate contrast with "forecasting". In their survey of scenario development techniques, Bishop, Hines, and Collins (2007) characterise back-casting as being conceived as an antidote to conceptual "baggage" which "limits creativity and might create futures that are too safe, not as bold as the actual future turns out to be"; to counter this perceived risk, back-casting directs the practitioner(s):

> "... to leap out into the future, jab a stake in the ground, and then work backward on how we might get there. The first step then is to envision a future state at the time horizon. It can be plausible or fantastical, preferred or catastrophic; but having established that state as a beachhead, it is easier to 'connect the dots' from the present to the future (or back again) than it is to imagine the events leading to an unknown future." (Bishop et al., 2007)

While there are arguably earlier precedents, particularly in the corporate space rather than the academic, backcasting is generally traced to its origins in Robinson (1990), and through an iterated variant outlined in Robinson (2003), "where the desired future is not determined in advance of the analysis but is an emergent property of the process of engaging with users and project partners"; this latter "second generation" backcasting methodology is seen as "contribut[ing] to a process of social learning about possible and desirable futures", rather than as a tool for developing a "roadmap" to be followed in order to realise the future(s) portrayed in the scenarios. However, it is the "roadmap" approach that has proved most popular for researchers engaged in projects related to infrastructural planning and/or sociotechnical transitions (as shall be discussed later in this chapter).

In Börjeson, Höjer, Dreborg, Ekvall, and Finnveden (2006), the authors propose three broad categories of scenario, through the production of which such methodologies might be characterised; these categories (Predictive, Explorative and Normative, respectively) are related to "the principal questions [the authors] believe a user may want to pose about the future. These are *What will happen?*, *What can happen?* and *How can a specific target be reached?*." The authors clearly identify backcasting with the *transforming* type of scenario, which belongs to the normative category, and identify the value of these "elaborate images of the future as a foundation for discussing goals and taking decisions in policy-forming processes" (Börjeson et al., 2006). While plentiful reports on the utility of backcasting methodologies for successfully producing "roadmaps" can be found in the literature (see e.g. Quist & Vergragt, 2006; Salter, Robinson, & Wiek, 2010), reports on the success of the roadmaps thus generated (which is to say: whether following those roadmaps was possible, and/or whether following them produced the hoped-for outcomes) are conspicuous by their absence from the academic corpus or elsewhere; many recent studies (see e.g. Vergragt & Quist, 2011) still describe the backcasting methodology as *potentially* useful rather than demonstrably so.* Furthermore, some some scholars (most notably Wangel, 2011) have highlighted the paucity of social dimensions in back-casting as commonly practiced.

The transforming category of scenarios to which backcasting belongs can be productively contrasted with the explorative category, which is

> "defined by the fact that they respond to the question *What can happen?* We distinguish between the two types, external scenarios and strategic scenarios. External scenarios respond to the user's question: What can happen to the development of external factors? Strategic scenarios respond to the question: What can happen if we act in a certain way?" (Börjeson et al., 2006)

Despite the proclaimed strategic orientation of many projects focussed on infrastructure futures (as shall be shown), they tend to make use of normative scenario processes such as back-casting far more often than they make use of explorative scenario processes, which have a special utility "in cases when the user may have fairly good knowledge regarding how the system works at present, but is

*The author made enquiries with fellow members of the Association of Professional Futurists via its listserv discussion board in search of non-academic evidence in support of backcasted roadmaps as successful-in-hindsight guides to action, but received no evidence of such, whether substantial or anecdotal.

interested in exploring the consequences of alternative developments." (Börjeson et al., 2006) As a subtype of the explorative category, external scenarios:

> "...focus only on factors beyond the control of the relevant actors. They are typically used to inform strategy development of a planning entity. Policies are not part of the scenarios but the scenarios provide a framework for the development and assessment of policies and strategies. The external scenarios can then help the user to develop robust strategies, i.e. *strategies that will survive several kinds of external development*." (Börjeson et al., 2006, , emphasis added)

The redeeming merit of scenario techniques is that they allow for the consideration of contextual uncertainty: by turning four sets of contextual parameters into four more thoroughly imagined and realised future "worlds", and by (re)presenting those worlds using narrative techniques rather than numbers and graphs, a qualitative (and far more human) perspective might be brought to the critical assessment of a future project. In short, scenarios techniques can be used to generate more plausible and reflexive visions of future infrastructures than are commonly produced, and provide a framework for dealing with contextual uncertainty in the process of deployment.

2.2.3 Telling tomorrows: narrative prototyping and design fictions

There is some precedent for more explicitly narrative-driven methods in technology foresight, most notably that known as science fiction prototyping (Johnson, 2011, SFP hereafter), wherein the writing of speculative fictions is used as a way to explore the ramifications (and the potential derivative products) of a new idea, invention or scientific discovery. Regrettably, however, SFP is largely devoid of theoretical grounding, which reflects its origins in commercial product development and corporate organisational foresight; it could certainly be used in more reflexive ways (see e.g. Burnam-Fink, 2015), but as it stands, it's little more than a visioning technique being promoted significantly above its abilities. Nonetheless, attempts have been made to extend this thinking-with-fiction technique so as to accommodate issues at the infrastructural scale, which demonstrate the potential utility of fictions as a space in which complex systems and their complex problems might be explored from a human perspective (Merrie, Keys, Metian, & Österblom, 2017; Raven, 2014).

Perhaps the only explicitly critical futures tradition is the still-nascent field of design fiction (a.k.a. speculative design, critical design); founded by Dunne and Raby during their tenure at the RCA in London (Dunne & Raby, 2013), this tradition draws on design thinking, critical theory and creative practice in order to develop prototypes for future products or services. But these prototypes are not intended to ever be produced—to the contrary, the prototype performs instead as an imaginative prop (or a *diegetic object*, in cinematic terms—see e.g. Kirby, 2010) that draws the observer into an implied understanding, or at least consideration, of the implied future world in which such a product might exist. Or, more simply: while scenario methods develop a series of future contexts (backgrounds) which suggest new strategies or products (foregrounds), design fiction does the inverse, by developing strategies or products which imply, and thereby critique, future contexts:

> "Suspending disbelief about change is in line with speculative design—an approach on which design fiction draws—and relates to a primary focus on generating understanding and insights rather than finished products [...] So a design fiction is (1) something that creates a story world, (2) has something being prototyped within that story world, (3) does so in order to create a discursive space." (Lindley & Coulton, 2015)

This "discursive space" is limited only by the imaginative capacity of those involved in the worldbuilding process:

> "Design fictions have the ability to experiment with technologies or situations that do not currently exist. They can also play with limitless varieties of interface, form-factor, user group, or any other relevant property. Further, as design fictions are self-contained worlds *they extend traditional prototyping approaches by demonstrating both the concept and the context simultaneously*." (Lindley & Coulton, 2015, emphasis added)

Thus a narrative-driven version of design fiction practice would be able to explore large, complex sociotechnical systems under contexts which would otherwise be impossible to simulate. Such a practice would also share some methods (as well as some ideals) with the emerging discipline of Transition Design, which seeks to bring the best out of transitions theory, Social Practice Theory and design thinking by combining them in a speculative-critical modality aimed at thinking about future infrastructures:

> "Transition design could be used to mediate between socio-technical transition theories with their top-down hierarchical approaches and,

> and social practice theories with their bottom-up focus on everyday life and flat ontology [...] what is specific in transition design is the connection to more macro-scaled societal structures and processes." (Hesselgren, Eriksson, Wangel, & Broms, 2018)

As has been shown, both scenarios and design fiction rely on the creation of fictional futures in order to do their work, whether that work is constructive/normative (scenarios) or critical-speculative (design fiction). Elements and strategies from both methods might therefore be combined productively, so as to sustain the critical thrust of the design fiction tradition within the framing of an uncertain, divergent future provided by scenarios. Indeed, the convergence of design thinking with established traditions of scenario practice is resulting in the development of methodologies that are explicitly speculative rather than normative—less interested in making predictive claims, in other words, than in the exploration of possibilities (Hodgkinson & Healey, 2008).

2.2.4 A brief survey of leading-edge infrastructure futures research in the UK

The preceding sections of this literature review have highlighted a lack of qualitative approaches to the assessment of proposed future infrastructures, and a tendency for those which are deployed to operate in the Predictive or Normative paradigms, before introducing some cutting edge alternatives algned with the Explorative paradigm which might be fruitfully put to use in this space. But what roles are currently being played by foresight approaches in state-of-the-art research projects concerned with infrastructural reconfigurations? A closer look at three such projects, recently or imminently completed at time of writing—*Liveable Cities*, *MISTRAL*, and the *International Centre for Infrastructure Futures*—will show that, while such projects are plentiful and generously funded, they are for the most part focussed on quantitative modelling and predictive futures paradigms. This project does not contend that these endeavours are pointless; rather that they are all missing an explicitly demand-side and situated perspective on sociotechnical change, such as this project aims to provide, and they further assume that the outputs of their models and strategic exercises are deliverable, without testing that assumption against the possibility of radically divergent contextual circumstances capable of generating difficulties or obstacles to delivery (or amplifying latent ones) which, by methodological necessity, are externalised in the course of their modelling processes.

The International Centre for Infrastructure Futures

The International Centre for Infrastructure Futures (ICIF) was an EPSRC-funded project (reference EP/K012347/1) based at University College, London that ran from June 2013 to April 2017. The framing of the project in the grant application summary makes it clear that the focus is very explicitly supply-side:

> "The Centre will focus on the development and implementation of innovative business models and aims to support UK firms wishing to exploit them in international markets [...] Beneficiaries from the Centre's activities include existing utility businesses, entrepreneurs wishing to enter the infrastructure sector, regulators, government and, perhaps most importantly, our communities who will benefit from more efficient and less vulnerable infrastructure based services." (EPSRC, 2013)

The ICIF project outline is distinctive in that it chose to focus in systemic interdependencies, but these are largely seen as opportunities for cost-reduction with regard to utility company business models, rather than as a challenge to understanding the dynamics of sociotechnical transitions. Despite the modal gesture toward community benefit in the project summary, the bulk of publications resulting from ICIF are focussed on the management and/or "delivery" of large infrastructure projects (e.g. Davies, MacAulay, DeBarro, & Thurston, 2014; Hartmann, Roehrich, Frederiksen, & Davies, 2014; Worsnop, Miraglia, & Davies, 2016), and the quantitative modelling of failure risk and/or operational efficiency in interdependent infrastructures (e.g. Daneshkhah, Stocks, & Jeffrey, 2017; Rigas, Ramchurn, & Bassiliades, 2015); very little of the project's published output considers communities or citizens as anything more than a statistical market of service users, and in such cases as "futures" are explicitly engaged with, they are the futures of governance—particularly as it "relates to the interactions and decision-making amongst multiple actors that result in the delivery, financing and payment for infrastructure services" (Hiteva & Watson, 2016).

However, one of a handful of ICIF publications with an explicitly social-scientific perspective concludes by advocating a strategy not dissimilar to that outlined in the previous section of this literature review. After outlining a "comprehensive" (and fairly complex) framework through which "inefficient energy habitual behaviour" might be studied and better understood, the authors conclude with the following suggestion: "In order to capture micro-trends, it is suggested that research should commence from local scale and move towards the regional scale. Thus, the proposed framework and potential intervention methods would be more effective first to be applied within a micro-scale (e.g. households)..." (Pothitou, Kolios, Varga, & Gu, 2016). Though described using very different terminology, this would nonetheless appear to be advocating in favour of a granular demand-side research perspective on the formation of consumptive practices. A similar point is made by Varga (2013), who observes that "[t]he fruitfulness of these recommendations [to address demand expansion] is impossible to predict because the system is complex, that is evolutionary and adaptive, and depends on future contexts..."

ITRC-MISTRAL: Multi-Scale Infrastructure Systems Analytics

MISTRAL is an EPSRC-funded project (reference EP/N017064/1) of the Infrastructure Transitions Research Consortium (ITRC) led by Oxford University, which started in February 2016 and is due to complete in August 2020. The project summary is succinct regarding its objectives:

> "Our vision is for infrastructure decisions to be guided by systems analysis. When this vision is realised, decision makers will have access to, and visualisation of, information that tells them how all infrastructure systems are performing. They will have models that help to pinpoint vulnerabilities and quantify the risks of failure. They will be able to perform 'what-if' analysis of proposed investments and explore the effects of future uncertainties, such as population growth, new technologies and climate change." (EPSRC, 2016)

Much as with ICIF (with which credit is shared on a significant number of publications), MISTRAL's published output to date is strongly oriented toward system management and simulation through quantitative modelling—which, given its founding intentions, is not at all surprising; it further appears that any significant engagement with "futures" in the project is intended to take place within these models (see e.g. Hall et al., 2016). Whether the final modelling system will include sociopolitical uncertainties alongside "population growth, new technologies and climate change" is unclear, but given that sociopolitical non-linearity is, by definition, largely intractable to quantitative modelling, it seems reasonable to assume that they will *not* feature; indeed, it would be surprising if they did, given the epistemological context.

As for the matter of sociological perspectives, MISTRAL's output thus far—again, unsurprisingly given its aims—seems entirely focussed on the quantitative supply-side perspective, dealing with topics such as "population synthesis" (Smith, Lovelace, & Birkin, 2017) and the "predict[ion of] future [transport] demand ... using an elasticity-based simulation approach" (Lovrić, Blainey, & Preston, 2017).

Liveable Cities

Liveable Cities was an EPSRC-funded project (reference EP/J017698/1) which ran from May 2012 to December 2017, executed by a consortium of universities led by investigators from the University of Birmingham. By comparison to both ICIF and MISTRAL, its orientation is markedly more social, but where the others focussed on infrastructural systems as their research object, Liveable Cities took the city as its unit of analysis and intervention. However, the emphasis was very much on "solutions delivery":

> "Our ambition is to create an holistic, integrated, truly multidisciplinary city analysis methodology that uniquely combines engineered solutions and quality-of-life indicators, accounts for social aspirations, is founded on an evidence base of trials of radical interventions in cities, and delivers the radical engineering solutions necessary to achieve our vision." (EPSRC, 2012)

The City Analysis Methodology at the heart of the Liveable Cities Project makes some use of a futures framework that includes some social factors, but because of the timescales and demographies in the analytical frame, the social aspects of demand for infrastructural services are (again, by epistemological necessity) reduced to collective rational choices made *en masse*, with no engagement as to the question of how those choices might have come to be made, how they might have been shaped and constrained by earlier decisions (infrastructural or otherwise), and how those decisions propagated throughout "society". For instance:

> "... an electrical demand exists only because society has chosen to adopt and use a range of technologies in the home (e.g. the TV, washing machines, dishwashers, the microwave) [...] Economics influences individual choice through a trade-off between running costs and the cost of investment in the technology (e.g. I may choose to use my TV less because fuel prices have increased or I may wish to purchase a more energy-efficient TV)." (Hunt, Rogers, & Jefferson, 2013, p259)

This is precisely the economic "rational choice" understanding of consumptive practices that this project aims to replace (see again section 2.1.2). The scenario methodology described in this paper does allow for changes in this social factor, but the dimensions of that potential change are an axis running from "a significant improvement to a significant worsening". There is no engagement with the possibility that existing practices and/or infrastructural regimes might be contributing to the obduracy of current levels of consumption, or indeed to their "significant worsening"; rather, it is implicit that "society", in aggregate, just doesn't know what's good for it. (This in spite of nearly two decades of research demonstrating that the "information deficit" model of behavioural change "lacks both empirical and theoretical support"—see e.g. Marteau, Sowden, & Armstrong, 2002). A similarly reductive approach to "user behaviour" (and the potential modification thereof) with regard to consumptive practices is found in Zadeh, Hunt, and Rogers (2014), though here the authors concede that "complex relationships influencing household water use make underlying patterns of behaviour are difficult to detect [sic]", and note that the inherent subjectivity of qualitative research presents a challenge to the quantitative analysis which is their goal.

That said, a number of papers (e.g. Hunt, Jefferson, & Rogers, 2012; Hunt et al., 2013; C. D. F. Rogers, 2018) show that Liveable Cities engaged much more directly with futures methodologies than either ICIF or MISTRAL. However, there was an early decision, as evidenced in the grant application project summary, to take a supply-side perspective and to work with the "preferred future" or "back-casting" paradigm of foresight:

> "A roadmap is required to chart the path from here to there, identify potential tipping points and determine how to integrate radical engineering strategies into norms. However, this roadmap can only be considered once that alternative future has been established, and a 'back-casting' exercise carried out, to explore where the major barriers to change lie and where interventions are needed." (EPSRC, 2012)

As noted above, back-casting is a popular methodology with considerable success when it comes to generating strategies or road-maps with "stakeholder buy-in", but little in the way of documented assessment of the success (or failure, for that matter) regarding the road-maps thus produced. More pertinently, the back-casting approach amounts to putting all of one's strategic eggs in a single basket: if at some point the direction of travel in reality goes off the edge of the mapped route, you're lost. The idealism of this approach is explicitly stated in Ortegon-Sanchez and Tyler (2016), though it does represent a move away from, as the authors succinctly put it, the "all-too-common 'political wish list'" approach to setting out the preferred future, relying instead on empirical situated studies in a variety of global settings, and a literature review of "exemplary urban transformations".

Liveable Cities also shows a much deeper engagement with social dynamics than either ICIF or MISTRAL: its outputs include papers on citizen aspirations (see e.g. Joffe & Smith, 2016) and urban "liveability" (see e.g. Hunt et al., 2014), as well as a rather unique typology of future-city visualisations (Dunn, Cureton, & Pollastri, 2014). It is also notable that, while not using the Harawayian terminology or justifications described previously, Liveable Cities nonetheless engaged in situated research (i.e. tending toward the use of real data from real locations rather than abstracted models or simulacra of "the social"), and also engaged with systems interdependency through the "energy-water-food nexus" approach (see e.g. De Laurentiis, Hunt, & Rogers, 2014, 2016).

Liveable Cities also supported a number of publications by the late John Urry, whose work is cited elsewhere in this literature review, and whose position on paradigmatic futures practices was broadly in line with (and indeed influential upon) that taken by this project. In Urry (2013) he engaged with a form of scenario-based "black-sky thinking" intended to problematise paradigmatic notions of progressive development through the depiction of futures where things don't work out according to plan, while in Urry (2014) he deals with the matter of obduracy (or "technological lock-in") with regard to the decarbonisation of the energy sector. However, Urry's position appears to have been marginal within the context of the project, and indeed within the urban transitions paradigm more broadly: Liveable Cities certainly represents a sort of sociological "best practice" among projects of this type, but it's still a long way away from sustained engagement with sociotechnical change as a demand-side phenomenon, or an engagement with futures that goes beyond the optimistic idealism and limited social dimensionality of the back-casting approach.

The infrastructure futures paradigm

In general, all three of the projects surveyed—while in some cases harbouring elements of more qualitative and/or sociological enquiry on their margins—tend to: see infrastructural interdependency as an opportunity to be exploited, rather than as a source of problematic complexity which generates emergent obstacles to the successful management of "preferred" sociotechnical transitions; propose the use of agent-based or other such quantitative simulacra for advanced variations on the predict-and-provide model of infrastructural planning, design and "delivery"; generate visions, solutions and "preferred futures" for infrastructural reconfigurations through the use of the back-casting approach.

On the basis of their published outputs, none of these three projects: ask how or why citizen practices might (or might not) change, beyond their standard assumption of the rational choice model of demographic behaviour; recognise the role of interface technologies in inextricable interaction with domestic practices and/or infrastructural systems as contributing to the obduracy or practices deemed problematic or over-consumptive; question the deliverability of their solutions and visions under potentially divergent sociopolitical contexts; or engage with sociotechnical change as the fundamental question underlying the challenge of infrastructural reconfigurations, in the manner of transitions theory (see again section 2.1.1).

In the preceding sections of this literature review, it has been argued that there is a significant bias in infrastructure futures research toward quantitative, normative and supply-side-oriented analytical paradigms, and that the balance might be redressed by recourse to the deployment of an alternative blend of qualitative, explorative and demand-side-oriented approaches. As exemplars of the leading edge of research into infrastructural futures, the three projects surveyed above highlight this persistent research gap: the prevailing paradigm in infrastructure futures is strongly (though not exclusively) quantitative, managerial, technologically determinist and oriented toward supply-side concerns, and lacking in sustained engagement with the question of the dynamics of sociotechnical change as a phenomenon on the demand-side of the system. Recognising this gap in the contemporary research landscape as a site for genuinely novel scholarship, this project aims to produce and demonstrate a methodology which might serve to fill it—and in doing so provide a vital qualitative, demand-side supplement to prevailing academic approaches to infrastructural futurity.

Summary

This chapter has explored two distinct literatures. In the first section, it examines models and methodologies for the study of sociotechnical change, looking first at technology-centric approaches, and then at more human-centric, anthropological approaches. The second section discusses methodologies for strategic foresight, planning and prototyping which might be appropriate at the infrastructural scale.

Regarding existing scholarship on sociotechnical change, it is concluded that the Multi-Level Perspective (and the associated Transitions and Transitions Management literatures) represents the dominant paradigm and the state-of-the-art in technology-centric approaches, but it is increasingly hampered by its failure or inability to address a series of long-standing critiques, including:

- its poor handling of agency and adherence to arbitrary hierarchies;
- its placelessness and holism;
- and its relentless reproduction of a generic and heroic innovation narrative.

In order to improve upon the MLP, therefore, one or more of these shortcomings must be addressed.

With regard to anthropological approaches, it is concluded that Actor-Network Theory, Cyborg Anthropology and Social Practice Theory are all rooted in the assumption of a flat ontology, and are distinguished by the metaphors through which that ontological assumption is framed; as such, methods, theories and strategies for studying sociotechnical change might be productively drawn from all three literatures without significant risk of contradiction. However, it seems clear that SPT, through its relentless focus on the practice as the site of study, provides the most suitable heuristics and models from which to start an investigation into infrastructural change: flat ontologies are challenging precisely due to their lack of hierarchy, but the relational structure of the practice concept allows for a structured entry into the assemblage at the site of agency. Furthermore, SPT's intimacy with the human scale, sometimes dismissed as its greatest flaw, positions it optimally for an examination of the dynamics of sociotechnical change, which inescapably emerges from individual human choices and desires.

Regarding methodologies for infrastructural foresight, it is concluded that some methods are particularly suited to dealing with the challenge of uncertainty and divergence in long-term planning (scenarios), while others possess the capacity, whether implicit or explicit, to subject proposed ideas or systems to the sort of qualitative critique which is largely absent from most infrastructural visions (design fiction, science fiction prototyping). Some combination of these narrative-driven methods might therefore unify qualitative critique with contextual uncertainty, thereby providing a sort of prototyping process to support and complement the established methods of qualitative assessment traditionally applied to infrastructural projects.

Chapter 3

Aim and Research Questions

This chapter sets out the overarching aim of the thesis, and defines three research questions which will serve as its orienting objectives.

Statement of Aim

It is the aim of this thesis to *make infrastructure legible*: to narrate it from a more human-centric perspective than that which prevails in the majority of contemporary research in the field. In less lyrical terms, the project aims to understand how infrastructures develop, how they evolve and entangle over time.

Research Question 1

The first research question is as follows:

> *Starting from a materialist and practice-oriented perspective, how might one model and analyse the mutually influential and longitudinal relationships between everyday consumptive practices and the infrastructures which enable them?*

The literature review illustrates the potential for social practice theory to inform new models of sociotechnical change and address the shortcomings of prevailing theories, and highlights particular calls for the application of such models to the understanding of consumptive behaviours supported by infrastructural systems. The first objective therefore involves the development of such a model, and using it to perform a longitudinal analysis of the sociotechnical evolution of a particular practice.

Put more simply, the first objective is to advance a theory of sociotechnical change, and apply it to historical data to see what explanatory power it has.

Research Question 2

The second research question is as follows:

> *Drawing on the model and analysis developed in fulfillment of Objective 1, how might such findings be used as the basis of a speculative exploration of the advantages and obstacles associated with the deployment of proposed future infrastructures?*

The use of futures methodologies in infrastructure planning is fairly well established, but such exercises are rarely rooted in longitudinal context, and tend toward assessments rooted in predominantly economic and technical terms. The second objective therefore is to take the insights acquired in fulfilment of the first objective, and use them as the basis for a prototyping process that focusses on systemic contextual challenges to proposed infrastructural reconfigurations, rather than technical feasibility or return on investment.

Put more simply, the second objective is to develop creative techniques for extrapolating from an understanding of how we ended up with the infrastructure we have in the present, so as to better understand how we might influence the infrastructure we get in the future.

Research Question 3

The third research question is as follows:

> *How might this methodology improve or expand our understanding of the concept of sociotechnical transition?*

Contemporary research into sociotechnical change at the infrastructural scale is dominated by the literature on transitions, and by the Multi-Level Perspective model from which that field stems. As shown in the literature review, there are three lingering shortcomings associated with the MLP:

- it obscures the role of agency, is heavily reliant on theoretical abstractions, and presupposes arbitrary hierarchical structures;
- it relies on geographical metaphors (e.g. niche, landscape, regime), but largely disregards the geographical distribution of the phenomena with which it is concerned;
- it (re)produces the a generic (and heroic) narrative of innovation, and appears unconcerned or unable to explain failed or stymied changes.

The third objective, therefore, is to assess the outputs produced in response to the first and second objectives, in order to determine whether they successfully address any or all of these shortcomings, and thereby shed further light on the concept of transition itself.

Chapter 4

Model and Methodology

Introduction: specification of requirements

This chapter introduces the novel methodology at the heart of this project. The overarching aim of the project is to understand the dynamic relationships which underpin the sociotechnical reconfigurations commonly referred to as "transitions", and to use that knowledge as the basis for speculative assessments of the challenges facing the deployment of technologies and infrastructures of the future.

This project is primarily a methodological enquiry, aimed at developing and testing a new approach to the study of sociotechnical change. In the preceding chapter, we specify a requirement for a two-part methodology which will be used in fulfilment of RQs 1 and 2: RQ1 requires a methodology for the study of historical sociotechnical change, while RQ2 requires a methodology for speculating on the sociotechnical changes of the future.

As such, the first section of this chapter will develop a novel model of sociotechnical change, which:

- approaches the question of sociotechnical change from an explicitly demand-side perspective, as informed by social practice theory;
- is based in a flat, materialist ontology, eschewing the arbitrary hierarchies and abstract entities which populate the Multi-Level Perspective model;
- and is universally applicable to any practice, and thus to any sociotechnical assemblage, at any point in timespace.

The second section of this chapter will then use the model as the core of a novel methodological framework for the historical analysis of sociotechnical change, which:

- directs the researcher toward the networks of relationships through which particular sociotechnical assemblages are (de)constructed;
- pays explicit attention to the situatedness (in time and space alike) and subjectivity of practices and the systems that enable them; and
- thus allows for the systematic comparison of a variety of sociotechnical assemblages, successful or otherwise.

The model and methodology thus described are a partial fulfillment of RQ1, to be completed through the experimental application of the methodology as documented in Chapters 5, 6 and 7.

The third section of this chapter will present a methodology which builds on the historical analysis by switching the model into a speculative modality, so allowing the findings generated by the analytical mode to inform a narrative prototyping method through which proposed sociotechnical assemblages of the future might be assessed in terms of the plausibility of their deployment, and tested against a variety of potential socioeconomic circumstances. This second methodological mode is a partial fulfillment of RQ2, to be completed through its application.

4.1 Constructing the model: the infrastructral trialectic

4.1.1 The evolution of the assemblage

The trialectic model is at the core of a novel theory of sociotechnical change which is concerned with the enrolment of new technologies and systems into the assemblages which enable and shape everyday consumptive practices. A brief (and necessarily generic) rehearsal of the evolution of potable water supply will demonstrate the sort of dynamics it seeks to explore.

So, consider a small settlement with no infrastructure at all: how would its residents obtain clean water for such practices as drinking, cooking, or bathing? Such an early settlement would likely be founded close to some sort of water supply: a spring, a river or a well. Prior to any infrastructural intervention in the landscape (making an exception for the bucket-pulley which might be fitted to the well), residents of the settlement would have to either fetch water from source and carry it back to their home, or perhaps make use of the water at source (e.g. washing clothes on the river bank). This is the simplest relationship possible between a performer and a resource, mediated by little more than a bucket (or the local analogue thereof); see item a, Figure 4.1 on page 52.

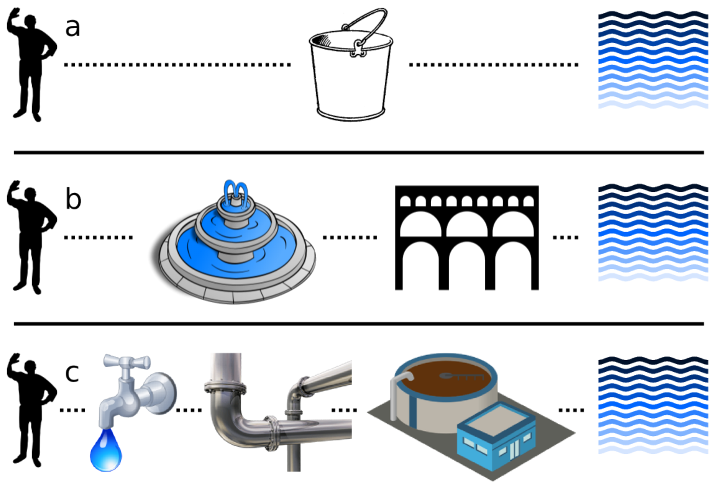

Figure 4.1: Evolution of the assemblage—potable water provision

Now consider a later settlement, something like a minor town of the Roman empire (item b, Figure 4.1). Population growth will have resulted in the over-abstraction of locally accessible water, necessitating the construction of an aqueduct to channel water into the town from further away. But it would be wasteful (not to mention destructive) to simply have the aqueduct debouch into the town square unimpeded—and so something like the public fountains of Rome would be developed, so as to capture as-yet-unused water (possibly redirecting it to other uses), and to make it easier (and safer) for citizens to either fetch water and take it home, or use/consume it on site.

Now consider a yet more modern settlement (item c, Figure 4.1). The aqueduct (which may or may not have been replaced, fully or in part, by a network of pipes) draws water from the abstraction source (which may be natural or artificial) and channels it to a treatment works, from where it is pumped into a water distribution network which connects to individual buildings and homes; those buildings will be fitted with some sort of plumbing system, however rudimentary, so as to prevent the water simply flooding out from the delivery network. The plumbing system may also allow for the direct connection of water-utilising appliances, such as washing machines.

4.1.2 Elements of the trialectic

As illustrated above, what we see is a gradual profusion of technologies and systems interposing themselves between the performer and the resource they wish to consume. In each case, the performer has to make use of some sort of interface technology: bucket, fountain, faucet, washing machine. As technology progresses, the interface used by the performer allows them to access the potential of an increasingly complex system of resource distribution and transformation. In accordance with social practice theory (see Literature Review), new infrastructures (re)shape the performance of practices; it follows, therefore, that new performances of practices (re)shape the infrastructures on which they depend. *Interface technologies mediate the mutual influence between performer and infrastructure*: they are the site where the parameters of a given performance are negotiated and constructed. As such, we can construct a simple tripartite model based on the three elements which persist across every configuration, from the simplest to the most complicated: those three elements are the performer (or protagonist), the interface, and the infrastructure (see Figure 4.2 on page 53).

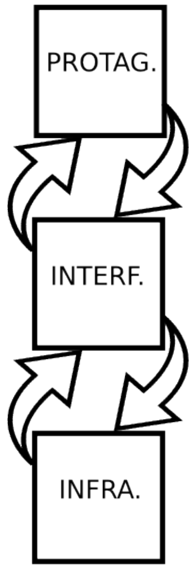

Figure 4.2: Three elements of the infrastructural trialectic

Note that the interface may be a physical device with which the performer interacts directly, or it may be a service within which a device or set of devices is packaged for the performer: so, a faucet is an interface to a water distribution infrastructure, but so is a corner-shop selling bottled water, or indeed an online service which delivers bottled water to your home. The interface is whatever the protagonist interacts with directly, and with intention.

4.1.3 Vectors of influence

In order to develop a theory of sociotechnical change, it is necessary to trace and account for the mutually shaping influences mentioned above: performances shaping infrastructures, and infrastructures shaping performances. With very few exceptions, performers never interact directly with infrastructures: all interactions, and therefore all influences, are mediated through the interface layer. Therefore we can introduce four vectors of influence into the model, as in Figure 4.3 on page 54. These vectors are (moving clockwise from top right):

- Hacks, Kludges & Jugaad (HKJ hereafter)
- Invention & Iteration (I&I hereafter)
- Standards & Regulations (S&R hereafter)
- Design Protocols (DP hereafter)

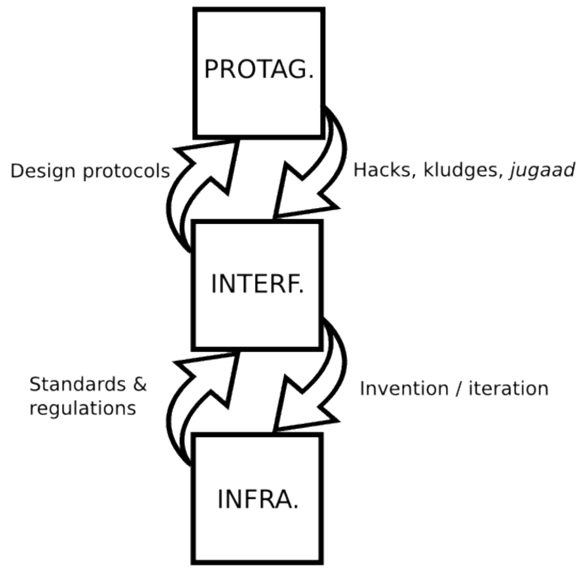

Figure 4.3: Infrastructural trialectic with vectors of influence

These relationships are complex and non-causal: no element necessarily takes the precedent or upper hand over another, and all four vectors of influence are active at the same time. We can characterise the relationships by considering one pair of elements at a time, and describing the interactions between them in more detail.

The Protagonist/Interface relationship (upper dyad)

The most immediate relationship is that between the protagonist and the interface: it is, in essence, a negotiation (or contest) between the protagonist's preferred performance, and the idealised performance as it is (pre)conceived in interface designer's use-case.

The design of an interface (whether device or service) constrains the manner in which it may be used. Design is, at least in part, a process of limiting and simplifying user choice to a greater or lesser degree—particularly in the case of consumer technologies, where it is assumed that a lack of expertise in the user necessitates the limiting and streamlining of potential function down to to a more simple set of choices. Think of a washing machine: rather than requiring the user to select each and every parameter of the wash, those options are bundled up and simplified into preset programmes based on the type of fabric to be washed, the extent of soiling, etc.

No matter how comprehensive the design, circumstances will inevitably arise in which the defaults or presets provided by the designer do not fully meet the protagonist's desired parameters of performance. So, returning to our hypothetical washing machine: perhaps an otherwise suitable programme lacks an extra rinse or spin cycle. In such a circumstance, the user may simply accept the limitations of the design, especially if there is no more suitable design available (or affordable) on the market. But human beings are not noted for their ability to accept what appears to them to be second best. This desire for a more suitable interface manifests in three related types of response: hacking, kludging, and *jugaad*.

- *Hacking:* drawing on the figure of 'the hacker' from computer culture, hacking is defined in this context as the deliberate circumvention of designed limitations in a device: think of motor scooters made faster (and louder) by the removal of the exhaust system's silencers and baffles, for example, or of the deliberate misuse of a water fountain's trigger in order to obtain a faster flow. Hacks are not *necessarily* destructive, though hacking for one particular optimum may end up restricting or breaking other aspects of functionality (or, indeed, the entire device, or even the system(s) to which the device acts as interface).

- *Kludging:* the kludge is related to the hack, but where the later seeks to circumvent design, the former attempts to extend or augment it: to return to the motor scooter, fitting it with a home-made parcel rack would be a kludge, particularly if doing so went strictly against the spirit of the original design. (In practice, the distinction between a hack and a kludge can be difficult to discern, but given both responses belong to the same vector of influence, the point is largely moot in the present context.)

- *Jugaad:* from the Urdu, in which language the word refers to what we might describe as preferential procurement: "to procure (x), rather than buying (x); to make a temporary or ersatz (x)". In its colloquial usage, it makes a broader signification of ingenuity, but with particular reference to that ingenuity which is born of poverty and limited opportunities. The jugaad response to an absent or not-fit-for-purpose interface is to build one's own from whatever materials are available to hand—so if one fitted a set of re-purposed blades to the back of a motor scooter in order to use it to plough furrows in a field in the absence of draft animals or a "proper" tractor, one would be doing serious *jugaad*.

These three strategies are widespread, if not ubiquitous, in daily practices all over the world, all throughout history. While design involves the limiting of options, it also responds to the use-case—that is, to a particular idealised performance which represents a commercial opportunity to the designer or their business. As such, hacks, kludges and jugaad observed "in the wild" form an influence on the designer, as they signify a use-case that is not yet being provided for.

But the use-case for which the designer has provided (or attempted to provide) has a complementary influence upon the protagonist and their performance, precisely through the protocols of usage designed into the device or service. This produces another vector of influence flowing in the opposite direction to HKJ, as these *design protocols* effectively determine what it is possible to achieve with the device or service in question, and as such present a set of limits to the performance which the performer may try to work around. This relationship between product and/or service design and the protagonist is a perpetual negotiation, driven by the protagonist's desire to fulfil a particular performance of a practice, and by the designer's desire (or that of the organisation for which they work) to supply more devices or services at a better profit margin.

The Interface/Infrastructure relationship (lower dyad)

The interface layer acts as a mediator between the protagonist and the infrastructure layer; as such, the relationship between interface and infrastructure shapes and informs the relationship between protagonist and interface, and vice versa. Both of these dialectical relationships share a similarly agonistic structure, which is to say a struggle or conflict in which each actor (or element, in this case) seeks to get the better of the deal. However, it should be noted that these struggles are not zero-sum—or at least not necessarily so.

As discussed above, designers seek to develop interfaces (be they devices or services) which fulfill the desire for an as-yet unfulfilled performance, or improve on an existing performance in some way. As industrial and service design are inherently commercial practices, the iteration of new designs are motivated, at least in part, by a desire to sell more devices or services. In order to sell a new interface, then, it is necessary for it to better meet the desire represented by the protagonist's use-case than the available alternatives. This most often manifests as an interface which somehow exceeds the parameters of the existing best-choice performance: bigger, faster, cheaper, and so forth. (Design strategies rooted purely in aesthetics and/or "reinventions of the wheel" are anathema to this model, and indeed to the study of innovation more generally.)

So, consider a car manufacturer: they compete with other manufacturers across a variety of different parameters, e.g. maximum vehicle capacity, maximum speed, fuel economy, safety. But considered as a market, the nature of the competition is to provide the greatest amount of use-of-the-road possible at any given price-point: through a motor car (interface), the protagonist accesses the mobility potential of the road network (infrastructure), and the design protocols of the specific vehicle they use serve to mediate that potential, often through trade-offs in functionalities: for instance, one might sacrifice safety and vehicle capacity to gain higher top speeds.

At the same time, the infrastructural layer will be seeking to limit the parameters of the way in which it is used (which is analogous to a design problem at the scale of the network). This is partly about demand management—avoiding brownouts, traffic jams or hosepipe bans—but also about maximising revenues and minimising wear and tear so as to keep overheads as low as possible.

So, while the interface is trying to get the best out of the transaction on the protagonist's behalf, the infrastructure must impose limits on the parameters of the transaction—or at least attempt to. Such limiting strategies are of two broad types, which are labelled as standards and regulations: with the acknowledgement that many strategies may straddle the distinction, *standards* are defined as restrictions which are a function of the material constitution of the infrastructure in question (e.g. standard railway gauges, which effectively prevent the use of non-standard rolling stock entirely), whereas *regulations* are social rules and norms against performances whose parameters exceed necessary limits (e.g. laws regarding maximum dimensions for road vehicles, speed limits); standards are usually difficult (or obviously dangerous) to circumvent, while regulations can be more easily flaunted (despite the real risks which they were designed to prevent). Much as the protagonist pushes against the design protocols baked into the interface, interface designers, in their attempts to provide a product or service which better fulfills the protagonist's desire, push against the hegemony of infrastructural standards and regulations, either by developing new products or services (invention) or improving and optimising existing ones (iteration).

In relation to the fourth and final vector, which flows from the interface layer to the infrastructure layer, *iterational* design seeks out as-yet-unexploited marginal gains and tradeoffs in transaction parameters (e.g. tweaking the design of an internal combustion engine to improve power and efficiency), while *invention* seeks to literally re-invent the transaction to the protagonist's perceived advantage (e.g. replacing the internal combustion engine with some novel, and presumably superior, source of motive power). As with standards and regulations, the distinction between iteration and invention is not always clear, and new products and services may involve some aspects of both approaches. Both have the effect of maximising (or at least improving) the infrastructural potential which can be accessed by the protagonist in fulfillment of their performance, and/or providing interfaces which allow new protagonists to access an infrastructure to which they were previously excluded by lack of the appropriate interface. As such, the influence of innovation and invention upon the infrastructural layer is predominantly experienced as in increase in demand, which can be responded to through adjustments to standards and regulations, or capacity expansion (or both).

4.2 Methodology: historical mode

Having built the model and explained the dynamics it captures, we can move on to explaining how it is used as part of the methodology, starting with the first of two modes, the historical. To reiterate: the role of the historical mode is to explore the dynamics of historical changes in the constitution of the assemblages which underpin a particular practice. Or, more simply: the analytical mode uses the trialectic model as a lens for studying sociotechnical change over long periods of time.

4.2.1 Populating the model

This methodology seeks to understand the variety of potential assemblages which might fulfil a performance of a given practice-as-entity at a given location in timespace. As such, the practice-as-entity under study must remain constant across the entire analysis: it is the independent variable. The protagonist element in the model represents an individual (or their proxy, performing on their behalf) and their desire to perform the practice under analysis; as such, the protagonist is also fairly stable throughout the process, allowing somewhat for the way in which extrinsic factors (e.g. sociocultural, commercial/economic, political) may modify the particular parameters of performance which they seek to maximise.

Having determined the practice under analysis, the next step is to determine which infrastructure(s) might be involved in performances thereof. In many cases (if not most), there are multiple possibilites—for example, a personal mobility practice could be performed across the road network, the rail network, rivers and canals, or the commercial airline network. Furthermore, it may be that any given performance might make use of multiple infrastructures. Consider the (idealised) map in Figure 4.4 on page 59:

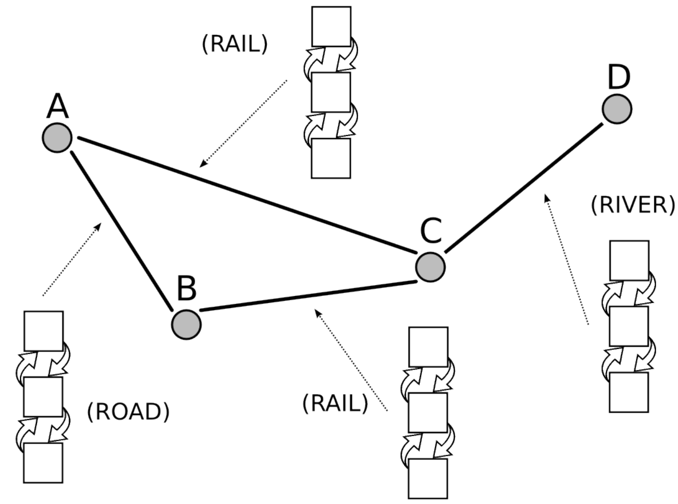

Figure 4.4: Idealised transport network map

As can be seen, a protagonist wishing to transport themselves from Town A to Town D has more than one possible route open to them; furthermore, each route involves the enrollment of more than one infrastructure. The aim of this methodology is not to describe the options and parameters of specific journeys, however. Rather, it is aimed at exploring the range of choices available to a range of protagonists seeking to fulfill a particular practice-as-entity in a particular location in timespace; in this case, the practice is personal mobility, or getting oneself from A to D. The model is therefore applied to a single infrastructure at a time: the practice-as-entity remains the master independent variable throughout the analysis, while each deployment of the model also treats the infrastructure layer as an independent variable. This leaves the interface layer as the dependent variable.

Of course, considered over historical timespans, the infrastructural layer undergoes changes of its own, in response to accumulating changes in performances and interfaces that make use of it. Given that this methodology is particularly concerned with the dynamics of sociotechnical transitions at the level of the entire assemblage, and further given that research resources are limited, the next stage is to look at the historical development of the infrastructure currently under analysis with the aim of identifying moments at which significant changes in the assemblage took place, and at which significant changes were resisted or deferred. Having identified these moments, they are taken as temporal anchors for a more detailed study of the infrastructure's constitution at that time, and of the array of interfaces which were available for use.

In such situations where there is only one interface-type through which the infrastructure could be enrolled, the analysis would be a simple case of following a linear succession of ever-better devices and/or services as they replaced their obsolete predecessors. However, such situations are extremely rare, if not entirely absent: rather than there being a single interface option, there is instead what we might think of metaphorically as a 'market' of options, each catering to different performances by emphasising certain parameters and de-emphasising others. As such, the interface layer most often represents a range of possible interface choices for the protagonist of any given specific performance, as shown in figure 4.5 on page 60.

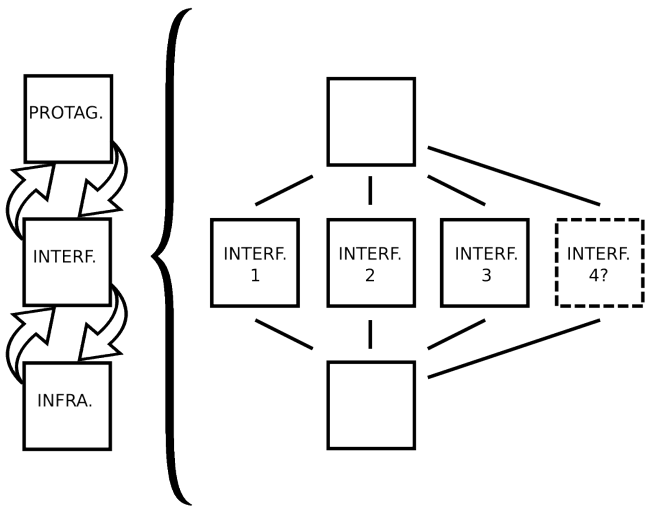

Figure 4.5: Unpacking the interface layer

As discussed in the literature review, "transitions" are a phenomenon pertaining to populations rather than individuals. The concept addresses an aggregate of choices rather than discrete changes of habit or practice: one person selling their car and buying a bicycle does not mark a transition, but a significant proportion of a population taking to two wheels rather than four represents something with more systemic significance. As such, we can unpack the model still further, so as to show what the interface layer represents in analytical terms, as in figure 4.6 on page 61.

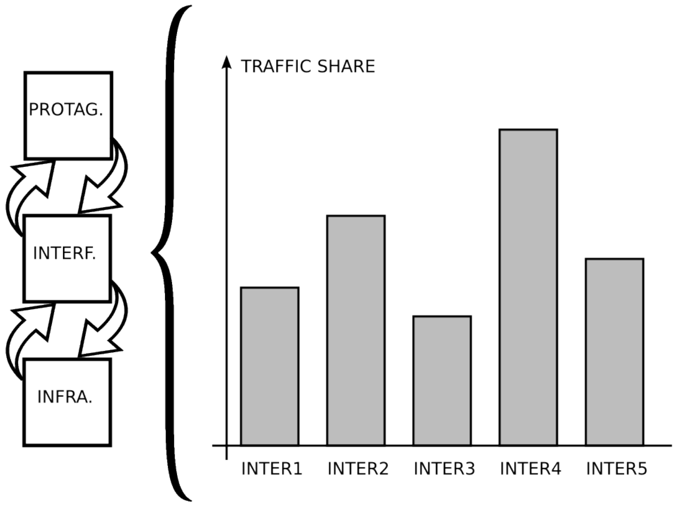

Figure 4.6: Interface layer considered as distribution of traffic types

However, recall that the practice-as-entity (e.g. "getting from A to D") is the master independent variable, and that the infrastructural layer is effectively stable within the context of each analytical moment. As such, the vectors of influence upon the interface layer (HKJ, S&R) are likewise fairly stable within the context of any given analytical moment. HKJ influences are bound up with the teleology of the practice-as-entity, which is to say with the fulfillment of a specific goal or purpose, and can as such be considered in the abstract throughout the analysis (while making allowances for cultural-contextual modifications to that teleology where appropriate), but each moment necessitates a close study of the infrastructural standards and regulations which pertained at the time.

So the next step is to make a close study of the interface-types available in the moment under analysis, paying particular attention to the manner in which their design parameters respond to particular protagonist use-cases (thus catering to particular performances over others), and how their invention or iteration responds to the standards and regulations which pertain to the supporting infrastructural layer(s). These *dialectics of desire* between the the elements of the model will thus illustrate the performance parameters which inform the choices being made.

Having populated the model for a given analytical moment, we can move to the second step of the analytical mode, in which the model is used as a framework upon which to map the social articulations which mediate the vectors of influence and stabilise the assemblage. Or, by way of simplification: with the model having captured the vital material elements of the assemblage and traced the vectors of influence between them, the next step is to capture and represent the interlocking control and influence exerted over the elements by organisations, institutions, communites, and other (predominantly, but not exclusively) social actants.

4.2.2 Mapping the articulations

The objective of the articulatory mapping process is to capture the most significant social actants involved in structuring the the sociotechnical assemblage which is represented by the the trialectic model, and to indicate the relationships between those actants, within which the dynamics of influence and change are negotiated, and the assemblage (de)stabilised.

Through close study of historical sources, the pertinent social actants are identified: these will include infrastructure trusts and companies, institutions of governance, craftspersons and manufacturers, communities-of-practice and alliances-of-interest... and even, in some cases, other infrastructural assemblages. These actants are then "mapped" in overlay upon the model of the assemblage, so as to indicate which elements and/or vectors the actant has control of or influence upon. As more actants are mapped onto the same diagram, the areas in which they overlap are indicative of relationships between those actants which are specifically concerned with the assemblage under study. By way of demonstration, refer to Figure 4.7 on page 63.

In Figure 4.7, Actant A [green] is shown as having considerable influence over the infrastuctural layer, some influence over the interface layer, and further influence over both of the lower vectors (S&R, I&I); that sort of strong influence would likely belong to a state agency of some kind. Actant B [mauve] has less influence over the protagonist than it has over the interface layer, and its influence is focussed on the DP vector; this might be a regulatory body or a consumer group seeking to influence the design of technologies or services in use in the assemblage. Actant C [yellow], meanwhile, exerts more influence over the interface layer than it does over the infrastructure layer, but its influence is expressed only over the I&I vector; this might be a vehicle manufacturer. Considered together, it becomes clear that all three actants are in negotiation with the other two, and that those negotiations are at their most intense and tangled around the interface layer and the S&R and I&I vectors; the infrastructure layer, positioned as it is entirely within Actant A but no other, is effectively under the exclusive control of Actant

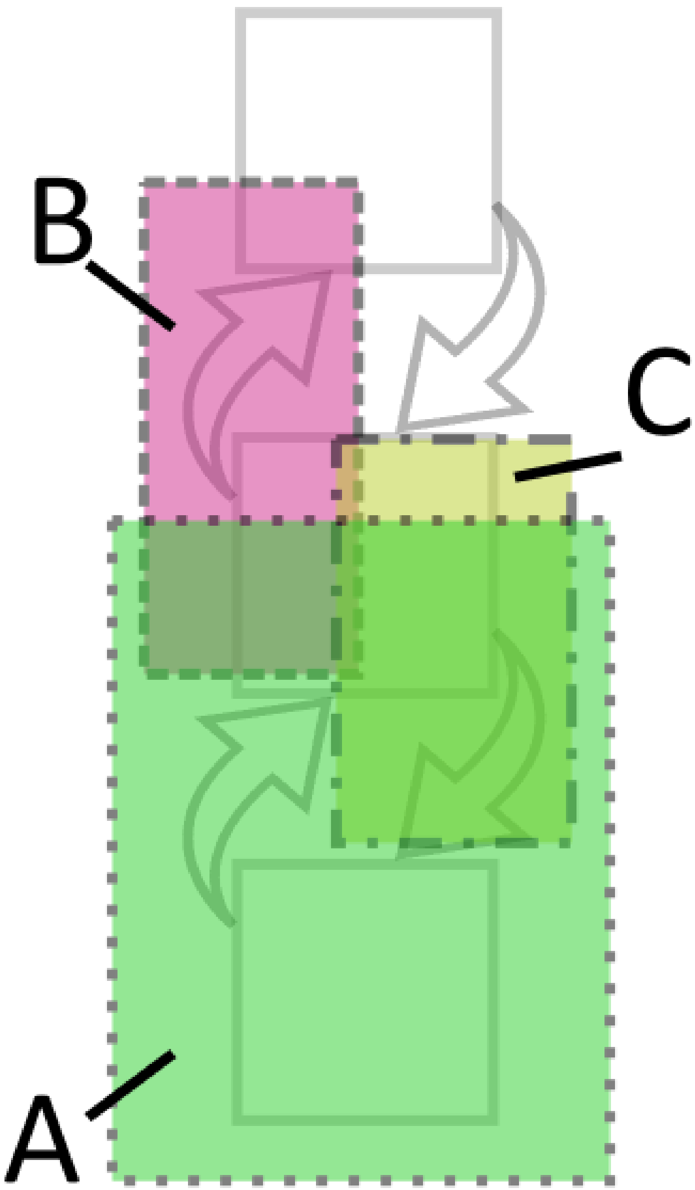

Figure 4.7: Articulatory mapping (generic example)

A (while still influencing and being influenced by the interface layer itself).*

The areas of overlap are of particular interest, because they indicate those relationships within which the possible parameters of a performance are negotiated, and through which the assemblage is articulated: the character of these negotiations—their success or failure, their antagonism or co-operativism—contribute to the stability or instability of the assemblage. These relationships make for the obduracy or plasticity of a sociotechnical assemblage; they are where change is born, or strangled.

And this is why, if one were to do a full "production run" with this methodology, the articulatory map would be only the beginning of the research, rather than its final output. To put it in the terminology of Actor-Network Theory, the actants represented in the diagram are only the very outermost "black boxes" within which the networks of relationships which constitute the assemblage are concealed; it is through prising open these black boxes with the crowbar of research, and zooming in more closely on those relationships—by "reassembling the social", as Latour would put it—that the dynamics of sociotechnical change can be traced. And in doing so, one also prises open the black box labelled "transition"—which may permit a more thorough understanding and definition of that term.

To reiterate an earlier point: this methodology is necessitated by the plurality of practices, interfaces and infrastructures, and by the requirement for analytical portability across a variety of cases. The front-line research methods to be deployed within it – which is to say predominantly desk-based and/or archival ethnographic enquiry, closely informed by the epistemology of Actor-Network Theory – are well established; however, the model and methodology themselves are a novel alternative to the prevailing modes of enquiry in the study of sociotechnical change, not least in their ability to direct qualitative research toward the material relationships between actants which are ignored by prevailing models, such as the Multi-Level Perspective.

4.2.3 Historical method

The trialectic model and methodology outlined in the previous sections of this chapter necessiates a base process of historical research from which the required data might be gathered. This section defines a method for guiding that process, and explores the choices which had to be made prior to beginning it.

*It bears repeating that the trialectic model and the articulatory map are relational representations, and in no way spatial; influence can, and often does, work at considerable distances (which is, ironically, itself an infrastructural phenomenon). Spatial proximity certainly has a role to play in transitions, but it is too granular a phenomena to be captured at this highly abstract level of analysis.

Site selection: why Sheffield?

Given this project's stated fidelity to Haraway's notion of situated research, it is necessary to first select a site upon which the study should focus. The trialectic model implicitly assumes a universality regarding the relationships it describes, but given the background of its architect, that universality should perhaps be delimited to the context of the "developed" or "Western" world, or even to that of the British Isles. Within that contextual delimit, however, there is an extent to which the selection of a specific site is arbitrary: it doesn't matter where you pick, so long as you pick somewhere.

As such, the city of Sheffield (and its surroundings) is no better or worse than any other—except in terms of ease of access for a researcher located within the city, where it obviously scores very highly. That said, the comparative paucity of attention paid thus far the infrastructural history of what was undeniably one of the great industrial cities could be taken as further justification: it seems likely that few would deny that Sheffield has shaped and been shaped by infrastructural development, but the story has yet to be told in those terms.

Practice selection: why freight logistics?

Having selected a site for the study, the next step is to identify the independent variable, namely the practice-as-entity in whose reconfiguration over time we are interested.

To reiterate: the practice-as-entity is a constellation of all of the meanings, competencies and materials which might possibly combine in the course of fulfilling a certain aim or purpose; a practice-as-performance, by contrast, is one particular and distinct combination of meanings, competencies and materials which fulfils a particular and distinct expression of a certain aim or purpose. In other words, the practice-as-entity, being defined by its teleology or purpose, is persistent over time, but the ways in which that practice are actually performed will change across timespace, due to the differing availability of the appropriate meanings, competencies and materials. Or, more simply still: the practice-as-entity is the sum total of ways and means relating to what the protagonist wants to do, while the practice-as-performance is the way they actually do it.

This project's aim is to make infrastructure legible, which implies a systemic consideration of infrastructure as a category rather than the consideration of a single discreet system: it seeks to understand something fundamental. As such, freight logistics seems a valid choice of practice-as-entity, given it is the earliest and most fundamental of the infrastructural functions, and—in the British isles, at least—it was the first non-gubernatorial practice to be substantially affected by infrastructural development. Freight logistics are foundational to the vast majority of contemporary practices, whether domestic or commercial, yet that very ubiquity leads to the illegibility with which this project is concerned; turning the analytical spotlight onto this understudied yet fundamental practice thus feels eminently appropriate.

The breadth of freight logistics as a practice-as-entity has an additional advantage, the first aspect of which is that it allows for the basic stability of the protagonist entity throughout a long historical analysis: put plainly, this means that the protagonist's motivations are essentially the same, regardless of where they're located, what they're trying to ship, or what period in history they're working in. (In practice, as shall be shown, there is a need to differentiate between the desires and preferences of protagonists involved with different freight types, but working through these more subtle differences is exactly what the trialectic is designed to do.)

The second advantageous aspect of the breadth of freight logistics as a practice-as-entity is that it forces the analysis to work with more than one infrastructural system, which in turn opens up the possibility of following sociotechnical change not only within any particular infrastructure, but across multiple infrastructures at once. This helps to avoid the generic heroic narratives of innovation generated by models like the MLP which, through their focus on the technology rather than the practice, cannot help but produce accounts of the success or failure of one particular way of doing things: by focussing instead on a broad and infrastructure-agnostic practice such as freight logistics, more complex narratives detailing the changing variety and distribution of different performances in timespace can be produced.

Sources, sampling and structural strategy

In essence, the strategy governing the research process is an archival equivalent to the snowball sampling method of informant recruitment: a gradual "drilling down" to specific local details from regional or national generalities. The first stage is to use general top-level sources to construct and populate a rough timeline or history which charts the rise and fall of infrastructures and interfaces of relvance to the practice-as-entity under study: this provides a frame through which to search for and analyse more local and specific expressions of the dynamics of sociotechnical change. So, by way of example, having identified the major eras of roadbuilding and road vehicle development in Britain, those eras may then provide a periodisation through which road and road vehicle developments specific to the site of the study might be identified.

While this methodology is historical, it is not aimed at producing history, but rather at generating productive anthropological readings of history; as such, it eschews the use of primary archival sources, thus avoiding the highly specialised work of assessing and interpreting original historical documents. By way of maintaining faith with the situatedness of the trialectic methodology, the strategy is to always seek out the most localised and specific secondary historical sources available. This means that a source directly germane to Sheffield and surrounds will always take first preference, but where such is not available, the nearest available approximation must suffice—so, in the absence of a Sheffield-specific source, sources specific to South Yorkshire or Derbyshire would take next preference, followed by sources dealing with "the East Midlands" or regions of a similar scale, followed by sources dealing with a more nebulous geographical distinction such as north/south, and with national-scale sources being the final recourse in the absence of anything more specific.

Within this broader strategy of data surveying, the trialectic model serves as its own sampling strategy: the secondary sources are scoured for references to the specifics of a performance which might provide evidence for the competing desires and influences that the trailectic model describes. Such details may include the physical standards of a given infrastructure, the design features of a given interface, the options available in a given service, or the particular way in which a particular commodity is dealt with in a particular place and time—any detail whatsoever which allows the researcher to truly envisage the practice in the moment of its performance, and thus interpret it from the perspective of the actors enrolled in it.

With the sampling process complete, the analysis may begin. Historical analyses tend to be structured chronologically, for obvious reasons; time is central to our understanding of narrative, after all. The obvious way to proceed would thus be to identify a series of historical "moments" in which the articulated trialectic appears to be, if not stable, then in a state of balance or equilibrium: the articulations and contestations in play during these moments would therefore speak to the consequences of the previous state of equilibrium, and to the preconditions of the subsequent state.

However, in a case such as freight logistics—a practice in which at least three major infrastructures are implicated—a single chronological narrative which had to span multiple systems would quickly become complicated and hard to follow. Furthermore, a multi-system narrative would be obliged to select for analytical moments which were relevant across all the systems in the frame, thus presenting a methodological restriction which might necessitate the jettisoning of otherwise valuable and pertinent data.

Therefore the chronological approach is applied instead to each implicated infrastructural system in turn, following the chronological order of their development: systematic intervention in the roads preceded the systematic building of waterways, which in turn preceded the systematic building of railways. This order further reflects the observation that any given infrastructure or interface implicitly includes the existence of all the other preexisting infrastructures in its design brief—or, more simply, that what came before informs and shapes that which comes next, and no invention of significance takes place in sociotechnical vacuum. Again, while this strategy adds complexity to the methodology, it simultaneously frees it to range more broadly in search of patterns and precedents than prevailing approaches, and opens up a space for exploring intricate narratives of sociotechnical contestation and/or cooperation not only between the elements of one particular assemblage, but between different assemblages.

That said, it bears noting that this separation of systems is entirely an artefact of the analytical method, and that in producing a rigorous account of the development of any one infrastructural system implicated in the freight logistics practice-as-entity, it will at some point become necessary to consider its linkages and contestations with other such systems. Therefore while the analytical chapters that follow are titled in such a way as to tie them to a specific infrastructure (i.e. roads, waterways, railways), the chapter on the roads is not "just about the roads"; rather, it's about the performance of freight logistics as a multi-systemic practice as it appears when seen from the perspective of the roads assemblage. All three chapters will necessarily and productively speak to one another, but their chronological ordering means that this analytical crosstalk will become more obvious as the reader progresses through them.

One final thing bears noting about freight logistics as a practice, however: it is a practice in which the protagonist rarely performs the practice themselves, and instead passes responsibility for fulfillment of the performance over to a commercial agent (or agents) who perform the logistical operations on their behalf. To use a modern example, the production controller of a a widgets firm might dispatch five batches of widgets to various clients in various locations over the course of a week, but the extent of his own involvement (or even that of his own warehouse staff) in the actual logistics probably goes no further than boxing, weighing and labelling the goods to be shipped, and requesting a collection from a courier company on the appropriate day. Therefore the courier firm, by way of its drivers and warehouse staff and vehicles, acts as a proxy agent for the protagonist: while the latter instigates the performance, it is the proxy which executes it.

What this means for the use of the trialectic model is that, when exploring the Design Protocol (DP) vectors of influence as they affect the Protagonist, the immediate physical affordances of the interface technologies being used to fulfil a freight logistics performance are not as important as the design protocols informing the commercial service within which the use of said technologies is bundled up. Our production controller may well see the first of a succession of vehicles which will carry his widgets when it arrives to collect the shipment, but that's as much contact as he will have with the tangible materiality of the sociotechnical stack which does his bidding. The top speed of the lorry or the comfort of the cab are anathema to him; of far greater interest are such configurational factors as cost, collection times, delivery speed, simple booking procedures.

Of course, the configuration of a service is intimately related to the affordances of the system which is used to deliver said service, and that relationship is one of many which the following analysis intends to reveal. But it bears noting that proxy practices therefore present a little more of an explanatory challenge to the trialectic model than would a simpler practice performed directly by its instigating protagonists, and that in a number of cases notions of service design and technology design will require some sustained untangling in the analysis to follow.

4.3 Methodology: speculative mode

As stated in the introduction to this chapter, the second, speculative mode of this methodology is a partial fulfillment of RQ2: it allows the findings generated by the analytical mode to inform a narrative prototyping method through which proposed sociotechnical assemblages of the future might be interrogated from the perspective of the people who might use them, and tested against a variety of potential socioeconomic circumstances. Or, more simply: by drawing on the historical dynamics of change revealed by the application of the analytical mode, scenario-creation and narrative techniques can be combined so as to "stress test" the deployment of a novel infrastructural system.

It should be emphasised at this point that the speculative mode of this methodology is not in any way intended to be predictive, despite its deliberate *détournement* of some tools and techniques often used for predictive forecasting and strategy development wherein a "preferred future" or strategy or vision is generated as a potential policy or business goal. On the contrary, rather than asking "what *will* happen?" or "what *should* happen?", the speculative methodology asks instead "what *might* happen, and what difficulties might result?". (For an explanation of the distinction between Predictive, Normative and Exploratory scenarios, please refer back to section 2.2 of this thesis.) The speculative methodology is not intended as a replacement for Predictive or Normative futures practices, but as a supplement to them—a process that fulfils an evaluative role related to that of the cost-benefit analysis or the physical prototype, but operating in the qualitative and non-linear dimensions of possibility. The speculative mode is designed to take the outputs of Predictive or Normative futures processes and subject them to stress-testing through exposure to the sorts of improbably but not implausible contextual constraints which are, by epistemological and methodological necessity, excluded and externalised from projections and models rooted in the extrapolation of linear trends.

The speculative mode therefore might be thought of as a constructed encounter with non-linearity—and while non-linear outcomes, by definition, cannot be predicted, they can nonetheless be imagined; they cannot be planned for, but they can be planned *against* by recourse to simulations of worst-case contexts, just as a new material or device is routinely exposed to physical and operational stresses far and beyond those which its designers expect it to ever encounter in deployment. (Another analogy might be to training in the martial arts: one cannot predict the sequence of attacks an opponent might deploy in the ring, but by training oneself against a hypothetical selection of the worst possible attacks one can imagine being deployed, one thereby increases one's likelihood of responding with a suitable defence when faced with an unexpected combination of moves.)

As such, the speculative mode relies on the sort of dramatic exaggeration of circumstance that is familiar to readers or viewers of science fiction: the point is not to imply that the scenarios so generated *will* happen, but to consider the types of outcomes that *might* result *if* that type of non-linearity did indeed manifest. This is not pessimism or Luddism, but critical thinking applied to the context (or "ambience", to use the language of complexity science) which is necessarily assumed to be "outside" of any quantitative model or simulation; it is an attempt not to predict the unpredictable, but to allow an imagined scenario to stand as a proxy for the unpredictable. The "trigger story" or plot which informs the selection of the axes used to generate the scenario parameters is merely a narrative convenience, a frame that helps the parameters hang together in a coherent, distinctive and dramatically engaging manner. It should have some basis in reality, in that it should root its non-linearity in a breach from contemporary trends, but the scenarios thus created should be deliberately extreme: not worst-case in the sense of an asteroid strike coming out of nowhere, but worst-case in the sense of things diverging drastically beyond the projection of linear trends. Such projections of linear trends are already "baked in" to the Predictive or Normative modelling processes which the speculative methodology is intended to supplement—going *beyond* those trends, using the Exploratory approach to futures in order to venture into the uncharted badlands where the models cannot go, is entirely the point of the speculative mode outlined herein.

4.3.1 Building the speculative assemblage

The first stage of the speculative mode is similar to the handling of a single historical moment in the analytical mode: the model is populated with pertinent elements and influences, and the articulatory actants are then mapped around the model of the assemblage. The crucial difference is that the speculative mode, dealing as it does with possible future configurations, relies upon a mix of informed speculation alongside the findings gleaned from the historical-analytical mode. However, the process is not one of invention *sui generis*, not a mere making-it-up. It is instead analogous to the engineering practice of "running the numbers" on a complex project—a qualitative equivalent to the paper prototype, in which the speculation is grounded in precedent.

The building of the assemblage has two phases, just as in the historical mode: the iteration of the trialectic model (see section 4.2.1 above), and the mapping of the articulatory entities (see section 4.2.2 above). While these processes are broadly similar in both modes, a closer look at the specifics will reveal that there is a clear movement of structured knowledge from the analytical mode and into the speculative, even as the methodology eventually gives way to pure fabulation.

This is an unusual approach to an increasingly commonplace challenge. Speculation on the rate of uptake of new technologies is far from uncommon—on the contrary, it's a lively industry, with the detailed findings derived from proprietary frameworks such as Gartner's "hype cycle" approach (see e.g. Fenn, Raskino, & Burton, 2017) often held up as paradigmatically rigorous. But Gartner's approach is in fact paradigmatic in other respects: firstly, it always focusses on the technology or "innovation" as the subject (and hero) of its (explicitly standardised and generic) narrative; secondly, it focusses on technologies in isolation, rather than as an element within a system-of-systems context in which all the other elements are constantly changing in interaction with one another. Furthermore, such approaches usually consider historical data in order to support their extrapolatory trends, but that data is rarely situated or specific to a certain location.

The trialectic approach to speculating on sociotechnical change, as outlined below, differs on all these fronts: it is concerned more with the practice to which the technology is being applied than with the technology itself; it thus considers new technologies as just one option among a number of established and/or competing alternatives; and it situates that consideration within a spatial understanding of the infrastructural underpinnings available to technologies both new and old, which might affect their viability on a number of factors.

To put it another way, the "hype cycle" approach sees a notion such as "the driverless car", and attempts to position this seemingly discrete invention within a near-term future context based on the extrapolation of market trends. The argument of this thesis is that such an isolated treatment of technology is missing an important point, namely the mutual entanglement of multiple infrastructures, as well as the inescapably social aspects of technological and infrastructural reconfigurations. By contrast, the trialectic approach sees "the driverless car" as a number of pre-existing technologies (supported by their attendant infrastructures) being combined into a novel "bundle", which is then considered as a potential entrant into the array of well-established interface options already available to protagonists seeking personal transportation functions; the trialectic approach then attempts to situate the fulfilment of the protagonist's performance through that new bundle within the context of the technological and infrastructural configurations already available in the location in question. Or, to speak more generally, the trialectic framework allows for a explicitly metasystemic sociotechnical analysis that considers multiple infrastructural systems and interfaces simultaneously in a specific locational context, rather than the more isolated, placeless and extrapolative techno-economic analysis offered by approaches such as Gartner's.

Populating the model

Having identified a proposed technology (or technologies) for assessment, the first task is to introduce it into the trialectic model.

This is simple, in some respects, but it is dependent on having already performed a historical analysis of the practice-as-entity with which one's speculation is concerned. In other words, in order to explore the possible reconfiguration of personal hygiene practices, one must have already traced their development both generally (i.e. at the scale of nations), and in the specific situated context (i.e. in a particular city or region); as a result, one will already have a model of the contemporary assemblage, to which the new technology under study can be added.

Also, the majority of such new technologies occupy the interface layer, not only because genuinely novel infrastructural systems are notable for their absence (e.g. fibre optic broadband is, *functionally speaking*, an iteration of the telegraph line, and never truly succeeded telegraphy so much as evolved from it), but because they are increasingly improbable, due to the sunk costs of building new networks to a scale that would enable them to compete with a deeply incumbent system, and to the path-dependencies of practices within which infrastructural function has become completely habituated (which is to say the vast majority of practices). Put simply, intervention in the contemporary assemblage increasingly happens at the interface layer because that's the only point in the assemblage where swapping one element out for another is remotely practical, let alone profitable.*

Furthermore, many "new technologies" are actually convergences of two or more existing technologies, or represent devices (whether old or new) reconfigured as part of a service offering. Take, for example, the "self-driving car", which is routinely presented as a spectacular irruption of the novel into personal and public transport futures alike: with reference to the trialectic model, the self-driving car represents little change in purely technological terms; the core teleology of the practices in which it would be enrolled (namely the personal-mobility bundle) is still fulfilled through the same basic device-type (small vehicle, internal combustion engine) running on the same infrastructures (road network plus global petroleum supply chain). If we then consider the extant ubiquity of satnavs or other devices with mapping and navigation funtions, the self-driving car's permanent reliance on wireless telecomms, cloud computing and the GPS system is revealed not to be novel, but merely a degree more acute.

Indeed, the change that the self-driving car truly represents for personal mobility practices in any realistic scenario of deployment will manifest in the articulation of the assemblage as much as in its elements, if not much more so: a significant step toward the vehicle being hired as a material component of a contracted service, and a departure from the paradigm of personal vehicle ownership which has pertained in the UK for at least half a century.

In terms of the speculative trialectic model, then, the significant changes are not to be found in the elements themselves—which, recall, will still contain all the "legacy modes" for the fulfilment of personal mobility performances, alongside the new or novel option under study—but in the relationships between the elements (as expressed through the vectors of influence), and the mediations and contestations of those relationships by a reconfigured network of articulatory actants.

As such, having introduced the novel element or elements into the model, the

*However, this is not at all to say that one couldn't use this methodology to prototype a genuinely novel infrastructure; it is merely to point out that any such speculation would be necessarily far less grounded in clear precedents of sociotechnical stucturation, and would furthermore describe a circumstance whose realisation is exceptionally unlikely. Lessons might well be learned from such projects—indeed, the EPRSC project "All in One" involved the development of prototypes for highly speculative infrastructural constitutions—but those lessons would not have the same bearing on questions relating to sociotechnical change as a process, which are the core concern of this thesis.

vectors of influence must be reconsidered in light of the new or changed relationships arising from that introduction. Returning to the example of the self-driving car: its more acute connection to (or reliance upon) wireless telecomms infrastructure and GPS represents a significant pressure for increased capacity and reliability (I&I vector), to which those infrastructures would need to respond, and which they would inevitably counter to some extent through new standards and regulations for use (S&R); likewise, the vehicle-as-a-service business model represents a significant change in design protocols (DP) as experienced by the protagonist, which in turn will shape (and be shaped by) the parameters of the protagonist's desired performance (HKJ). An appreciation of the character and dynamics of these agonisms provides part of the evidence base for the speculative articulations of the second phase: by understanding the contestations of the past, we are better placed to speculate upon the contestations of the future.

Articulating the assemblage

Much as in the analytical mode, the articulation process involves identifying high-level actants involved in the mediation of the influences and contestations attendant on a particular assemblage; the principle difference is that, given the assemblage in question is itself speculative, the articulation is likewise an act of imagination.

But it is not a creation *ex nihilo*. As remarked above, the speculative assemblage is a response to a consideration of the relational consequences of an assemblage which, while partly reconfigured (whether through the introduction of novel technologies or services), is nonetheless preexisting; many existing articulatory actants will persist into times yet to come, even as the introduction of new ones (and the demise and diminishment of older ones) results in the reconfiguration of the relationships between them. Novel technologies find their place in the assemblage among and alongside the technologies which we've been using for years; no matter what the word "transition" may imply, assemblages are not replaced wholesale overnight, but reconfigured piecemeal over years, if not decades. As such, knowing what (and who) is currently involved in the articulation of any given assemblage is the best guide for speculation on possible future configurations and articulations of that assemblage.

Furthermore, the speculative articulation is informed by broader precedents of articulation; this is why a situated longitudinal analysis holding the practice-as-entity as an independent variable (i.e. the analytical mode already described) is a necessary precondition for success (or at least rigour) in the speculative mode. The stability of the model throughout such an analysis provides a stable set of relationships between elements, and this abstraction allows for comparisons regarding the manner of their mediation, wherein the exact technologies and systems enrolled are less important than the functions which they exist to fulfill. This can be seen as refusal of the solutionist impulse to privilege the role of technology in sociotechnical change, and as honouring the demand-side focus implicit in social practice theory (see literature review).

Or, more simply: the speculative articulation process, while anchored to a materialist model based on a relational ontology, indulges necessarily in the abstraction and comparison of functionally similar but technologically dissimilar systems—but it does so only because there is no other realistic recourse. In the absence of verifiable data, futures can only ever be generated from the projection of abstractions; if the historical structuration of assemblage relationships turns out *not* to provide useful examples of precedent for the future articulation of assemblages, it is hard to imagine wherelse, if anywhere, one might seek for such.

But in order to compare such different assemblages as those pertaining to the fulfilment of a given practice throughout history—which is to say: multiple performances involving multitudinous interfaces, and a variety of infrastructures which may well be incomparable on a purely material level—the researcher must abstract out to the level of inter-assemblage relationships and contestations in order to identify possible precedents without getting tangled up in their technical specifics. Or, more plainly: while abstraction is both a risky strategy and somewhat counter to the letter of materialist research paradigms such as social practice theory and A-NT (though not, I would argue, counter to their spirit), it nonetheless offers what might be the only useful way in which one might compare *what was* and *what is* with *what might yet be*.

And so, returning to our exemplary self-driving car: the articulation process would involve examining the vectors of influence as altered by its introduction into the contemporary assemblage, determining which existing actants are implicated in mediating the resulting relationships, and identifying any influences that remain unmediated; these latter unmediated relationships may then be accommodated by a change in the territorial "shape" of one or more existing actants as mapped over the trialectic model, or by the introduction of new actants to the map, or both. These speculative articulations should refer, where possible, to precedents found in earlier articulations, particularly those in which the relationships between elements, influences and existing actants can be seen to share characteristics with the speculative system under study. In other words, if the speculative assemblage contains a new contestation between an infrastructure company and a product-design community-of-practice (as might well be the case with the self-driving car, for instance), the analyst should then refer to those historical moments in which contestations arose between elements or actants of a similar kind, and thus to the character of the resulting relationships, the asymmetries of their agonisms, and so forth. For example, the advent of driverless cars promises to involve the entry of a number of new and powerful industrial players into the roads assemblage; as such, useful precedents for the resulting contestations might be found in other eras (or indeed other assemblages) which feature a similar influx of "disruptor" actors.

The output of the speculative model and articulation will therefore be a model assemblage, based around the same elements and relationships used in the historical-analyticial mode—but unlike the historical models, it will necessarily lack a context. Generating a context (or contexts) against which to prototype the assemblage is the second stage of the speculative mode.

4.3.2 Setting the speculative assemblage in context

In one sense, the entire speculative mode of this methodology can be described as a prototyping process: the purpose is not merely to imagine a possible assemblage, but to test it.

However, it is not a *technical* prototyping process, intended to uncover design flaws in new devices or services; nor is it an evaluation akin to the cost-benefit analysis. Quantitative methodologies of evaluation are plentiful, but many fail to consider the social alongside the technical—and those methodologies which do consider the social often do so in problematic ways. Historical analyses of infrastructural change, even as performed within the framework of the Multi-Level Perspective, make it clear that sociotechnical change takes place in a broader social, political and economic context, and is ineluctably shaped by that context—particularly with regard to prevailing attitudes to institutional interventions, and to the dynamics of inter-actant relationships. By way of example, the earliest infrastructural revolutions—turnpikes, canal and navigations, and the first decade or so of the railway boom—took their forms due, in some significant part, to the *laissez faire* economic doctrine which prevailed across Britain as mercantilism gave way to early capitalism; similarly, the post-ww2 transport systems were (re)shaped in a context of muscular and interventionist state socialism.

"The future" is uncertain and unknowable, only "a plastic possibility immanent in the present" (Raven & Elahi, 2015). All that we can be sure of is that things will be different in some way, and to some degree; that the context will have changed. The purpose of this prototyping process, then, is to take the technical prototypes of the proposed new technologies at their own word (i.e. assuming that their technical offer is both plausible and buildable, if not necessarily profitable), and then to ask whether an equally plausible articulation of that technical offer can be identified. But while technological devices perform in much the same way regardless of the social context, the same is not true of social and sociotechnical actants—and so the task at hand is to assess the speculative assemblage against the socioeconomic and political circumstances in which it might end up operating: is it, in other words, compatible with the context? And if not, in which relationships or actants might that incompatibility or dysfunction be manifest?

The matrix: generating a suite of divergent futures

The simplest way to prototype a system against future change would be to test it against a context based on predictive trends and extrapolations from the present day. However, if we understand "the future" as being plastic and uncertain, prototyping against a single projected future is both short-sighted and unambitious; testing against many possible futures, by contrast, offers the opportunity for a more thorough assessment that accounts for the "risk" represented by the uncertainty of future circumstances. By testing against multiple futures, one gets more than a simple "pass" or "fail"; rather, one acquires an awareness not only of the *possibility* of success or failure, but also of the *parameters and conditions* of success or failure—in other words, in *what sort of future* is it more likely to succeed or fail?

This "divergent futures" approach is well established in scenario practices from futures studies and strategic foresight (both within the academy and without), to the extent that simple off-the-peg methods for generating suites of related-yet-divergent futures are commonplace, as discussed in section 2.2 of the literature review. One such method, often known as the "2x2 matrix", is a simple yet versatile way to generate a suite of four related yet divergent futures for such a purpose. Due to that versatility, it is more easily demonstrated in action than in the abstract, and so the discussion that follows draws upon a matrix prepared for Raven (2014), reproduced here as Figure 4.8 on page 78.

The 2x2 matrix plots the interaction of two high-level contextual trends. Each axis represents a spectrum of outcomes related to a particular dimension of contextual change, broadly understood. In this matrix, which was developed for a global-scale project, the two dimensions of contextual change are Energy Availability (x axis) and International Interaction (y axis). The dimensions are intentionally broad and fuzzy, and intentionally mutually entangled: the breadth allows for maximum interpretive room-to-maneuvre (which say to say that both the causes and manifestations of Energy Availability are open to imaginative interpretation, within the scope of plausibility), while the entanglement is intended to reflect the

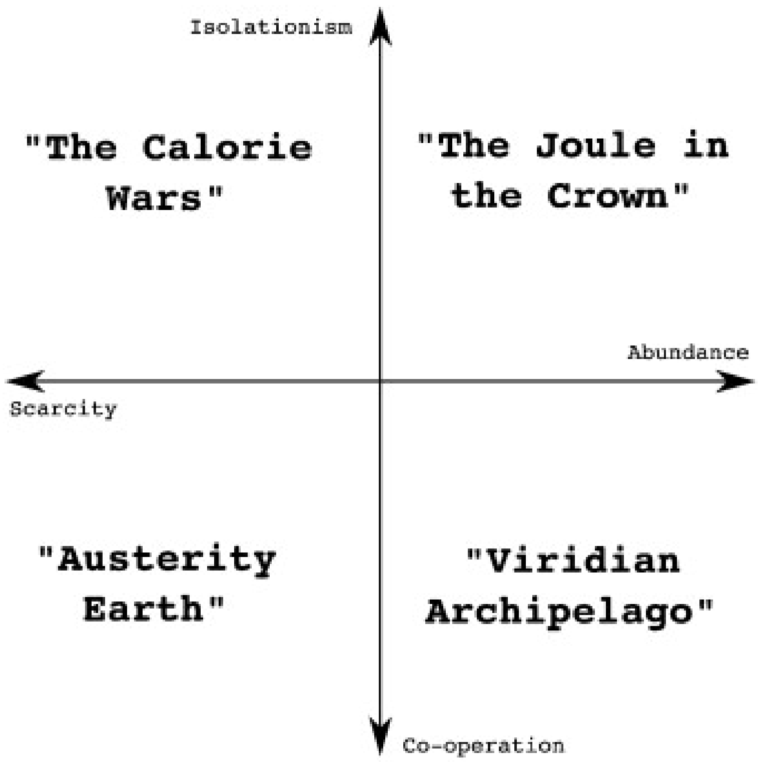

Figure 4.8: Example 2x2 scenario generation matrix prepared for Raven (2014)

inescapable multidimensionality of contextual change (which is to say that context is intensely systemic, and the isolation of dimensions or variables from one another is not reflective of real processes).

The axes have a positive and negative direction, representing trend divergence from the origin-point of the status quo: thus the x axis extends out to Scarcity (negative) and Abundance (positive), while the y axis runs between Co-operation (negative) and Isolationism (positive). The valence of the trends is not necessarily reflected by the valence of the axes—meaning that appearing on the negative side of an axis does not necessarily correlate with a negative valuation of the trend in question.*

If this matrix were retooled for a national- or regional-level project, some adjustment of the dimensional definitions might be required. Energy Availability could likely survive such a scalar shift without alteration, but International Interaction might be better reframed as Foreign Policy, thus reflecting the unilateral positionality of a national project; the phenomena and conditions represented by the

*While there is no *necessary* heuristic of valuation implicit in the 2x2 matrix, some combination of tradition and habit has resulted in the upper-right quadrant being typically the more desirable or "preferred" future of the four, toward which the project is often (if only implicitly) attempting to propel its participants; the matrix illustrated was a deliberate attempt to break this pattern.

axis would likely not change a great deal, but the choice of label should nonetheless frame the dimension in such a way that it illustrates and echoes the contextual scale with which the dimension is concerned.

Having determined the axes, the base properties of the four quadrants are established: [energy scarcity + isolationism], top left; [energy abundance + isolationism], top right; [energy scarcity + co-operation], bottom left; [energy abundance + co-operation], bottom right. At this point in a more quantitatively-oriented study, the quadrant properties might then be fleshed out with data and trends to give the resulting scenarios a sense of rigour from extrapolation—indeed, in any "full production run" of this methodology, it would be an opportunity missed not to develop the scenarios more thoroughly, not least so that they might be used as the basis for complementary analytical approaches.

For our purposes here, however, it is sufficient to assign a series of parameters to each axis which will define the basic circumstances of each scenario quadrant. So, by reference to the example matrix above, the parameters of the Energy Availability axis might include Domestic Energy Prices (low for the quadrants on the right, high for those on the left) and Population Mobility (low for the quadrants on the left, high for those on the right), while the parameters of International Interaction might include Diplomatic Style (warm and cooperative for the lower quadrants, cold and standoffish for the upper quadrants) and Intervention Style (unilateral for the upper quadrants, multilateral for the lower quadrants). When collected together, the parameters for each quadrant thereby form the basis for the scenario the quadrant represents.

The next step is to name each of the quadrants, much as one might name a short story or film. Again, and as with the deliberate broadness of the dimensions of change, the point is to create an imaginative space—to literally conjure a world using words alone. The resulting titles might be accompanied by a brief pen-sketch of the scenario properties, but ideally they should have sufficient affect that they suggest future images and circumstances without too much further prompting. To use a regrettably topical and slightly flippant illustration: if one quadrant were labelled Trumpistan and another Hillaryville, most audiences would have a fairly instant idea of what would be going on in those particular futures! Though they need not be so pointed or direct as that: the quadrant names in the example matrix above were intended to allude to the state of the worlds to which they applied, but in a manner that invites further curiosity rather than sating it. The point is to provide a ready-made cognitive package or box into which the reader can easily fold up the complex parameters of each quadrant without losing its narrative essence: ideally, the title becomes an apposite and memorable placeholder for the scenario as a whole. Once named and defined, a brief account of how each future came about should be produced; a simple timeline of major events will compound the sense of verisimilitude, and make the futures depicted a bit more believable.

Note, however, that the quadrants should represent the plausible extremes of the entangled dimensions—not quite the very best- and worst-case scenarios, perhaps, but the divergence from the status quo should be deliberately drastic and dramatic. This can be thought of as analogous to stress-testing a structure using loads significantly beyond its designed operational parameters: drastic circumstances may expose problems (or, conceivably, advantages) which might not come to light in a context less distant from the status quo within which the assemblage was designed or proposed. The plausibility of the scenarios is very much subordinate to their purpose, which is to provide a series of stress-test environments for assessing the plausibility of the assemblage—and the most plausible assemblage is that which can "survive" the greatest number of divergent, perhaps-not-so-plausible contexts.

4.3.3 Narrative prototyping

Here at the end of the process, methodology must give way to something closer to an artist's statement-of-intent. By drawing upon the precedents for sociotechnical change (or stasis) revealed by the analytical mode, and on the trialectic analysis of the disruptor technology, the researcher's next task is to imagine the consequences of an attempt to deploy said technology in each of the four divergent futures generated by the scenario matrix. There are two possible stages to this process of fabulation: the first (and simplest) is what we might call a deployment sketch, and the second is a full-blown short story.

The deployment sketch is just that: a high-level (third-person-omniscient) narrative account that describes an attempt to deploy the disruptor, and the obstacles and difficulties attending to it. As a genre, this form is stylistically similar to historical accounts of sociotechnical change, such as are found in the Transitions literature; the only difference is that the deployment sketch is an account of imagined future sociotechnical change. (It might even be considered as equivalent to a speculative discussion of the results gathered in the course of the analytical mode.)

The deployment sketch is sufficient to generate a critique of the disruptor technology which is understandable and plausible to experts, but in order to truly return to the human perspective mandated by Social Practice Theory, the deployment sketch might become the basis of a short story which depicts the disruptor technology from the perspective of protagonists making use of it (or trying to). This would be a time-consuming end-game, but it offers the potential of presenting the prototype to a far wider audience, thus despecialising a specialist topic at the same time as providing a critical end-user's perspective on sociotechnical change which is so often lacking from infrastructural futures work.

Summary

This chapter began by developing a novel model of sociotechnical change known as the infrastructural trialectic, and then used that model as the basis for the development of a methodology for the historical analysis of sociotechnical change. In the third and final section, the trialectic model and the historical methodology were reconfigured from a historical modality into a speculative modality, which allows the findings from the application of the historical mode to inform a narrative prototyping exercise through which possible future (re)configurations of infrastructural assemblages might be assessed and critiqued in an accessible qualitative form. The experimental application of the historical modality (thus completing fulfillment of RQ1) will be documented in Chapter 5, while the application of the speculative modality (thus completing fulfillment of RQ2) will be documented in Chapter 6.

Chapter 5

Historical analysis A—Coordination: the evolution of road freight

A preamble on sources

As described in section 4.2.3, the aim of the analytical portion of this thesis is to generate an anthropological reading of sociotechnical history: to describe, in other words, the specifics of the freight distribution function as informed by the technologies and the social systems which combine to provide it and, as far is as possible, to couch that description in the perspective of the person making use of the service (whether directly or by proxy), rather than that of the technicians providing it. This is an inherently interpretive and speculative enterprise in some respects, and it is made somewhat more so by the paucity of sources specific to the cases with which it is concerned.

As such, it was necessary to lean very hard on the limited sources which were available, which were for the most part either broad histories of the infrastructures in question; while there is no shortage of academic literature on infrastructural topics, their disciplinary narrowness (and hence their highly specific analytical focus) made them for the most part useless in the context of this project. Furthermore, and in reflection of the cross-systemic perspective of this project, it was necessary to synthesise the historical facts and dynamics found in the available sources into a single coherent narrative.

Therefore any statement of broad or contextual fact in the analysis chapters of this thesis (namely chapters 5, 6 and 7) which do not bear an inline citation should be taken to be drawn from a synthesis of the sources pertinent to the chapter in question; in the case of this chapter, those sources are Albert (1972); Barker and Gerhold (1995); Copeland (1968); Crofts (2006); Guldi (2012); Hey (1980) and Hey (2010) in particular, though some degree of contextual information may have been drawn from or corroborated by those sources with more direct pertinence to chapters 6 and 7. Direct inline citations, therefore, should be taken to indicate the sourcing of a unique and precise detail upon which the analysis is particularly dependent.

While it would be desirable in some respects to provide direct references for every statement of fact in what follows, actually doing so would render the results all but unreadable. As such, the rigour of referencing has to some extent been sacrificed on the altar of readability. To describe the development and change occurring in these systems at this scale and over such long periods of time necessitated a narrative approach; that such an approach has limitations—particularly in relation to disciplinary expectations regarding form and style—is granted; however, it is hoped that the resulting accounts demonstrate its unique advantages, also.

The structuring of the subsections serves to assist in the distinction between data and analysis, as much as said distinction is practicably possible in such an approach. The introduction and "Elements" subsections of each historical moment should be considered to represent statements of fact, to the extent that such are possible regarding the period in question, except where the narration clearly indicates a supposition or conjecture on the narrator's part.

By contrast, the "Influences" and "Articulations" subsections of each historical moment should be considered to be predominantly speculative analysis based upon the materials already cited and discussed; where it adds clarity, the introduction of further specific data within these sections is accompanied by a direct reference to its source wherever such is realistically possible.

For a discussion of the epistemological and methodological challenges inherent in this research, particularly in regard to the the availability of and reliance upon pertinent sources, the reader is directed to section 9.4.5 of the discussion chapter of this thesis.

5.1 The Old Roads (early 1700s)

The early 1700s saw the first significant and systematic efforts at roadbuilding in Britain since the Roman invasion; known as (General) Wade's Roads, they were built by the military to the purpose of putting down those parts of Scotland which had risen up in the Jacobite rebellion of 1715, and effectively seeded the professions of surveying and civil engineering. Outside of this highly instrumental

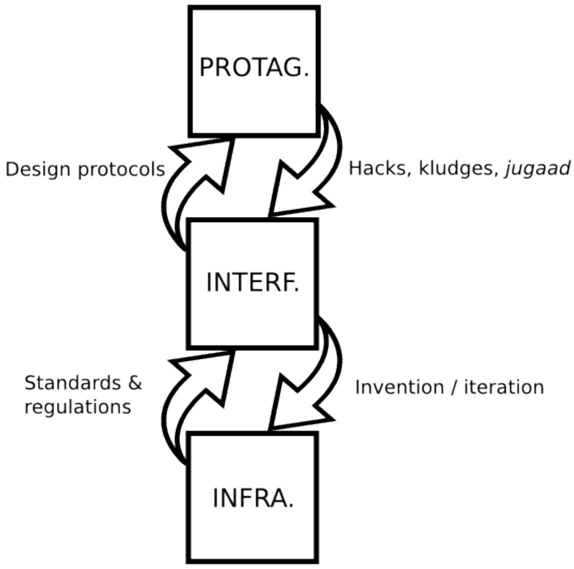

Figure 5.1: Infrastructural trialectic with vectors of influence

military network, however, Britain's roads were rarely worthy of the name.

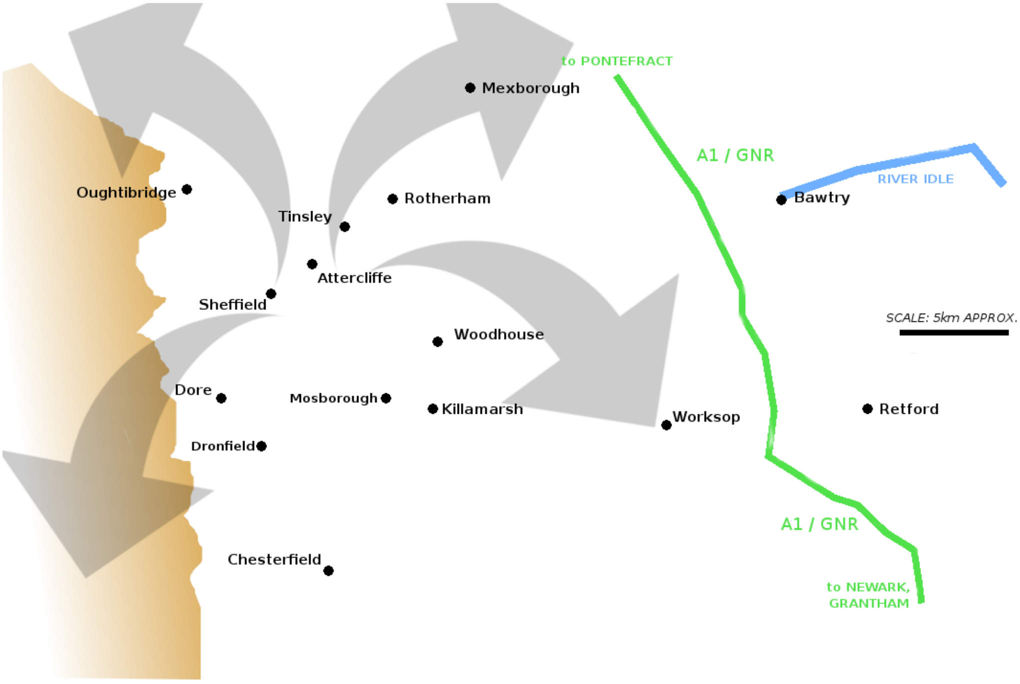

Figure 5.2: Roads in the Sheffield region, early 1700s

The constitution and condition of the roads of this period will be discussed in more detail below. But first, a brief summary of the distribution of those roads in the Sheffield region is provided, making reference to figure 5.2 on page 84.

The only road marked explicitly on figure 5.2 is what was then still known as the Great North Road, the traditional and ancient overland route from London to Edinburgh via the east midlands and York; the modern A1 follows pretty much the same route. Prior to turnpiking, the Great North Road was the only north-south overland of any significant capacity that passed close to Sheffield, but as can be seen, it was never any closer than 15km from the town centre—and that would be as the crow flies.

But why not simply send goods directly southwards from Sheffield? Figure 5.2 also features four grey arrows, which serve to indicate general vectors of trade flowing out of (and into) the city. Counting clockwise from the upper left, the first arrow indicates flows over the salt routes of the Longdendale Valley toward Manchester and Liverpool. The salt routes were so named due to their long history of being used to move salt and other such agricultural commodities across the Pennines.

The second arrow indicates goods moving toward the Humber estuary, whence they might travel on by ship to Europe, or to the southern counties. Prior to the advent of turnpiking, to move a ton of coal—or indeed a ton of anything—10km from its site of extraction or production would be to effectively double its price (Barker & Gerhold, 1995, p18). Pure overland carriage all the way to the Humber was hence possible in theory, but in practice overland carriage to Bawtry and onward shipment by water starting on the River Idle was a cheaper and faster option for those shipping goods with a high mass-to-value ratio, such as coal or building stone.

The third arrow indicates goods moving southward on the Great North Road after having first moved directly eastwards out of Sheffield proper. This route would have been more popular with those shipping goods southwards with a high value-to-mass ratio, such as the fine cutlery and bladeware for which Sheffield was already well famed in this period: the higher unit price on such goods meant that the expense of overland shipping was a much smaller fraction of the overheads than would be the case with cheaper commodities.

The fourth arrow indicates goods moving southwestwards across the Pennines toward Chapel-en-le-Frith, Buxton and Leek, and to the rich agricultural lands of the west midlands, which provided many of the staples that couldn't be produced in Sheffield and much of the surrounding area: salt came to Sheffield by these routes, as the old road names sometime betray, but so did dairy products, for example.

Indeed, despite the omnidirectionality of the illustrative arrows, these flows are duplex: they represent flows into the city as well as flows outward. But again: why no vector of flow directly south from Sheffield, toward Chesterfield? Because of the terrain: the area between Sheffield in the north, Chesterfield in the south, Dore in the west and Killamarsh in the east is particularly hilly, to the extent that, prior to the advent of vehicles powered by anything other than animals, it was quicker and easier to come overland to Sheffield from the south by following the Great North Road to Tickhill (just west of Bawtry) and joining the local routes westward from there.

There are no local routes marked on this map—but that's not to say there were no local routes. Quite to the contrary: as in much of the rest of the country at the time, local routes were plentiful, if not ubiquitous. But they were all also of much of the same poor quality, as shall be shown. They go unmarked here because to mark them all would impossible, while to mark but a few would be to misrepresent the topology of the network at that time (which might be thought of as being highly dense and decentralised—or rhizomic—in structure, but with appalling bandwidth and availability). Certainly there were more important, dominant or well-trafficced routes—but as it is those routes which tended to get the turnpike treatment later on, their illustration will be deferred until that point for the sake of making the illustrations easier to follow.

5.1.1 Elements

Protagonist

As remarked in the introduction to this chapter, the Protagonist is effectively the stable element throughout the process of historical analysis, representing a population's desire to fulfill a variety of performances of the freight logistics practice-as-entity—or, more simply, the Protagonist always represents someone who wants to send some mass of stuff from one place to another place, and has a variety of options available as to how this might be achieved. Because freight logistics over any significant distance is almost inevitably a commercial operation, the dominant desires for change in the parameters of available performances will therefore be rooted in efficiencies that affect the bottom line. This is compounded by the likelihood that the instigating protagonist ends up securing the performance as a third-party service, and handing fulfillment over to a proxy performer acting on their behalf: someone sending goods via a shipping service will surely be bothered if poor waggon design results in late deliveries or broken merchandise, but is unlikely to care much about the ergonomics of the driver's seat.

Interfaces

In the region around Sheffield, much as elsewhere in the country at the time, there were two main modes of freight transport that made use of roads: the pack-horse, sometimes solo but more usually roped in a train of multiple animals; and assorted variations on horse-drawn carts and waggons.

There is regrettably little data on the pack-horse, despite its ubiquity during this and subsequent periods, but they are assumed to have been a small and sturdy breed, reared for a stolid and calm temperament, and likely to have had hooves which splayed on soft ground, lending them a sureness of foot in wet conditions. The animals were fitted with custom-made panniers designed to accommodate the various loads they might carry, which could be anything from bushels of wheat or finished cutlery to raw coal or unfinished millstones.

Drawn by horses or oxen, cart and waggons were the cutting edge of transport technology, most likely introduced to Britain by Dutch settlers (Hey, 1980): carts, with their single axle, were used for lighter loads, while waggons, with two or more axles and multiple draft animals, took larger, heavier loads.

Infrastructure

The simplest way to describe the bulk of British roads during this period would be "unmade". As such, their condition was highly variable, depending on the local climate, the local traffic types (and density), and the local maintenance regime: since Tudor times, responsibility for the upkeep of roads fell to the parishes the road passed through, but the implementation of this statute was piecemeal, and the indentured labour it required could be a cause of resentment among the locals (who were themselves highly unlikely to see any significant improvement in their personal circumstances as a result of the roads being more easily travelled—the majority of agricultural trade with which they might be involved was still highly localised, and the peasantry didn't travel for fun).

In the south of the country, dryer weather and chalkier ground meant that, while roads and tracks eroded due to the impact of weather and cartwheels alike, wet weather didn't necessarily turn the roads into an impassable morass; hence carts and waggons were already well established in the southern counties, with a significant modal share advantage over the pack-horse.

But the Sheffield region has a peaty soil which soaks up rain and turns into a glutinous mud during the inevitable periods of wet weather. This resulted in a phenomenon known as the "holloway": long-standing routes across the dales which, thanks to continued traffic and rainfall, slowly eroded away and sank into the landscape around them (thus becoming ever-more effective channels for further pluvial erosion). The other regional route type was known as an "edge", which would follow the dry, rocky ridges of the Pennines and their foothills; these were far from smooth or short routes, and utterly unsuited to anything with wheels, but they could at least be relied upon to be solid underfoot for much of the year.

Notwithstanding General Wade's military surveying techniques, which were only applied north of the border with Scotland, the most common intervention into rutted roads and holloways was the "causey" (causeway), which involved paving the routes with large slabs of stone. However, given that oxen hitched to waggons could get better purchase on softer going, most of the width of causey routes was actually left unpaved, with a narrow paved section providing firmer footing for horses (Crofts, 2006, p7). As one can imagine, making and maintaining a causey was expensive, and highly labour-intensive in proportion to its effectiveness.

5.1.2 Influences

HKJ

Deriving as it does directly from the desires of the protagonist, the HKJ influence is fairly consistent over time and space, as it represents the protagonist's generalised desire for the improvement of one or more parameters of the performance they seek to fulfill. In the case of a broad and basic practice such as freight logistics, the HKJ influence is likewise broad and basic: as freight logistics is almost always a commercial operation (and, even when not, tends to be governed by budgets and bottom lines), the protagonist is looking to exceed any parameter which might push down costs, streamline procedures, or allow for economies of scale. However, protagonists with very particular goods or commodities to ship may have correspondingly particular desires for parameter excession, and these will be specified as necessary in the analysis that follows.

As remarked above, the pack-horse was still the hegemonic road interface for freight in the Sheffield region at this point, because it tended to be able to provide a performance with superior parameters to that of carts and waggons—but the reasons for that bear further examination.

Those routes most needed for carrying heavy loads were inevitably also the most likely to suffer the consequences of heavy traffic: as such, the more carts and waggons which passed a particular way, the worse the way would be for those that came behind them, as the wheels cut deep ruts into the wet soil. As such, waggon usage in what is now South Yorkshire and Derbyshire was actually restricted—whether by tradition or by statute—to the carriage of certain freight types at certain times of year, such as the few weeks either side of the annual hay harvest, when it was assumed they would be both more effective and less damaging to the roads. This meant that, despite the obvious efficiencies of scale achievable with carts and waggons over pack-horses, there were large parts of the countryside (and large parts of the calendar) where they were effectively useless.

The major downside of the pack-horse was that of capacity: a waggon might use a team of four to move a ton or more, while a single horse would struggle to take a tenth of that load. But a pack-horse was nimble and patient on soggy, rutted routes; furthermore, a waggon would need to regularly replace its team with fresh animals on a long trip, while a pack-horse could put in day after day of steady plodding; yet furthermore, a waggon needed a crew of at least two, while a single packmaster could lead a train of a dozen horses on his own. As such, among the rocky edges and muddy dales around Sheffield, the pack-horse reigned supreme: of all the options available, it best met the general needs of freight protagonists in the area.

But it was clear enough to see that waggons would be a far better option, if it weren't for the condition of the roads—and this observation manifested itself in continued attempts to use carts and waggons in any circumstance where one might have a chance of getting away with it, and indeed in a documented practice of overloading vehicles (and thus exacerbating the problem of rutted roads), as shall be seen.

DP

As mentioned above, freight logistics practices were (and still are) often performed by proxy: rather than a merchant saddling up and leading a pack-horse train himself, he'd have turned the work over to a carrier (or, more rarely, to his own personal packmasters). As such, the physical/technical design protocols of the interfaces used in the fulfillment of freight practices are of little concern to the protagonist-instigator of the practice; for the instigator, they interact not with the interface device itself, but with a service within which the use of the interface is bundled.

While there had presumably always been long-distance traders and merchants, the role of the carrier starts to formalise in this period, likely in response to the first economic stirrings of what would become the industrial revolution. What we now describe as "local carriers" probably didn't think of themselves as carriers at all; they were simply a local person with a spare cart or waggon and the time to make a few deliveries (and some extra coin) in between their artisanal or agricultural activities. The "common carrier", on the other hand, had a status in common law which, among other things, required him to accept any commission from any customer provided the appropriate fee was offered—which goes some way to explaining why many of those who carried were not always keen to be known as carriers, as one thereby became liable for any losses of things entrusted to your care. Such carriers were often family businesses, and tended to accumulate around or along a particular route: rather than providing an end-to-end service, they would instead cover a significant stretch of a major route, and hand off any forward deliveries to fellow carriers who might complete the route. Regional carriers specialised in regional routes, while London carriers plied their trade between the regions and the capital. Evidence can be seen of attempts to formalise and regularise the service in order to further accommodate protagonist desires, but the seasonal uncertainties of road condition meant that schedules were sparse and loose, and better considered as optimistic estimates than promises of service.

As such, it's likely that most carrying commissions were bespoke arrangements rather than regular contracts; in other words, the service offered to the protagonist is built afresh each time, customised to their requirements. For such arrangements to be made, the itinerant carriers needed locations at which to transact their business—places where they could be found, in other words. Given the nature of their business kept them close to stables (so as to procure fresh horses), and that stables were often associated with inns, the public spaces of the latter soon became the semi-official offices of carriers.

I&I

The pack-horse holds hegemony during this period, which goes some way to explaining why the innovative focus was elsewhere; no amount of improved pannier design was going to transcend the fundamental strength and endurance limitations of a biological organism. Anyone wanting to intervene in the freight logistics assemblage was therefore looking to carts and waggons for improved parameters of performance.

The narrow cartwheels which were commonplace at the time were an already embedded adaptation to the conditions: narrow wheels focus the weight on a smaller area, thus increasing traction, but this also has the effect of increasing the extent of rutting produced by the wheel's passing. Laws insisting upon wider wheels and maximum laden weights were either ignored or circumvented by cunning cartwrights: one such iteration featured wheels of the new regulation width whose customised profile meant that only two narrow strips of the wheel were in contact with the ground, thus (marginally) improving performance, and further enhancing road damage (Crofts, 2006, p18). Another tactic involved studded, bolted or toothed wheels, which acted much like snowchains on a modern vehicle (Crofts, 2006, p19); needless to say, these made even more of a mess of the roads, and the majority of civic authorities did their best to ban their use. However, such was the crude effectiveness of these iterations that “they remained the bane of English traffic until [...] the turnpike companies taxed them out of existence” (Crofts, 2006, p19), as shall be shown.

Not all iterations were locally applicable, however: waggons with a movable front axle were easier to steer, which made the design catch on in the southern counties, but the movable axle is a disadvantage in muddy, rutted soil, which explains why it got little traction (pun fully intended) in the Sheffield region. These inventions and interations, whether successfully applied or nor, combine to produce a pressure of influence for change upon the infrastructure layer with which they are enmeshed.

S&R

As has been remarked, the roads of this period are distinguished by their lack of coherent physical standards; as such, their influence upon the interface layer might best be conceived of as the degree of difficulty they present to the transit of any given vehicle. Therefore these standards (or lack thereof) serve to uphold the packhorse hegemony, because they make the routes impassable to wheeled vehicles for much (or all) of the year.

Regulations on road usage, on the other hand, long predate this moment: for example, the 1618 proclamation banning the use of heavier waggon types and limiting loading to one ton per vehicle. However, these regulations merely “tempted the carrier to load upon two wheels [i.e. a cart] what ought to have been carried on four [i.e. a waggon]” (Crofts, 2006, p18), and the resulting overloading ensured that the damage continued; likewise with the 1662 proclamation insisting on wider cartwheels, as mentioned above, which was later withdrawn as a result of being universally flouted and impossible to enforce. So while there is a pressure of influence upon the interface layer in the form of S&R, it’s weak and ineffective in its attempts to counter the reciprocal excessions of the I&I influence—and this imbalance creates the conditions for change.

5.1.3 Articulations

The articulatory mapping for this moment is shown in figure 5.3 on page 92.

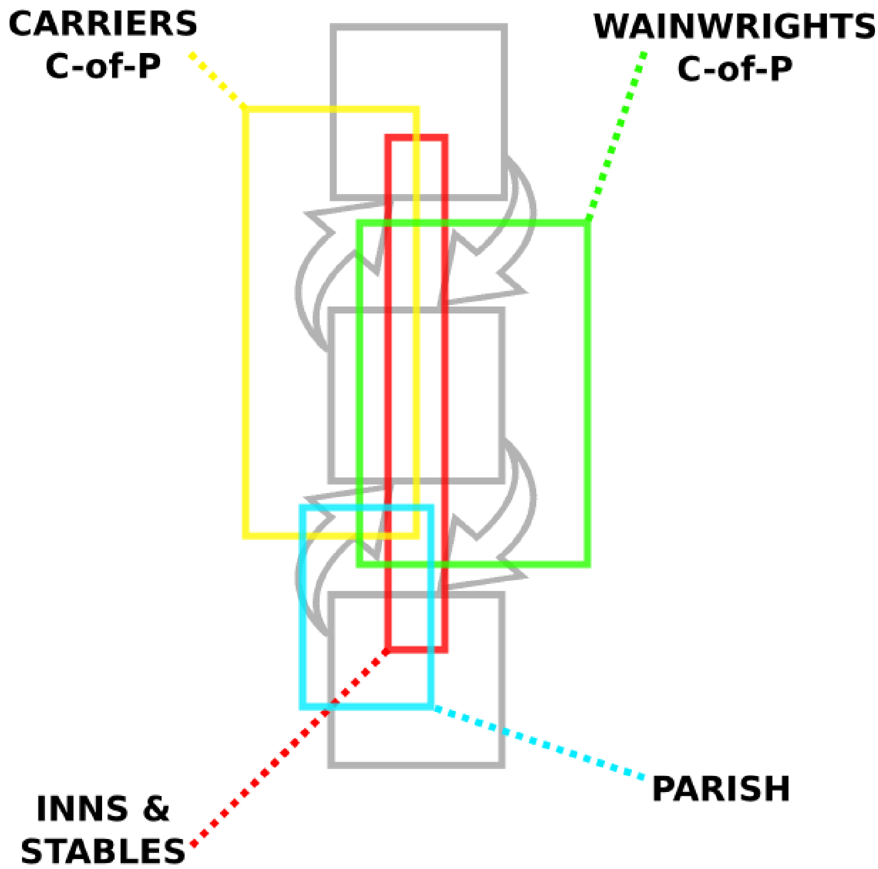

Figure 5.3: Articulated trialectic model for section 5.1 (The Old Roads)

Wainwrights' community-of-practice

The role of wainwrights (an Old English term for a waggon-makers) in the articulation of the assemblage is clear, but also delimited: as can be seen, they have significant influence over the interface layer, and dominate the I&I vector, but little influence elsewhere.

Carriers community-of-practice

The influence of carriers considered as a community-of-practice is omnipresent: this reflects their role as bundlers of interfaces into services, which is to say that they effectively provide the organisational connective tissue that connects the protagonist to the infrastructure. Through setting their schedules and their conditions of carriage, and the lack of alternative options, they have the whip hand over the DP vector (i.e. the shaping of the service), which dominates the HKJ vector: put simply, you could tell them you'd like a faster or more frequent service, and they'd just shrug and suggest you go find yourself one. Note also their considerable influence over the wainwrights, the latter of whom were likely listening closely to what the carriers wanted from their interface devices.

Parishes

Parishes are represented due to their responsibility for the upkeep of the roads, but their influence is hence weak and marginal, limited to the infrastructural element itself, and to the S&R vector.

Inns and stables

As mentioned above, carrying over any significant distance required regular feedings and changes of draft animal, and carriers were accustomed to transacting their business in inns. This would have been the case for packhorse operator as well as those using carts and waggons, for while packhorses didn't need changing so regularly as teams pulling carts or waggons, they'd still need a good feed from time to time—and their drivers would need places to get their own rest and to meet with clients and colleagues, perhaps even more so than the waggoneers, whose routes were a little more regular. As such, these two related businesses, inns and stables, can be considered as a sort of secondary infrastructure, without the support of which the early road freight assemblage would collapse.

But that support is not passive; it's about more than the simple provision of space for carriers to make deals. By providing horses and feed, stables were acting as a secondary infrastructure for the distribution of motive power units and fuel, thus funtionally binding together the infrastructure and interface layers. Furthermore, inns played a role analogous to that of a railway station: not merely a site to transact, but a node on a network of knowledge and communications that makes longer routings possible.

5.2 Surfacing Trust: the turnpike era (1760—1820)

Turnpiking was arguably the first infrastructural revolution in Britain, which effectively upgraded the major overland trunk routes of the road network to a far higher standard than had been seen since the Romans first laid down their post-conquest routes around the country.

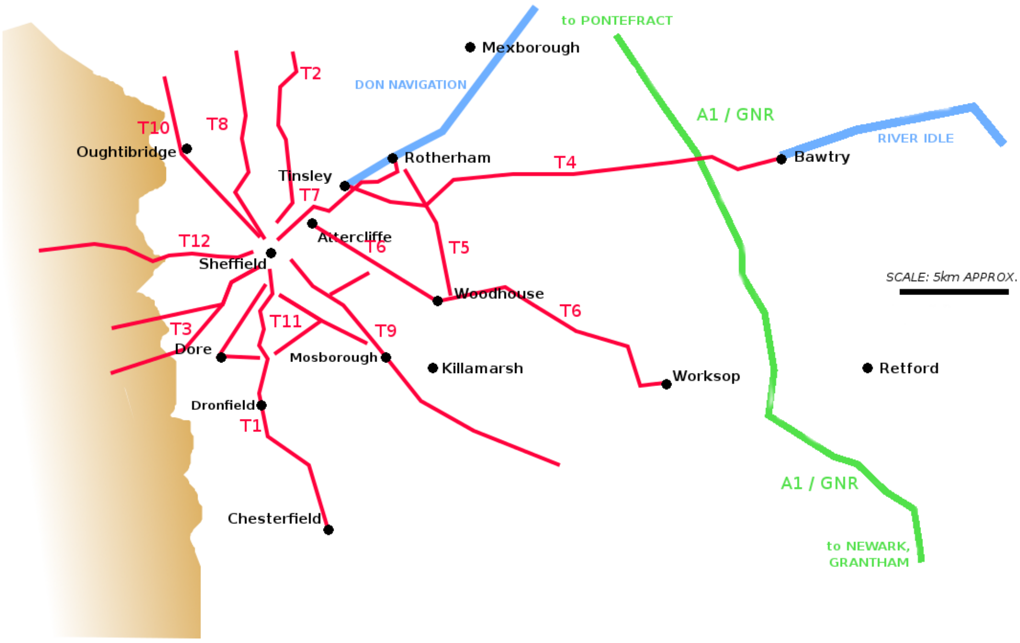

Figure 5.4: Roads in the Sheffield region, circa 1820

The era of turnpiking covers roughly a century, from around 1750 to around 1850. The pioneer routes were the radial roads of London, which were turned over to trust control in the early decades of the 18th century, but by the middle of the century the same theory was being applied to the Great Roads connecting London to the regions, and other trade-vital routes. There were two waves or pulses of turnpiking, the first of which was the initial boom in the creation of trusts: between 1750 and 1772, more than 400 new trusts were established, out of what would be a national total of around 1,000, and it was during this first pulse

Table 5.1: Table of major turnpikes in the Sheffield region

Road ID	Route	Build date
T1	Duffield to Sheffield	1756
T2	Wakefield to Sheffield	1758
T3	Sheffield to Chapel-en-le-Frith	1758
T4	Bawtry to Tinsley	1760
T5	Rotherham to Pleasely	1764
T6	Worksop to Attercliffe	1764
T7	Tinsley to Doncaster	1764
T8	Halifax to Sheffield (3rd district)	1777
T9	Sheffield to Gander Lane	1779
T10	Wadsley to Langsett	1805
T11	Ecclesall to Dore (and Mosborough)	1812
T12	Sheffield to Glossop (aka the Manchester Road)	1818

that the majority of routes were established. The second pulse might be better thought of as an upgrade to the form: a "turnpike 2.0", if you will, which was based around the innovative surfacing improvements that bear the name of their inventor, the civil engineer John Loudon Macadam, and began around 1820. The second pulse of turnpiking thus represents a general enhancement of bandwidth and availability on existing trunk routes, rather than the creation of new trunk routes through upgrading heretofore unimproved routes. The turnpiking boom came fairly late to Sheffield, with the first regional turnpikes appearing in the 1750s—hot on the heels of Enclosure, of which turnpiking could be considered a tacit component.

The major turnpikes around Sheffield are illustrated in 5.4 on page 94, and are numbered in order of their completion; table 5.1 on page 95 lists the routes and their dates of construction. The list is not exhaustive, but illustrative, not least because the routes illustrated correspond very closely to the dominant regional road routes that still prevail in the area: in other words, these are the routes that became the A-roads of the present, and those routes were surveyed and set down two centuries ago, if not more.

With that in mind, note that the earliest turnpikes to and from Sheffield are connections directly north and south: these are a clear attempt to address the difficulties which had long prevailed in trying to ship goods overland in these directions. But they are swiftly followed by upgrades to routes carrying the flows identified in the previous section: the Sheffield to Chapel-en-le-Frith turnpike, for instance (T3), was an upgrade to the southwestern salt routes, while the Bawtry to Tinsley (T4) and Worksop to Attercliffe (T6) are attempts to ease the overland routes to the waterway connections to the east. (Note also that the Don Navigation to Tinsley opened around the same time as the first turnpikes; the Don Navigation will be discussed in greater detail in chapter 6.)

5.2.1 Elements

Protagonist

The Protagonist, and their desires, remain stable. However, the nascent industrial revolution can be felt during this period in the form of a general speeding-up and thickening of economic activity, and in the gradual extension of trade networks from local to national and international. Therefore parameters such as delivery speed and reliability begin to matter more, particularly in the context of a commercial practice such as freight logistics.

Interfaces

The pack-horse is still very much in play in the Sheffield region, as are carts and waggons. During the latter of the two pulses of turnpiking, we also see the rise of the light, horse-drawn leaf-sprung van.

Infrastructure

The imbalance of the previous moment caused the government to develop a new institution called the "turnpike trust"—a body comprising local notables with a stake in the road and its trade, which was responsible for building and maintaining a properly surveyed and surfaced road surface, and for collecting tolls to pay for the upkeep. While a far cry from modern road surfaces, and considerably variable by region (not least due to a statutory reliance on local materials and labour), turnpikes had superior drainage, and the stones used for the surfacing were of a uniform size, making the going far more amenable to wheeled vehicles.

However, at this point it bears noting that even after both pulses of turnpiking were complete (around 1840), the vast majority—80%—of routes were not turnpiked (Copeland, 1968, p61-62); the process was reserved for major trunk routes where the improvements would most quickly be recouped through the collection of tolls (or so the theory went). Turnpiking occured in parallel with the latter phases of Enclosure, and indeed played a role in it: prior to agricultural enclousre, there would have existed a great number of narrow paths across local areas, but as the fields were consolidated and turned over to landowners, many of these rights of way were erased (which would have driven ever more local traffic onto those that remained, thus accelerating their demise).

In the terminology of network theory, then, we might say that turnpiking considered as a whole involved both a bolstering of the bandwidth of trunk connections and a massive pruning of "last mile" routes. In one sense, this can be seen as a rationalisation and a simplification of the network. On the other hand, however, it can be seen as a profound reordering and restriction of mobility options for ordinary people: having lost many free local routes, they are now increasingly obliged to use the turnpikes and pay for the privilege.

5.2.2 Influences

HKJ

As remarked above, the HKJ influence remains fairly stable throughout the analysis, as it is so closely related to the teleology of the practice under study. As such, HKJ manifests here as a continuing desire for greater speed and reliability of delivery, and is amplified by the implicit promise of the turnpikes to provide exactly that.

DP

Given the predominantly commercial nature of freight logistics, the "interface-as-a-service" model continues to apply, which is to say that the design protocols facing the protagonist are not those of the vehicle being used, but of the service being offered.

As such, there is little change from the previous moment, merely an intensification of the process of formalisation in carrier businesses, which during this period start to resemble an early form of the logistics and delivery companies we know today; indeed some, such as Pickfords, can be traced back to this period. This formalisation and consolidation was in no small part enabled by the advent of the turnpike, whose improved surfaces meant that the roads were more reliable for a greater portion of the year, which in turn meant schedules could become more frequent and more reliable, hence encouraging more merchants to deal ever more further afield.

This regularity served the common carriers more directly, as longer faster journeys meant ever more changes of draft animals, and an ever greater need for coordination with other carriers and factors to ensure hand-overs happened when expected; however, local/casual carriers would have suffered from the loss of countless free-to-use local routes, with the new (and hard to avoid) tolls eating into what had once been a fairly healthy profit margin. As the carrier sector professionalised and expanded, so did the network of inns and stables, which still served as places for carriers to transact their business (whether with customers or one another), alongside the newer crop of exchange buildings which were starting to appear in busy trading towns. This is all in response to a growing volume of trade, and a corresponding swelling of desire for the excession of practice parameters: more merchants looking to ship more goods on better terms than ever before.

I&I

While there were quite likely a number of new vehicle types developed in response to the improved affordances of the turnpikes, the one that stuck around was the horse-drawn van, which emerged during the second pulse of turnpiking, around 1815. Essentially an evolution of the horse and cart, and likely looking something like a small, light stagecoach, these vehicles had narrow wheels and leaf-sprung suspension, developed by wainwrights so as to maximise the speed parameter on freight performances by getting the very best out of those improved surfaces. While lacking the heavy capacity of the waggons (still very much in operation), vans could carry smaller loads of more delicate goods much more quickly: they replaced waggons on Pickford's main routes at a rate which clearly indicates a massive superiority for purpose (Copeland, 1968, p83-84). This in turn increased the influence upon the infrastructure layer, as ever more vehicles needing a decent surface came into operation.

S&R

It bears noting at this point that while most turnpikes came with standards and regulations, these were not uniformly applied across the country: for instance, the Acts of Parliament establishing the turnpike trusts frequently stipulated surfacing techniques and materials to be used, in order to exploit local materials wherever possible. However, as a rule of thumb, it can safely be assumed that all turnpikes were considerably more passable than the unimproved routes in the region, and the S&R influence of this more open set of physical standards upon the interface layer thereby encourages the increased usage of wheeled vehicles throughout the year.

The influence is not entirely open and permissive, however. Accompanying the material standards of the road surface were the rates and regulations imposed upon traffic by the turnpike trusts, and a secondary infrastructure of fences and tollbooths designed to prevent anyone shirking their pecuniary obligations. Regulations specified limits such as a maximum load per axle, or a maximum number of draft animals per team. Toll rates were, by and large, designed so as to compensate the trust for the wear and tear of the traffic to which they applied, while also sustaining the affordable local circulation of essential resources. For example, one can frequently find toll exemptions or reductions for certain sorts of load taken as "back-carriage", which refers to loads carried on a return journey for which the vehicle would otherwise have been empty. By exempting loads such as coal, quicklime or hay, local notables could ensure that tolls didn't prevent vital materials circulating in the local economy. Quicklime in particular was vital for the regeneration of agricultural land, which is particularly poor in the Sheffield region, but without the inducement of waived tolls on the back-carriage of quicklime, no one could have covered their costs by carrying it.

Other regulatory concessions betray the considerable influence of local landowners and industrialists with loads from certain mines, mills, factories or estates allowed to pass at reduced rates. While the character of this influence varies from trust to trust, it is clear that the regulatory role of the trusts gave them great influence over every aspect of the traffic profile that passed through their jurisdiction: vehicle types, cargo types, and even the seasons during which carriage was permitted. As such, they were finally able to achieve what earlier legislation had signally failed to do, namely stamp out the modified cartwheel types that tore up road surfaces—but they could only do so by first improving the surfaces in question.

It bears noting that tolls and tollgates existed before the turnpike system, and that for the most case the tolls imposed by the turnpike trusts were considerably higher than those imposed on the earlier, unimproved routes. Regrettably, much of the primary sources to do with turnpikes—the accounts and transactions of the trusts, for instance—disappeared long ago, and there are no sources particular to the Sheffield routes upon which we can draw. However, the general evidence pertaining to the regional turnpike network suggests that the higher tolls were more than compensated for by the surface improvements: noting that standardised rates for carriers legislated in the early 1700s were reconfirmed by further law in 1773, Hey (1980, p220) remarks that "if they were at all realistic, they must mean that the early Derbyshire turnpike roads that led toward the capital made no difference to transport costs", which in turn implies that sufficient efficiencies were found by the carriers (e.g. speed, seasonal availability, reliability) to counteract the increased outlay.

5.2.3 Articulations

The articulatory mapping for this moment is shown in figure 5.5 on page 100.

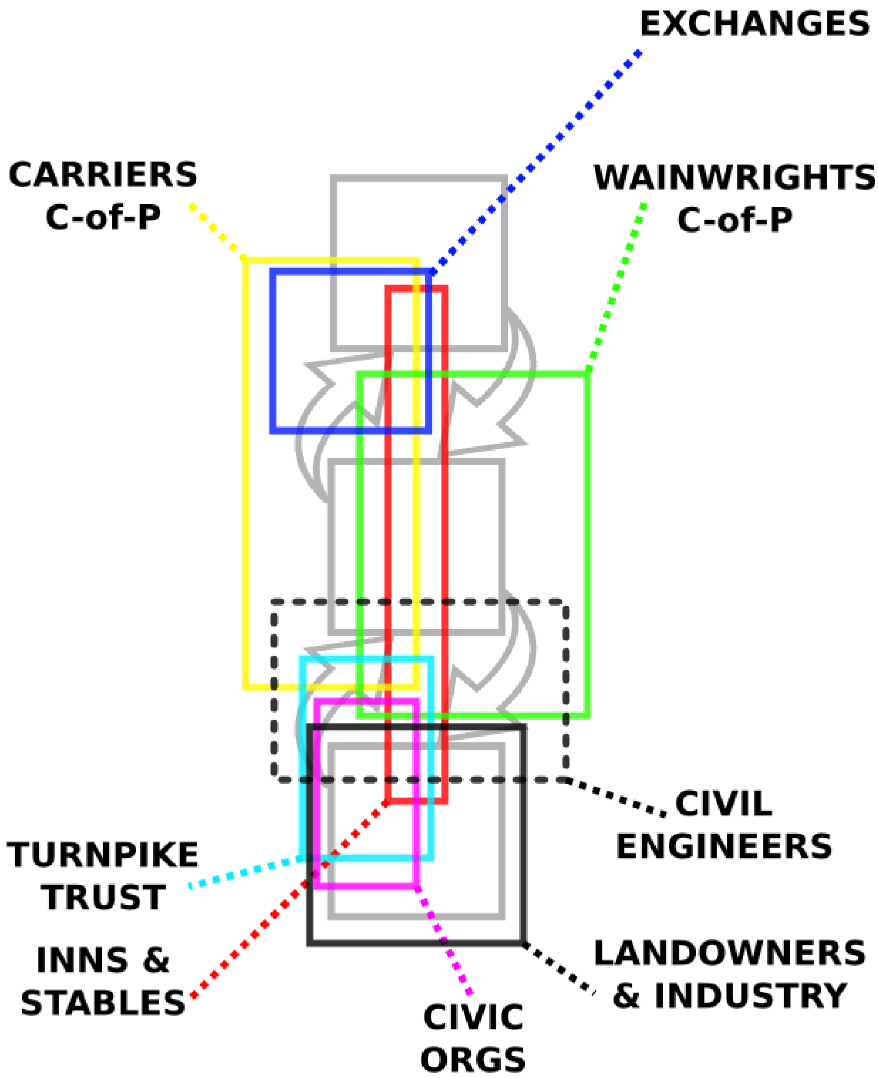

Figure 5.5: Articulated trialectic model for section 5.2 (Surfacing Trust)

Incumbents: Carriers; Inns and stables; Cartwrights

These articulatory entities largely retain and retrench the relationships which they established in the previous moment, while developing new relationships with new actors entering the assemblage.

Turnpike Trusts

The basic form of the Turnpike Trust was a sort of investment vehicle through which a collection of local notables and industrialists could invest in road improvements in the knowledge (or, in some cases, the unwarranted assumption) that the running costs would be met by the resulting increase in traffic. They were not private or joint-stock companies, and permission to form a trust had to be obtained from parliament; this meant they could be blocked outright, or simply loaded down with exemptions and caveats, due to vigorous lobbying by influential local gentry. But they effectively displaced the role of the parish with regard to road maintenance, even as they initially inherited the habit of using local bonded labour to get the work done.

Landowners and Industrialists

As noted above, the political nature of the turnpike trust meant that the constitution of the road networks became a political question: this allowed for the possibility of concerted action, in the form of the trusts themselves, but also for the possibility of reaction from those opposed to change, for whatever reason. During this period, political lobbying remained the predominantly the province of the landed gentry, though the rising stars of industry were also beginning to make their influence felt locally and nationally, as indicated by the inevitable exemptions and concessions scattered through the majority of Turnpike Acts. Hence this entity has something close to a dominant position over the infrastructural layer: civic organisations, and even the turnpike trusts themselves, were frequently forced to provide concessions or exemptions for the powerful or well-connected.

Civic Organisations

Town councils and city corporations retained the power to regulate behaviours within their jurisdiction, such as vehicle usage; as noted above, however, regulation was not necessarily very effective. Nonetheless, there is a clear (if marginal) influence over the infrastructure layer and the S&R vector from these entities.

Exchanges

Exchanges here play much the same role as the incumbent inns and stables, being a secondary infrastructure for the increasingly formalised carrier organisations within which the service is transacted; they also form a linkage between civic organisations and the carriers.

The Civil Engineer

The civil engineer community-of-practice deserves to be a distinct articulatory entity at this particular point in history, as it is during the turnpiking era that the role of the civil engineer coalesces from a mixture of related competencies such as surveying and mapping, earthworks, basic mechanics, and what we would now describe as basic project management. As Guldi (2012) has shown, turnpiking—along with other contemporary feats of infrastructural engineering—provided an opportunity for a disparate group of men largely outside of the normal hierarchies of power to quite literally talk their way into a crucial role. Put more simply: turnpiking brings with it the birth of the expert industrial consultant, whose role is to advise parliament (and, later, local government) on matters technical. The civil engineer will not appear in many further articulatory maps—but not because the role disappeared. To the contrary, over the course of a few decades, civil engineers went from being largely unknown, to being incredibly useful, to being utterly ubiquitous. The civil engineer did not disappear, then, so much as he became distributed throughout the assemblage.

5.3 Off the Boil: the failure of the steam waggon (1820—1840)

In this third moment, there arises an opportunity to explore what might be described as a failed transition: inspired by the earliest successes of the railways, the steam-powered waggon was the exciting innovation of the moment, but it struggled to compete on major routes against seemingly inferior incumbent technologies. According to Copeland (1968, p163-183), most experiments into the prospects of steam vehicles for passenger transit on the existing roads network took place in London or the south, and were broadly unsuccessful; if there were experiments with steam-waggons local to Sheffield or specific to the carriage of freight during this period, then we have no record of them. But nonetheless we have clear evidence of the idea being worked on for a considerable period of time, and (perhaps more importantly) during a period in which the intercommunication of gentlemen engineers was noted for its frequency and enthusiasm (if not also a degree of competitive animosity and paranoia). Therefore, and further given the preponderance of early steam technologies (and steam engineers) in the Sheffield region during the time (as shall be shown in section 7.2), it does not seem unreasonable to speculate that someone in or around Sheffield might well have been making similar experiments with steam locomotion on regular roads during this period. Furthermore, it doesn't seem unreasonable to assume that any such experiment would likely have met a similar fate to those undertaken elsewhere. As such, while it is admittedly a speculative exercise, it should be possible to use the trialectic model to explore the constitution and circumstances of the early steam-waggon, and thus explain why it would have been as unsuccessful in Sheffield as it appeared to be elsewhere.

As discussed in the previous section, the major roads of the Sheffield region are all established by this point, and the second pulse of turnpiking—which was about resurfacing established routes rather then building new ones—is beginning; as such, we may refer back to the map in Figure 5.4, which captures pretty much the same moment. That means that while there's still a great deal of packhorse traffic in the region, particularly on the unimproved "last mile" routes in between the turnpikes, carts, waggons and vans would have been very much in the ascendancy, taking advantage of the faster, smoother road surfaces.

5.3.1 Elements

Protagonist

Again, the protagonist remains stable.

Interfaces

All prior interface technologies (pack-horse, cart, waggon, van) are still very much in play. The novel invention in the frame is the steam waggon, a steam-powered vehicle designed for use on roads rather than rails. It bears noting that these earliest steam waggons were largely developed with passenger services in mind, though parallel attempts at establishing freight services bring the vehicle into the analytical frame of this project. Furthermore, as shall be shown below, steam waggons for freight eventually ended up being fairly successful for local and regional freight purposes, particularly agricultural, which suggests that their failure to gain traction early on cannot be blamed exclusively on their being a poor invention.

Infrastructure

By this point in history, the second pulse of turnpiking is largely complete, resulting in a network of trunk routes with fairly consistent and reliable surfaces; however, as noted above, turnpiked routes count for at most 20% of the network, with the remaining 80%—the “last mile”, in network theoretical terms—still largely unimproved.

5.3.2 Influences

HKJ

As remarked above, the imperatives of commerce ensure that the HKJ influence is largely consistent across all freight practices, manifesting predominantly as the protagonist’s desire for faster delivery of more goods at a lower cost.

DP

Given the expense in developing and constructing a steam waggon, they were almost from the outset offered as as service rather than an interface for personal use; as such, the business model drew strongly on established routes and schedules, a strategy already adopted by the carrier companies.

I&I

I&I is the big push in this particular iteration of the trialectic, in that the steam waggon represents a bold innovation, an attempt to pick up the steam engine technology at the heart of the railways and apply it to the pre-existing (and far more accessible) road network. It might be thought of as a sort of leap of maximisation: if I&I is all about designing an interface so as to get the best parameters out of any given performance, then why not leverage steam power for a massive increase in maximum loaded capacity? Better yet, a steam waggon required no draft animals (and hence no fresh teams), thus potentially reducing one of the carrier’s biggest operational overheads, and the initial investment was comparable

It bears noting that steam power at this point was trendy and exciting, and already identified clearly with the ongoing transformation of British society; as such, it was also considered threatening and revolutionary, in both senses of that latter term.

S&R

Despite the improved standards represented by the turnpikes, the poor state of the majority of unimproved roads was a barrier to early steam waggons; the first viable models emerged around 1820, marked by Hancock's introduction of coach-sprung suspension to his designs: "an important development, since so many of the earlier carriages had their engines damaged by the rough state of the roads" (Copeland, 1968, p168-182).

Expert opinion, alongside that of their inventors, believed that steam waggons, with their wide wheels, would be fairly forgiving to the turnpike surface by comparison to horse-drawn vehicles; so the famed civil engineer Thomas Telford told Parliament in 1831, at any rate. However, not for the first or the last time, popular opinion would differ, and the viability of steam vehicles on roads meant little to those concerned about the risks of exploding boilers, or worried that encouraging the steam revolution would rapidly devalue horses, leading to a knock-on collapse in the price of feed, and hence a more general economic ruination. These concerns were sufficient to result in mob action against early steam vehicles in some locations. But "by far the most serious opposition came from horse-coach proprietors and turnpike trustees", who "feared that the heavy steam carriages would damage the surface of their roads and drive away horse-drawn traffic. Some [...] resorted to placing rocks and stones in the path of the steamers, and many imposed much higher tolls than were levied on stage-coaches" (Copeland, 1968, p174-175); outright bans and arbitrary fines were commonplace, also.

So heavy-handed regulation, if not outright technophobia, seems to have played a role in sidelining the steam waggon as a viable interface option—but that's not the only difficulty that the technology faced. While the steam engine did away with the need for fresh teams of draft animals at regular intervals, it replaced it with an equally imperative need for supplies of coke and water at equally regular intervals. This was never much of a problem for the railways, which (as shall be shown) in effect started out as a coal distribution system; wherever the railways went, they inevitably had the ability to get fuel and water there in bulk, because that provision was a fundamental component of the rail infrastructure itself.

The steam waggon entrepreneurs, however, found themselves in dire need of a secondary infrastructure for the distribution and storage of water and fuel: in terms of the trialectic, the physical standards of the infrastructure layer were way below their requirements. The inns and stables network had grown up in co-evolution with the carriers, meaning that their secondary infrastructure developed of its own accord without any need for direct investment. But in order to establish a similar network of coke and water provision, the steam waggon entrepreneurs would have needed to build it (or underwrite it) themselves—or perhaps gone to the railways in search of a deal.

But the railways weren't likely to give a possible competitor any advantage, and as their ballooning share prices were already attracting the majority of investment money; by the time the worst technological flaws of the early steam waggons had been addressed, investors had eyes only for the railways, which as a result hoovered up most of the freight traffic—and passengers, for that matter—which might have used the challenger mode. (Steam vehicles would not become commonplace on the trunk road network until the short-lived late Victorian phenomenon of the passenger steam car.)

5.3.3 Articulations

Given that the steam waggon is a failed transition, it cannot be articulated: indeed, the lack of articulation explains the failure to achieve stability in the assemblage. As such, the articulations cannot be illustrated—but we can refer back to the articulation map for the prior moment (see Figure 5.5 on page 100) which effectively pictures the incumbent assemblage into which the steam waggon attempted to impose itself. Here we can observe the entities whose influence has successfully held the steam waggon (and its developers) out of the network. If successful, the steam waggon intervention would enter from the middle right (the same region of influence as the cartwrights and carriers, as they are taking on the role of both developer and operators of the interface) with its developers and operators responding to HKJ desires by producing a new vehicle type, thereby gaining some influence over the Interface element, and over the I&I vector. But that part of the assemblage is already tangled up in a complex set of relationships between coachmakers, carriers and the turnpike trusts—the latter two of which entities have already been shown to have actively prevented the steam waggon's accession into the assemblage. Metaphorically speaking, the steam waggon was unable to elbow its way past the incumbent articulations, whose strong interdependencies caused them to unite in defence of their mutual interests.

But it bears noting that the steam waggon in fact went on through the 19th century to become a commonplace vehicle at the "last mile" extremities of the transport network, particularly performing short-range logistics of a predominantly agricultural character, along with whatever odd carrying jobs might crop up in their owner's local area. With many towns and villages still a fair distance away from the nearest turnpike or railway, nimble modern vehicles such as the horse-drawn van would still face the same old problems on the unimproved roads of the rural boondocks, but the steam waggon's great power and broad wheels made them suitable replacements for oxen teams doing agricultural work. All across the British Isles, these “agricultural engines” survived well into the twentieth century, and remain popular on the heritage circuit today; as such, it seems reasonable to assume that they were just as popular in the Sheffield region—if not in fact more so, given both the cheapness of coal and the peatiness of the local soil, both of which would have worked in their favour. As such, rather than seeing the steam waggon as a failed or even deferred transition, it might make more sense to see it as an interface technology that gravitated successfully toward a very specific application niche—which rather upends the standard transitions narrative, wherein innovations are nurtured in niches before emerging to conquer the entire sociotechnical landscape.

5.4 Man with Van: the inter-war years (1920—1939)

From the end of the turnpike era (circa 1850) until the first world war, there was little significant change in the constitution of road freight assemblages in the UK; as shall be seen, this is due to the phenomenal success of the railways at capturing medium- and long-distance traffic. But the war changed everything—and not just close to home.

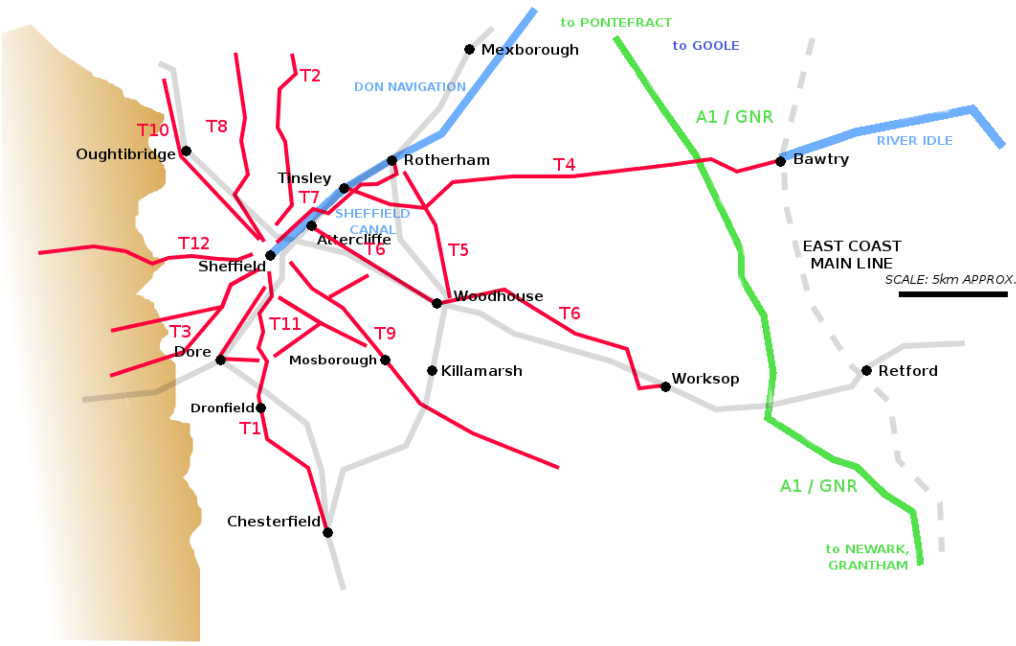

Figure 5.6: Roads in the Sheffield region, circa 1930

Figure 5.6 on page 107 shows the major roads in the region, as established during earlier periods; it also shows the extension of the Don Navigation via the Sheffield canal and (faintly) the major rail routes in the region, as they were between the two world wars. What is perhaps most noteworthy is the topology of the roads network, which remains largely unchanged from the turnpike era in terms of its extent and connectivity: the old routes live on, in other words, though their bandwidth is being improved in fits and starts. It should be plain that the arrival of waterway and railway connections served to effectively block the development of new road routes, particularly to the east. The golden era of personal powered transportation for work or pleasure had yet to arrive, so new and improved roads were prioritised in accordance with the volume of freight traffic they carried.

5.4.1 Elements

Protagonist

Again, the protagonist is essentially stable.

Interfaces

Pack-horses and horse-drawn vehicles (cart, waggon, van) are still very much in use up to and during the first world war, particularly once agricultural and industrial steam waggons were requisitioned for military purposes. The design of steam waggons had much improved since the previous analytical moment, making them safe, reliable and effective, if necessarily slow; the steam waggon had thus slowly consolidated its ubiquity for taking heavy loads over short to medium distances, which is to say those routings for which rail transport was unavailable or impractical.

The challenger interfaces of the era are the first generations of road vehicles powered by the internal combustion engine (ICE hereafter). The ICE had been around for a while, but it took the ferment of the first world war for its potential as a replacement for animal horsepower to be fully realised and exploited—and that exploitation was only made possible by Churchill's earlier securing of British access to Persian oil supplies, from which the fuels might be refined.

Infrastructure

As mentioned above, there was little change to the physical constitution of the road network until after the first world war, though responsibility for them had changed hands a few times. With the now debt-burdened turnpike trusts being merged, consolidated or wound up through the 1870s, the 1888 Local Government Act gave over responsibility for the upkeep of the roads to the newly formed county and borough councils.

The improved road surfacing process known as tarmaccing had been patented by a British civil engineer at the turn of the century, but was not widely applied until the 1920s, by which time an explosion of new traffic drew attention back to the parlous state of the roads; the ready availability of bitumen—another fraction derived from Middle Eastern oil—as an alternative to tar made it more affordable. The 1920 Roads Act saw central government reclaim responsibility and created a Roads Fund, to be topped up with vehicle excise duty and license fees for horse-drawn and ICE vehicles alike, from which money for improvements might be drawn; widespread unemployment offered an affordable workforce who were put to building bypasses and upgrading trunk routes. In 1930, the government handed the roads back to the county councils, only to reclaim the trunk routes in the Trunk Roads Act of 1936, to a backdrop of (unsuccessful) popular technocractic lobbying in favour of a network of high-speed roads, much like the new autobahns being built in Germany; all such plans were sidelined by the second world war.

5.4.2 Influences

HKJ

As remarked above, the HKJ influence remains consistent in nature throughout the analysis, but becomes ever more intense as trade and competition expand: the protagonist seeks to exceed the parameters of the prevailing performance.

But this takes a very particular form with a certain group of actors during this period, namely the burgeoning community-of-practice of one-man carrier operators. Steam waggons requisitioned during the war were subsequently sold off as military surplus, often to freshly demobbed servicemen seeking a return to a productive civilian life. These new carriers were able to scrape a living by systematically exceeding the manufacturer's speed and loading limits of their vehicles, and just as systematically turning a blind eye to the established laws and customs of the carrying business (Barker & Gerhold, 1995, p85-88); this is the birth of the particularly British socioeconomic phenomenon of the "man with van".

As discussed above, freight practices tend to involve a proxy performer who acts on the behalf of the actual instigating protagonist; put more simply, the man-with-van is most likely to be carrying on someone else's behalf. Therefore his overloadings of the interface can be seen as expressions of the HKJ influence, because even though they are not carried out by the protagonist themselves, the very direct nature of the relationship between protagonist and proxy in such a transaction suggests that the instigating protagonist would be knowingly complicit to at least some degree—you'd have to be fairly innocent to not realise how these operators were undercutting the standard rates. This is therefore clearly indicative of the ever-increasing desire to exceed performance parameters, even though the HKJ influence is actually expressed at one remove from the protagonist.

DP

Freight interfaces are still being bundled up as a service during this period, and the range of organisational styles is still largely unchanged from the pre-turnpike era: large and increasingly formalised carrier companies operating as common carriers, and smaller firms (right the way down to the independent man-with-van) taking the more marginal and local work out in the last mile. In both cases, logistical tasks are essentially outsourced by the protagonist to another organisation entirely; the entire appeal of the service is that you don't need to know how best to get your shipment from A to B, you just need to hand it over to an organisation that does. However, there is also a clear interaction between vehicle design and service design, because by this point the ICE vehicle has become a platform technology upon which supplementary functions can be stacked, such as refrigeration; this in turn allows the design of services which feature the supplementary function in distinction from the regular offer.

Things are slightly different when a business such as Sainsburys effectively sets up a carrier company as an internal division of the firm. In such a case, the protagonist has a more direct interest in the technical affordances of the vehicle itself, as they are no longer concealed behind another organisation's service design, and must therefore be integrated into the sub-assemblage of the company through the development of internal protocols for usage which suitably accommodate the new vehicles.

Put more simply, this means that vehicle design can, in such cases, be a direct influence on the protagonist and their choice of performance. If the driver who acts as the protagonist's proxy tells the protagonist that he could do a longer or faster day behind the wheel if he had a more powerful or comfortable vehicle, that's a strong vehicle design DP influence in action—perhaps the strongest example of such influence to be found in any assemblage specific to freight practices, given how common it is (and always has been) to outsource logistics to external firms.

I&I

If we consider the interface layer as representing an array of possible road vehicle choices (see Chapter 4, Model and Methodology), the inter-war period sees the modal share of horse-drawn and steam-powered vehicles start to decline, while ICE vehicles surge. That this was fertile ground for invention is indicated by the proliferation of vehicle manufacturers, all seeking to meet a variety of demands for improved performance parameters, whether in the form of speed, capacity, safety or comfort—though perhaps not as markedly as in the United States, the general trend was for larger, faster vehicles, and many more of them.

This in turn meant far greater wear and tear for the roads themselves, the best of which were still surfaced with horse-drawn vehicles in mind, and the worst of which were still effectively unimproved: faster, heavier ICE vehicles literally pounded such roads to dust in hot weather, and tore them into ruts in the wet season.

S&R

In terms of physical standards, tarmaccing was a huge leap beyond the simple madacam process which preceded it, with the application of tar or bitumen producing a road surface of heretofore unprecedented solidity and durability—a needful response to the rapid expansion of fast, heavy traffic. But surfacing alone was not sufficient to enable the network to handle this new intensity of traffic: also needed were physical subsystems for managing the flow of traffic around the system (e.g. signals and signage, junctions and roundabouts), and for preventing accidents. National standards emerged not only for the quality of surfacing but for carriageway width and camber, or the maximum heights of bridges—and while these physical standards were fairly open and permissive, they nonetheless helped to reinforce tacit norms around vehicle size and maneuverability, and to shape the practices of driving (which are subordinate to the practice of freight logistics, but nonetheless influential upon it).

Even as improved road standards opened up the possibility of larger, faster vehicles, regulatory interventions applied by earlier governments to the road network had been working over decades to side-line the steam waggon. The 1896 Locomotives on Highways Act recategorised vehicles weighing under three tons unladen as "light locomotives", exempted them from the requirement to have a crew of at least three, and set a new speed limit of 14mph (or 12mph at local authority discretion); this was followed by the 1903 Motor Car Act, which raised the limit to 20mph. While still restrictive for steam vehicles (which had finally enjoyed a brief period of faddish popularity as recreational sports vehicles for wealthy Victorians), these laws were predominantly aimed at curtailing the popularity of the still nascent ICE vehicle.

It was a different story after the war, however: through the 1920s and 1930s, regulations and taxes were stacked upon steam vehicles, eroding their ability to compete with ICE on operational costs, despite the significant taxes levied on imported oil by comparison with domestic coal supplies. An axle-weight tax followed in 1933, then more taxes on steam engines and a reduced import duty on oil fractions in 1934, with the result that fewer than 1,000 steam waggons were still in operation in 1938 (Barker & Gerhold, 1995, p85-86).

5.4.3 Articulations

In order to capture a particularly complex moment, this articulatory map will focus on 1936, by which time all the legislature discussed above had been enacted. The articulatory mapping for this moment is shown in figure 5.7 on page 113.

Incumbents:

Vehicle-makers, Carriers

Rather than considering vehicle manufacturers as a new articulatory community-of-practice, they are here considered as having inherited the position held by their predecessors, the wainwrights. Likewise the carriers entity is seen as a continuation of that which went before, given that the two main subtypes—the formalised carrier firm, and the informal local carrier or man-with-van—perform broadly contiguous roles throughout the period of analysis, namely using available vehicle technologies to provide a freight logistics service. Unpicking the variances between the different business models would serve only to clutter the model further.

Company fleets

The company fleet gets a separate billing to the carriers, because it represents a different configuration of the assemblage in which freight logistics performance are not outsourced, but provided in-house. As discussed above, this configuration results in vehicle design having a more immediate influence on the protagonist than in previous articulations, as there is no service design behind which the affordances of the vehicle can be occluded.

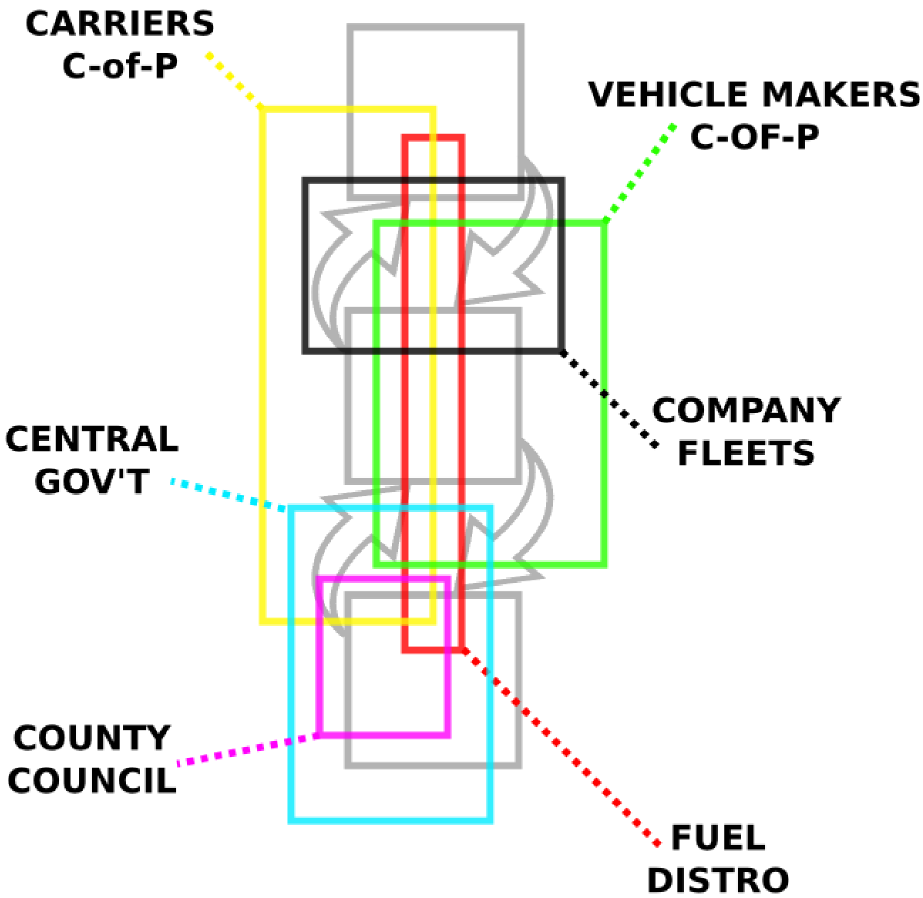

Figure 5.7: Articulated trialectic model for section 5.4 (Man with Van)

This results in a closer relationship between fleet operators and vehicle-makers which, while it doesn't entirely exclude the protagonist's HKJ influence, certainly relegates it to second place: if vehicle-makers are to sell more vehicles, they need to be influenced by those who buy the most vehicles, and this enshrines the influence over vehicle design of operators—whether of company fleets or carrier firms—above that of drivers or instigating protagonists.

Central government; County councils

Always an implicit player in the road network, in 1936 the central government reclaimed responsibility and control over the trunk routes. Non-trunk routes—which is to say the "last mile" routes—remained the responsibility of county councils, but the lion's share of decision-making powers remained with parliament.

Fuel distribution infrastructure

Effectively replacing the old network of stables, the emergence of a system for the refining and distribution of oil-fraction fuels in the UK was a prerequisite for the success of the ICE; this network would have started as refineries and fuel stations linked by tanker trucks on road and rail routes. But it bears noting that this infrastructure did not (and does not) not end at the border: indeed, it stretched all the way to the oilfields of the Middle East, and incorporated such massive and contentious overseas infrastructures as the Suez Canal—which is to say that even prior to the second world war, the supporting assemblage of freight logistics in Britain necessarily extended halfway around the globe.

Outgoing:

Inns and stables; Exchanges

As traditional carrying using horses begins to decline, the importance of inns, stables and exchanges to the assemblage likewise begins to fade; hence their absence from the articulatory map, so as to make space for other more vital relationships. By this point, business can be transacted more efficiently by mail or telegram, and carriers increasingly provide either an end-to-end service or goods yard facilities of their own.

5.5 The Long Boom: the motorway era (1955—2000)

The arrival of the ICE vehicle in the interwar years established a paradigm which is only now showing signs of ending, but that paradigm was largely stabilised and "locked in" by decisions made in the second half of the twentieth century.

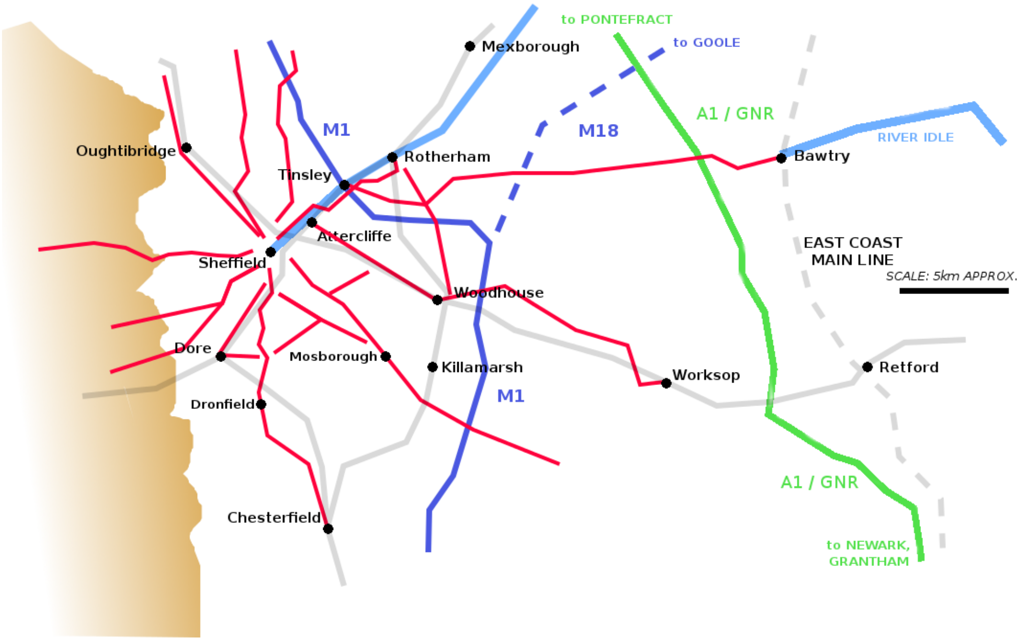

Figure 5.8: Roads in the Sheffield region, circa 1972

Figure 5.8 on page 115 shows the road network as it was in the early 1970s, which—with the exception of some improvements and widenings—was much as it still is today. The M1 was completed as far as Sheffield by 1967, and while only junctions 1 to 2 (Sheffield to Doncaster) and 5 to 6 (Scunthorpe to Thorne) of the M18 were complete by this date—the M18 began life as a spur to the M1 that provided a direct connection to the A1(M) at Retford, but was extended in a rather piecemeal and contingent fashion so as to link up a number of other small motorways in the north-east—this direct overland route from to Goole and Hull would be completed by the end of the 1970s.

5.5.1 Elements

Protagonist

Again, the protagonist is essentially stable.

Interfaces

Much like the first war, the second world war set domestic transportation standards back a few decades, as all potentially useful machinery was requisitioned by the state, and petrol severely rationed. But war tends to foment technological iteration: the durability and versatility of ICE vehicles over steam-powered or horse-drawn vehicles had been made apparent by a diversity of challenging circumstances, with the result that new vehicles were almost invariably ICE-based thenceforth. Personal passenger vehicles came in the most plentiful variations, but freight vehicles also diversified: the paradigmatic chasing of capacity efficiencies which has resulted in today's articulated HGV begins here, with a succession of larger vehicle types, but the pool also diversified down to freight vehicles which would be hard to distinguish from passenger vehicles based on size alone.

As remarked above, the steam waggon is already a marginal anachronism by this point, though it will survive as such out in the rural badlands of the last mile until the fag-end of the 20th century. Horse-drawn vehicles likewise hung on into the 1970s in similar circumstances, but gradually declining into predominantly "heritage" roles.

Infrastructure

As mentioned above, the notion of a national network of high-speed roads, inspired by European and American advances, had been kicking around in British discourse since before the second world war; however that war, and the financial restrictions which followed it, effectively prevented any such thing occurring for some time. In 1949 the Special Roads Act was passed, which enabled the building of roads to which access was limited by vehicle type, but it wasn't until the late 1950s that the first motorways and bypasses began to open, and the M1 did not reach Sheffield until the late 1960s; lesser roads were also improved during this period, not least so as to make the motorcar as practical on the last mile as on the trunk routes, but the difference in bandwidth between local roads and motorways is comparable to that between turnpikes and unmade roads in the late 1700s. Network expansion stalled in the 1970s, due in part to the oil crisis (thus indicating a dependency on global supply chains), but surged again under the Thatcher administration, only to peter out in the late 1990s in the face of a sustained protest movement and a general antipathy to roadbuilding among the general populace.

Numerous sources and documentaries attest to the novelty of the motorway's affordances: wide, well-surfaced, fairly straight, optimised for smooth flows of traffic, and all but unrestricted with regards to top speed. Best of all, they were all but empty—for a little while, at least. Much as had the railways in a previous era, the motorways—in combination with personal vehicle ownership—became a tangible symbol and product of modernity; to make use of them was not merely advantageous, it was progressive, trendy. To drive on the motorway was to partake in the future, in a real and visceral sense.

Such cultural significance was likely of secondary concern to those involved in freight, however, who would have seen motorways pragmatically as the turnpikes of their era: a massive improvement to the bandwidth and availability of major trunk routes in the national network, which was particularly beneficial to heavy goods vehicles. Although it was never stated in so many words, it seems likely that this was very much in line with government intentions—note, for instance, that the beginning of the motorways program coincides with the infamous Beeching Report, which recommended the downsizing of the then-struggling British Rail network; then note further that it was Ernest Marples, Tory minister for transport from 1959 to 1964, who appointed Beeching—a friend and business partner of some standing—to the role, and that Marples himself owned a construction business which specialised in road-building.

5.5.2 Influences

Note that the analysis which follows is focussed on the state of the system as it was in around 1972, by which time the M1 was complete as far as Sheffield (or, more accurately, as far as Tinsley), but the motorway network more broadly was far from complete. After 1972 the motorways program first continued to expand under a succession of Conservative governments, before shrinking again in the wake of the protest movement that sprung up against it in the early 1990s. As far as substantial changes to the assemblage are concerned, what follows 1972 is a further consolidation of the assemblage, and a stability rooted in its dominance over the alternatives in terms of not only funding but political willpower; the ebb and flow of quangos and regulatory bodies notwithstanding, the road assemblage of today was articulated in 1972, and has changed little since.

HKJ

As before, the essence of the HKJ influence is the desire to exceed performance parameters; in the case of commercial freight, this tends to mean changes which make a delivery faster or cheaper. However, other priorities may attend the transportation of more specialist items—and the late twentieth century in Britain is arguably defined by the explosion of consumerism, and the plethora of specialist goods that underpin it. Put simply, there's ever more stuff to be transported ever more urgently, of ever more diverse sizes and weights and fragilities.

DP: Service design

There was no paradigmatic shift in the way that road transportation services are offered as services within this period, merely a continuing diversification of operators (so: plentiful men-with-ven, but also plentiful formalised carrier firms, the latter having an increasingly international remit as EU trade slowly opens up). By this point, the process of formalisation means that some carrier companies are indistinguishable from any other large corporation, but for their actual line of business; these larger firms tend to be generalists, to find their efficiencies in scale, and to offer a very simple turn-key service. This is a response to HKJ desires for a more "magical" service: protagonists with a lot of freight to move about want to get it moved with the minimum of input or concern on their part, because time is money.

However, there remains plenty of space for operators focussing on a particular locality, or a particular type of freight; due to their niche specialisations, these organisations tend to be smaller and less formal, and hence have a more bespoke service model. This is in response to the HKJ desires of protagonists who are less concerned about speed or affordability, and more concerned about other parameters, such as fragility, awkward sizes or shapes.

DP: Vehicle design

The design protocols of the vehicles themselves have some limited influence over the protagonist during this period. This is due to an increase in company fleets, and in specialist carrier operations, both of whom would have a much more specific performance in mind when selecting a vehicle by comparison to a bulk carrier such as Pickfords, where the focus would be on leveraging the maximum capacity from a fleet of largely identical general-purpose vehicles. Specialised vehicles are therefore a response to specialist forms of the HKJ influence, where the emphasis is on the improvement of a parameter other than speed or efficiency: for instance, an operator specialising in moving heavy engineering components might happily trade off the maximum capacity and top speed of their vehicle against its having a loading crane fitted to it.

I&I

We have already discussed those elements of vehicle design which "face" the protagonist (or their proxy) in DP above; these tend to address very particular variations of performance parameters, so as to accommodate the needs of niche protagonists, which can fall between the cracks of generalised corporate freight-as-a-service.

The reader may recall that the Invention and Iteration influence "faces" the infrastructure layer: it represents the efforts by interface makers to develop interfaces that maximise the infrastructural capacity accessible through their use. By way of a related example: as mentioned above, the new motorways presented as long, empty stretches of largely unregulated road, implicitly offering almost limitless speeds to the user—an offer which was enthusiastically taken up by motorists, particularly the young (a form of HKJ influence in the passenger sector). Their experiments quickly revealed that the ICE technology of the time couldn't actually sustain the sort of speed that motorway travel involved; as a result, vehicle makers begun improving engines (and running gear, suspension, brakes and bodywork) in order to produce vehicles that could fully exploit this new infrastructure.

Speed was certainly important to freight vehicle manufacturers, but significantly less so than capacity, particularly once speed limits were established; as such, the real I&I influence in this assemblage expresses as a continual escalation of freight vehicle capacity, which involves both optimisation within the frame of pre-existing regulatory vehicle categories (i.e. "just how much stuff can we cram into a vehicle that obeys these rules?"), and the development of new larger (or, occasionally, smaller) vehicle categories; this is a direct response to the increasing formalisation, globalisation and quantification of commercial manufacturing, which encouraged firms to see the transportation functions they outsourced as a component of their own logistics system, and hence to optimise for efficiency as ruthlessly there as they did everywhere else. This influence thereby pushes at the infrastructural layer: by soaking up the capacity made available, filling the roads with ever more trucks of ever greater maximum load, it provides an ongoing rationale for the expansion of infrastructural capacity in response.

S&R

The motorways are hence probably best seen as the manifestation of a commitment to respond to the I&I rationale of increased demand by providing greater capacity: as suggested above, the government's commitment to further developing the roads network was unswerving, and may also have been seen as a progressive (and economically beneficial) counter to the struggling rail sector (if not as the nails for its coffin lid). It is uncontroversial to describe ICE vehicles as essentially hegemonic in Britain from the 1960s to the present day, and the reasons for that are fairly plain to see: the ICE hegemony was established by the government's commitment to expanding the infrastructural layer upon which it was dependent (and abetted by its lack of commitment to expanding or supporting others). Or, more simply: Britain became saturated with cars and lorries because the state did everything that could possibly be done to encourage and enable such a circumstance. In terms of physical standards, this meant building ever more motorways and bypasses (and the gradual improvement of A and B roads), plus bridges tall enough for large vehicles to pass beneath, and surfaces capable of enduring the passage of thousands of heavy, multi-axle vehicles.

As the physical standards of the motorways were generous and accommodating, so too did the regulations respond encouragingly to increases in goods vehicle capacity, resulting in an expanding array of goods vehicle classifications (and their corresponding licenses and tax brackets) permitted to make use of the network. However, other aspects of freight performances began to be subject to regulation: the introduction of tachometers and restrictions on the maximum number of hours a driver might stay behind the wheel, for instance. The roads in general, and the motorways in particular, are notable for the openness of their physical standards, but for the complexity of their regulations.

5.5.3 Articulations

The articulatory map for this period is essentially unchanged from the map for the preceding moment (see Figure 5.7 on page 113); the dominant players, and their essential relationships and spheres of influence, have stayed stable for decades. In truth, there are many more actors bound up in the assemblage than are shown here, from the small (e.g. road safety campaigners) to the large (e.g. distant regulatory authorities such as the EU), but their role is akin to that of mortar in a brick wall: far from pushing aside or interposing an incumbent actor in the assemblage, these actors fill out chinks and niches in the assemblage, binding it together and making for a more stable articulation.

However, it bears repeating that this stability seems entirely dependent upon the government's commitment to the network—an impression supported by the observation that, once the public mandate for further roadbuilding dried up in the mid-1990s, the total amount of goods moved by road vehicles peaked, though it has not declined significantly in the two decades since. This suggests that the massive growth in the modal share of road freight recorded from 1953 onwards correlates clearly with the continued expansion of network capacity during that period; or, more plainly, that the stability and growth of the road freight assemblage is inseparable from the political will to underwrite it. It further serves to validate the time-worn observation that traffic inevitably expands to consume whatever network capacity is available.

5.6 Summary

This chapter has deployed the trialectic model and methodology in order to perform a historical analysis of the evolution of freight logistics assemblages based upon the road network in the Sheffield region.

The analysis has shown that the topology of the road network was formalised and fixed during the first pulse of turnpiking in the late 1700s, thus producing a web of major routes which went largely unchanged and unsupplemented until the motorway era in the late twentieth century. While the topology of the network has changed very little since turnpiking, however, its capacity has developed in sympathy with the vehicles through which it might be made use of.

In terms of the trialectic model, we observe that the roads are a consistently open system: open in the sense that anyone can use them (within regulatory parameters, of course), and open in the sense that their physical affordances have tended to allow for the accommodation of a wide variety of different vehicle types. Phrased another way, the road network is a protocol: a network with fairly open provisions and rules, upon which third-party players are welcome, if not encouraged, to build services and businesses using commercially produced interface devices.

In terms of the articulation of the trialectic, it is notable that while there are strong vertical entities providing a supportive spine to the assemblage, there is no entity which can make a claim to having dominance or control over the assemblage. It is clear that the ability of central government to push through improvements in the infrastructural layer plays an important role in sustaining the roads assemblage and ensuring its dominant modal share of freight traffic, but the contestation around the interface layer—while bounded by standards and regulations—has proved capable of producing vigorous (if exploitative and occasionally criminal) new models for the business of providing freight logistics as a service. But those new business models are almost invariably iterations of a very old model indeed, namely that of the common carrier, and the experience of the instigating protagonist of such a practice has really changed very little: one gives over one's goods, and one pays the going rate for the relevant destination. However, the assemblage through which that service is performed has been through several substantial reconfigurations, some more successful than others. Furthermore, the success or failure of new entrants into the assemblage is shown to be at least as dependent upon social, political and economic factors as upon the validity of the technology in question.

Chapter 6

Historical analysis B—Cooperation: the evolution of waterways

A preamble on sources

As explained in greater detail at the beginning of chapter 5, the narrative approach of this thesis to its blending of data and analysis precludes the referencing of every fact that follows in the manner that might be considered traditional to some disciplines. Therefore any statement of broad or contextual fact in the analysis chapters of this thesis (namely chapters 5, 6 and 7) which do not bear an inline citation should be taken to be drawn from a synthesis of the sources pertinent to the chapter in question; in the case of this chapter, those sources are Ball, Crossley, and Flavell (2006); Boughey and Hadfield (2012); Burton (1995); Guldi (2012); Hadfield (1972); Hey (2010); McIvor (2015) and Shell (2015) in particular, though some degree of contextual information may have been drawn from or corroborated by those sources with more direct pertinence to chapters 5 and 7. Direct inline citations, therefore, should be taken to indicate the sourcing of a unique and precise detail upon which the analysis is particularly dependent.

The structuring of the subsections serves to assist in the distinction between data and analysis, as much as said distinction is practicably possible in such an approach. The introduction and "Elements" subsections of each historical moment should be considered to represent statements of fact, to the extent that such are possible regarding the period in question, except where the narration clearly indicates a supposition or conjecture on the narrator's part.

By contrast, the "Influences" and "Articulations" subsections of each historical moment should be considered to be predominantly speculative analysis based upon the materials already cited and discussed; where it adds clarity, the introduction of further specific data within these sections is accompanied by a direct reference to its source wherever such is realistically possible.

For a discussion of the epistemological and methodological challenges inherent in this research, particularly in regard to the the availability of and reliance upon pertinent sources, the reader is directed to section 9.4.5 of the discussion chapter of this thesis.

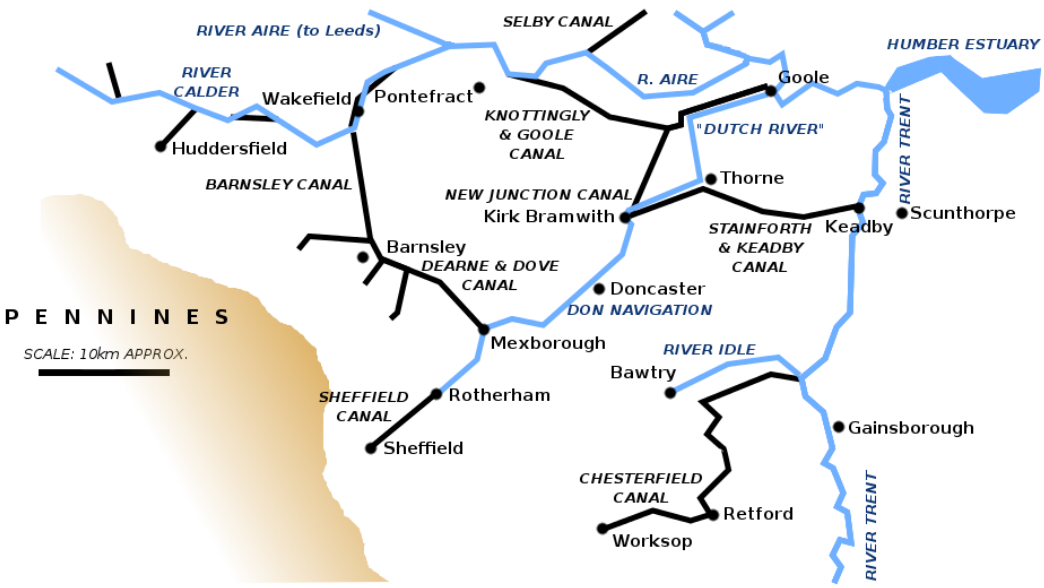

Figure 6.1: Rivers, navigations and canals in Derbyshire and South Yorkshire

Sheffield grew up around the point of confluence of the River Don and the River Sheaf. In exploring the story of waterway freight in the Sheffield region, this part of the analysis will predominantly focus on the River Don. This is less of a choice than an inevitability rooted in the fundamental differences between the two rivers: arriving in Sheffield after a long flat run roughly southwards from Penistone, the Don is broad and slow, while the Sheaf clatters down a rocky valley directly from the foothills of the Pennines to the south-west of the city. In short, the Sheaf was never a viable transport route: too narrow, shallow and fast for even fairly small boats. As such, it is of little immediate relevance to this analysis, as are the numerous minor rivers in the area—many of which, though not all, have disappeared from view due to a combination of over-abstraction, pollution, and culverting.

However, looking at the uses other than transportation to which the Sheaf has been put will help clarify the story of transportation on the Don, and further illuminate the stories of road and rail transportation in Sheffield, also. As such, a brief examination of the industrialisation of the River Sheaf will follow the four analytical moments examining the River Don, the first of which begins below.

The sections of this chapter will refer to Figure 6.1 on page 124, which is an illustrative and not-to-scale map of the waterways and major river systems to which Sheffield is connected; rivers and navigations (natural waterways enhanced by human intervention) are shown as blue lines, while canals are in black. What should be immediately apparent is Sheffield's isolation in the context of waterways: jammed up tight against the Pennines to the West, at the point before any rivers were made navigable or canals dug, Sheffield was a good 20km overland away from the nearest point at which it could connect to the national network of waterways transport, namely Bawtry on the Idle to the east.

6.1 The Dutch River: early experiments in inland navigation (~1700)

Sheffield's axis of economic orientation was traditionally East-West, thanks to the local topography preventing easy movement southwards. The eastern link was to Europe via the port of Hull, at the mouth of the Humber estuary: long prior to the industrial revolution, steelmakers in the Sheffield area had been importing Swedish iron, rather than making use of the inferior local resource, and finished products flowed back in the opposite direction, whether they were ultimately bound for the continent or for the south of England.

The Upper Don is that part of the river which begins in the Pennines and ends where it joins the Sheaf; this section has never been made navigable in any significant sense (and is hence not illustrated in Figure 6.1), though it played a significant role as a source of water and power for many mills, forges and factories along its banks, as well as being a handy dumping site for unwanted industrial byproducts. The Lower Don flows north-east out of the city, passing through Tinsley and Rotherham and Doncaster; prior to any improvements or interventions (circa 1620), it debouched into both the River Aire and the River Trent, around the location of what is now the town of Goole.

In the late 1620s, a Dutch engineer named Cornelius Vermuyden was hired to drain Hatfield Chase, and closed off the Don's connection to the Trent as part of the work; this resulted in repeated floods (and riots) in the Fishlake region, and Vermuyden's sponsors demanded another channel to fix the problem. The result was what is known as the "Dutch River", which joined the rechanneled Don to the Ouse (see again Figure 6.1); the village of Goole was founded at this location.

Sluice gates had been fitted to the Dutch River, but they were washed away in 1688 and never replaced, allowing the tide to flow into the channel, thereby making it wider and deeper than it had been previously. As a result, barges of between 10 and 30 tons could travel between Fishlake and the estuary in all seasons, while smaller craft could make it as far as Doncaster "during three-quarters of the year" (Hadfield, 1972, p64-65). This was of little advantage to makers or merchants in Sheffield who, if they wished to transport goods by water, were obliged to send them overground as far as Bawtry, which was the nearest head-of-navigation through which they could link up to the growing national waterways network.

6.1.1 Elements

Protagonist

The protagonist's desires remain essentially stable: to move goods around the map and make a profit doing so. However, there is a specificity to their demography that bears noting. Shipment by water appealed to different businesses for different reasons—the potteries of what is now Stoke-on-Trent, for example, realised that porcelain shipped by water was less likely to break than pottery shipped by pack-horse or cart, providing it was loaded and unloaded with caution. The businesses of the Sheffield region, by contrast, were bulk commodity producers (e.g. mines, collieries, quarries) and/or bulk commodity consumers (mines again, but also forges and mills) and weren't worried about breakages so much as bulk cost efficiencies: put simply, what they had to sell would only be worth selling if they could move it more cheaply over long distances than could pack-horses, carts or waggons. This was of much less concern to producers of more expensive products, such as Sheffield's famed cutlery and blades, which were still profitable when sent by more expensive (but faster and more direct) overland modes of transport.

Interfaces

That the Lower Don was not considered "navigable" is certainly not to suggest it had no boat traffic; it is merely to emphasise that what boat traffic there was would have been minimal, and considerably constrained by the prevailing conditions of the river. Detailed records for the period are unavailable, but it seems reasonable to suggest that an array of small rivercraft might have been in use: given we know that a 10-ton barge could travel no further than Doncaster, we can therefore assume that most if not all boats in use between there and Sheffield would necessarily have a capacity lower than 10 tons.

It is an interesting to note that for waterway transportation in the Sheffield region, the local state-of-the-art in interface technology was way behind that available further down the waterways to which they aspired to connect. Ships and boats are a venerable branch of technology, and time-honoured and traditional designs were well established long before the era of navigations and canals: the design still known (and in use today) as the "Humber hull" dates back to the 13th century, and successfully meets the special requirements of sailing on both the Humber estuary itself, and the inland waterways to which it was connected. For inland operations, a deep keel is anathema, but boats with a shallow keel will drift when exposed to sidewinds out on the open waters of the estuary, so the Humber hull came with lee boards to be deployed against this risk. Two different sail configurations pertained: a square rig was traditional for boats based on the northern bank of the estuary, and a sloop rig on the south. But the square rig was particularly suited to inland waterways: it was more easily raised and lowered (so as to pass under bridges), and was tall enough to catch the wind that might otherwise be blocked by buildings or trees along the riverside. Rather than having a rigid standard size, Humber hull variants emerged to adapt to the particular waterways they plied: by way of example, Sheffield-class hulls were 18m long by 4.5m beam with a capacity of 100 tons, while Trent-class hulls were up to 5 meters longer (Burton, 1995, 121). (At this point, of course, the Sheffield class does not yet exist, as there is not yet a route to Sheffield that such a boat could pass.)

Infrastructure

While the Don had not yet been meddled with to the end of making it navigable, it was already subject to plenty of other interventions, many of which contributed to compounding its being considered unnavigable. Boats using the Don were obliged to share the river with the water-powered mills and factories that had sprung up along its banks during the early pre-steam phases of the industrial revolution. These mills required weirs and millponds to impound a large head of water, by which could power their machinery; boats could pass these obstacles by way of a "flash lock" or side-sluice, but mill owners were often reluctant to allow them to do so, as operating the locks diverted the water supply for the duration of passage, which could means hours of lucrative production lost to each passing barge.

6.1.2 Influences

HKJ

Given the stability of the protagonist's role, the basic qualities of HKJ influence are likewise consistent across time and across systems: the parameters to be exceeded are those which will most affect the profit margin. However, more specific logics come into play in this particular moment, which bear some closer examination. Cost is inescapably important, but there are other factors which might recommend a practice be performed through the use of one technological mode rather than another.

Given the established overland flow of goods from Sheffield to Bawtry for onward shipment by water (whether to Europe or the southern counties), the advantages of waterborne transport were obvious to local traders, particularly those dealing with cheap-but-bulky commodities such as coal. For example, during this period the cost of carting coal ten miles overland was reckoned to effectively double its price by comparison to that at the minehead, which is why only colliers based in Newcastle, with its direct access to littoral shipping, could make a profit selling it in London despite the tax placed on it at the end of the 17th century (and why Sheffielders of this period burned coal at home, but no one shipped it far from where it was found).

Or, more simply: if you could load coal straight onto some form of boat, you could make good money selling it, but if you had to send it even a few dozen miles overland beforehand, you were literally better off burning it yourself. With higher value goods, the profit margin could absorb the overland costs to some extent—hence the established overland connection to Bawtry. But that overland connection would only ever have presented itself as a drain on profits, which goes some way to explaining the existence of an influence in favour of developing the waterways assemblage in Sheffield, even when alternative modes of transportation were available to complete the route.

DP

Given the extreme informality of the sector, there was likely little in the way of service design: barge operators on the Don presumably operated in much the same manner as the informal "local carriers" who worked the roads, being restricted to small loads and short journeys by the unimproved condition of the river itself. Regular schedules in particular would have been impossible to maintain while dealing with fractious mill-owners for passage through weirs; likewise, capacity and costs would have depended on the affordances of the particular barge in play, the boatman's availability, and other such factors.

I&I

In this case, the I&I influence upon the infrastructural layer comes not from a new technology, but a pre-existing technology already in operation not very far away, but which has yet to be deployed here: namely, the Humber hulls (and indeed more capacious vessels elsewhere in the country). Very simply, the existence of larger boats travelling inland waterways elsewhere is a precedent which anyone involved in trading or shipping would have been very much aware of, and which revealed the commercial possibilities of an improved river; thus the long-standing busyness of the port at Hull (to which some Sheffield businesses were likely already shipping, by way of the overland link to Bawtry), and the early success of the nearby Aire & Calder Navigation would inform and strengthen the I&I influence upon the infrastructural layer, manifesting as calls for improving the navigability of the Don.

S&R

At this point, the "standards" of the infrastructural layer are the innate and unimproved conditions of the river itself—its depth, breadth, speed of flow, sharpness of turns, seasonal variances—plus the design of the flash locks. These are the main influences on the material form of the interface, which manifests as the presumed hegemony of small, shallow barges: no other types of boat would have been at all practical, because they simply wouldn't fit.

Likewise there were few of what we would now think of as "regulations", not least due to the lack of activity to be regulated. However, the leasing of mooring points and riverside property, and the tolling and/or licensing of local waterborne carriers are actions with a distinctly regulatory character. Other such regulatory activity of a more mutual kind would include the negotiation of fees and customs around the use of the locks (such as waiting for a suitable number of boats to arrive, and then passing them through as a batch), which mediated between the competing interests of the mill-owners and the boat operators—interests which were presumably not always in opposition, given the need to ship the goods that the mills produced (and the raw materials they consumed).

6.1.3 Articulations

The articulatory mapping for this moment is shown in figure 6.2 on page 130.

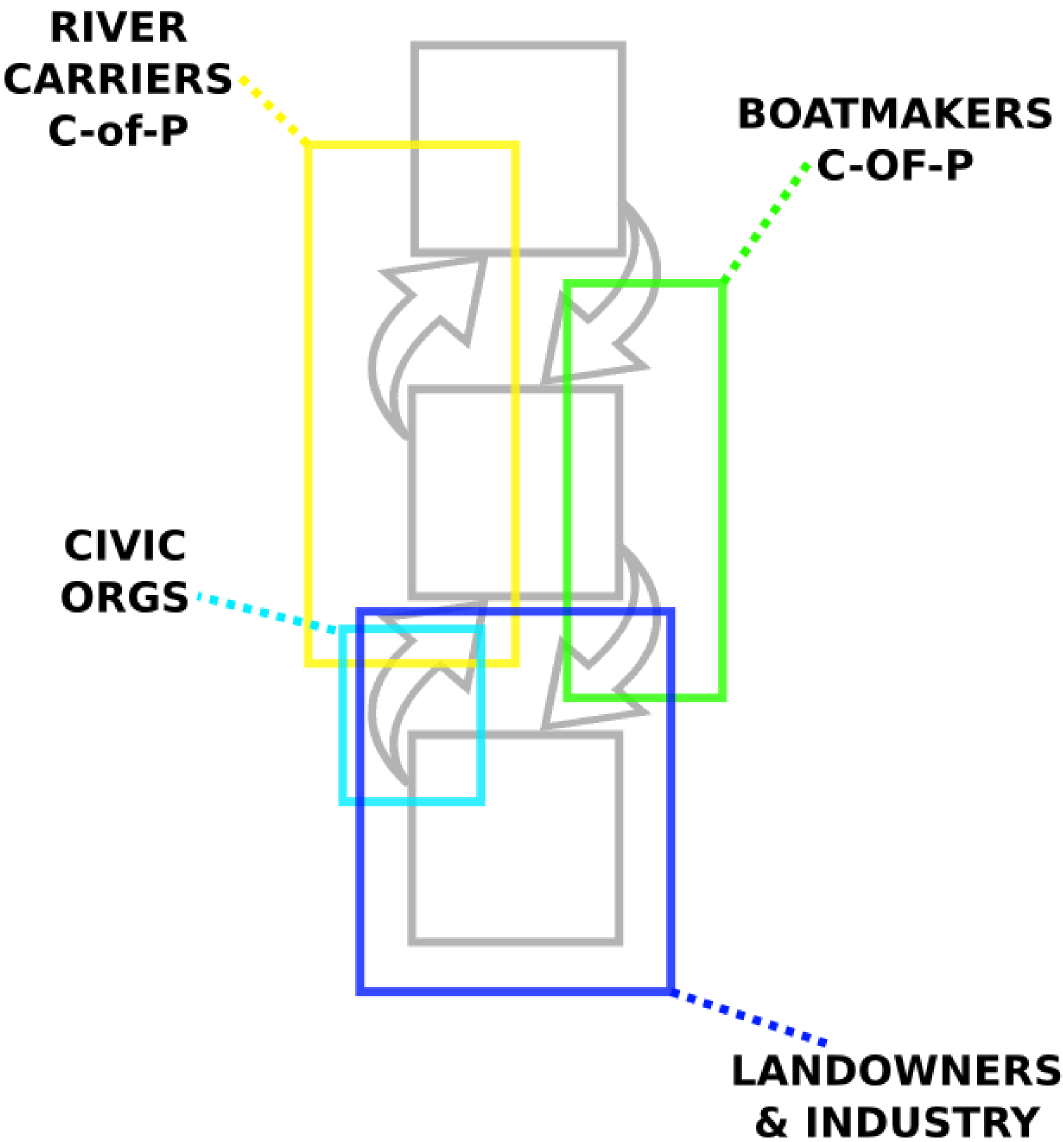

Figure 6.2: Articulated trialectic model for section 6.1 (The Dutch River)

River carriers community-of-practice

The presence and placement of the community of river carriers—inferred to be broadly similar in operational style to the informal local and regional carriers operating on the roads during the same period—should be self-explanatory: any protagonist seeking to fulfill a performance using the waterways assemblage necessarily has to deal with the operator directly, leaving said operator considerable leeway to adjust the service on offer as they see fit.

Boatbuilders community-of-practice

Likewise, the influence of boatbuilders is clear—although, as mentioned above, their influence on the I&I vector arrives as if from a distance. Boatbuilders along the Don would have no cause to build boats which could not be used upon it, but would doubtless be well aware of the various hulls being made and used elsewhere—a knowledge likely shared with the river carriers, if not actually transmitted through them.

Civic organisations

The Hallamshire Cutlers and the other Sheffield authorities would as yet have little reason to get involved in the waterways, given they did not yet extend into the town. However, the corporations and councils of Doncaster, Rotherham, and other regional towns with conflicting or competing interests (whether as transport hubs or rival producers of commodities) were already making their influence felt, and would continue to do so (as shall be shown).

Landowners and industrialists

Much of the land alongside the Don was owned by either members of the landed aristocracy or early successful industrialists. For the former, the river represented both drainage and irrigation opportunities (or simply bounds upon lands they liked the way they were), while the latter saw the river as a source of power (as well as a source of water for industrial purposes); for both, the status quo is predominantly satisfactory. However, this articulatory entity should not be seen as in any way unified or monolithic in its concerns: on the contrary, landowners and industrialists were as likely to dispute amongst themselves as with any other actor, and some of them could see personal advantage in more general improvements, as shall be shown.

Implicit: Roads

At this point it bears noting that the existence of the road network as a potential alternative assemblage (even if not a particularly good alternative in many cases) must have exerted an influence on not only the uptake of waterway performances, but on their form: put simply, road transport would have been the performance mode against which water transport was defined in contrast. As such, the influence of the roads is universal across the whole waterways assemblage, but in an implicit and distanced way: hence its listing here as an implicit articulation, and its absence from the articulatory map.

Rather than considering the road assemblage as an entity intruding into the waterways assemblage as pictured here, it is perhaps better conceived of as being in something not unlike a quantum superposition with it: for any given performance (or sub-route of a performance), both assemblages await their potential enrollment, but only become relevant when (if) the performance enrolls them. Hence the lack of visual representation; there is no way to show both assemblages at once without one effectively obscuring the other (which, metaphorically speaking, is what happens at the moment of assemblage selection).

6.2 The Don Navigation (~1770)

Much as with turnpiking, the fad for making rivers navigable came fairly late to Sheffield, but that was not for want of local efforts in that direction. The scale of those efforts bears consideration, as they inform and illuminate later events—and while this account and those that follow may seem complex, they in fact represent a significant simplification of the actual sequence of events, and of the cast of significant actors.

As with turnpikes, navigation projects required an Act of Parliament before they could proceed. The first Bill filed in favour of improving the Don came in 1698 from Sir Godfrey Copley of Sprotbrough, and was backed in Parliament by notable figures in Leeds and the West Riding, but it was opposed by Sheffield, the Doncaster corporation (due to worries about damage to mills), and those with vested interests in shipping on the Idle and the Trent. The 1704 Bill came from Doncaster itself, but quickly ran afoul of riparian landowners. Another emerged from a coalition between Sheffield (the town authorities in alliance with the Hallamshire Cutlers) and Rotherham in 1721, making a clear argument not just for the enhancement of regional and national connectivity, but for an improved ability to export manufactured goods; backed by the already-established Aire & Calder Navigation, it also encountered resistance from riverside landowners and mill-owners.

The Bill introduced in 1726 by Sheffield and the Cutlers did the trick, despite continued opposition from landowners, interests on the Idle, and their former allies in the Aire & Calder. The Bill only passed after it dropped the idea of extending the navigable stretch beyond Tinsley, replacing it with a short turnpike-esque road between Tinsley and Sheffield proper; the resulting Act, once finally passed, came loaded with a uniquely extraordinary number of concessions to local business interests as a condition of its passing, including a promise to build no new weirs (meaning locks would have to be integrated into existing millponds), nor alter the height of existing ones (Hadfield, 1972, p61). Construction began soon after, but the trust struggled to secure enough funding, and eventually had to go back to Parliament for permission to become a joint-stock company (the creation of which had been constrained in the wake of assorted speculative "bubbles", most notably the infamous South Seas Bubble, resulting from enthusiastic over-investment in the transAtlantic slave trade), as well as battling with mill-owners and other interests over land rights, water supply and concessionary toll schemes.

By 1740, the river had been made navigable as far as Rotherham for vessels of up to 20 tons, and the company petitioned Parliament again for the rights to extend their remit downriver to Fishlake—another proposal whose acceptance came loaded with concessions. By 1751 the navigation had reached Tinsley, and the Tinsley-Sheffield road stipulated in the original Act was completed in 1755. The original lease to the shareholders expired in 1759, and the company took over management of the navigation itself. Through the 1760s, the regional trade in coal was picking up (thanks to other navigations elsewhere, and also turnpiking, which was opening up the roads to heavier loads), and the navigation experienced year on year growth in receipts taken (and in dividends paid) right through to the 1790s (Hadfield, 1972, p80).

6.2.1 Elements

Protagonist

The role of the protagonist remains stable. However, as happened with the roads, the general level of economic energy is increasing everywhere, lending a growing intensity to commerce and competition. Note also the bubble phenomenon in the broader socioeconomic context, indicative of what economists euphemistically refer to as "irrational exuberance" in financial decisions—and a prelude to the speculative booms that will underwrite the railways and canals to follow.

Interfaces

There is no detail to be found regarding the constitution of the small craft operating on the completed Don Navigation, other than that they could carry up to 20 tons—twice the earlier limit—as far up the river as Tinsley (at which point goods bound for Sheffield proper would be transferred onto the Tinsley-to-Sheffield turnpike), and would have been either powered by sails or pulled by horses.

But as before, a whole selection of other hull variants are implicitly in play, due to their ubiquity elsewhere in the waterways system to which the Don Navigation is connected: boats such as the Humber hulls thereby act as a sort of "absent presence", an unrealised yet nonetheless easily perceived potential for improved performance parameters.

Infrastructure

The main work in making a river navigable was dredging to a consistent depth, and broadening and straightening the route to accommodate longer vessels, but some secondary infrastructures were also necessary, such as new or replacement bridges, towpaths and wharfage facilities. Also crucial were the development of the two-gated pound-lock, which allowed for faster throughput of longer, broader vessels while allowing any mills on the weir to continue working as the shipping passed by; such locks often necessitated the construction of extra reservoirs and sluices.

6.2.2 Influences

HKJ

As discussed in the previous moment, the HKJ influence is broadly consistent.

DP

The shape of the service as experienced by the protagonist changes considerably with the arrival of the Navigation, not least because the navigation company itself acts as the interface to the service: the company would accept goods for transit in exchange for standardised tolls and fees, and then farm out the work of carrying the goods to river carriers who were either contracted to the company or who took pick-up work on a more ad hoc basis. This enabled a sort of arbitrage of capacity, which in turn meant greater regularity and reliability of service, as well as regularised (or at least predictable) pricing; that reliability would in turn have attracted more traffic.

Note however that this period sees the emergence of the earliest corporate carriers, and that these organisations could and did use subsystems like the Don navigation as components of multimodal services across much longer routes, transferring goods (and sometimes passengers) from carts and waggons to rivers and coastal shipping (and vice versa) whenever doing so offered their clients an advantage in speed, cost or reliability. In such cases, the carrier company is acting as a proxy for the protagonist, whose contract would have been with the carrier alone; the carrier would then subcontract such sections of the journey as they could not perform themselves. But these arrangements are obscure to the protagonist, concealed behind the opacity of a turn-key delivery service: they pay the tolls, hand over the goods, and forget about it.

I&I

As before, there's little opportunity for innovation in the interface layer to push against the infrastructural layer in an attempt to extract more capacity: the limitations of the infrastructure form a hard ceiling on vessel capacity, and there is no other parameter on which a boatbuilder could compete with the hegemonic designs (which, in the cases of river barges, had already been optimised to purpose by the passing of time). However, the larger vessels known to be operating on other waterways—and, indeed, further toward the coast on the same system—would serve as an influence in favour of infrastructural improvements which could accommodate their like.

S&R

As mentioned above, rivers are restrictive upon the interfaces that use them in ways that roads are not: put plainly, if your boat is too deep, broad or long for the river at any point along the route, you simply cannot use it. This limits the extent to which interface innovations which focus on size or capacity can exceed the current configuration of the infrastructure layer. That said, there would be little to prevent the ongoing use of vessels which were *smaller* than the now-standard size, at least in purely practical terms. But smaller boats would find themselves at a disadvantage regarding economies of scale alongside boats of the maximum size, which would have restricted their use to jobs involving short routes and small loads; as such, while the standards of the river enforce an upper bound on vessel capacity, they consequentially generate an economic pressure that raises the lower bound of capacity.

As with turnpikes, toll schedules—mandated by Acts of Parliament, and often tailored to support local economic dynamics—regulated what was carried, and when. Meanwhile, the old informal agreements and customs around lock usage and other such activities become codified into operational rules and regulations, and it is these shifting norms and customs to which minor innovations in vessel design and organisational practices would be best able to react.

6.2.3 Articulations

The articulatory mapping for this moment is shown in figure 6.3 on page 137.

Incumbents: River carriers; Boatbuilders; Civic organisations; Landowners and industrialists

All these players from the previous moment are still very much in the game. Note, however, the increased influence of the Civics over the DP vector (reflecting the increased but still partial influence of Sheffield authorities over an infrastructure for which they agitated).

The Navigation Company

The role of the Navigation company itself—initially a trust, much like those which managed turnpikes, but ultimately a joint-stock for-profit company—is self-explanatory. Note, however, the way in which its centrality positions it as a site of conflict and mediation between other interests: it forms a sort of spinal column at the heart of the assemblage, and holds the system together.

Mining concerns

The coal trade was the main impetus behind the Don navigation: as mentioned above, transporting coal by road was unprofitable on anything but the shortest of local routes, but the prospect of connecting directly to the coast by barge made the local coalfields look like a viable business. And of course, that export channel could also act as an import channel for mining supplies, such as wooden pit-props from Scandinavia. There were more strictly functional benefits to this relationship, also: the closeness of canals to mining comes in part from the former's maintaining its depth by using water pumped out from the latter.

Colliery owners (and other such extractive producers of heavy materials, e.g. of slate, lime, millstones, building stone) get their own articulatory entity due to their closeness to the navigation—a closeness that was both spatial and commercial. The arrival of the navigation prompted many mine owners to run tramways

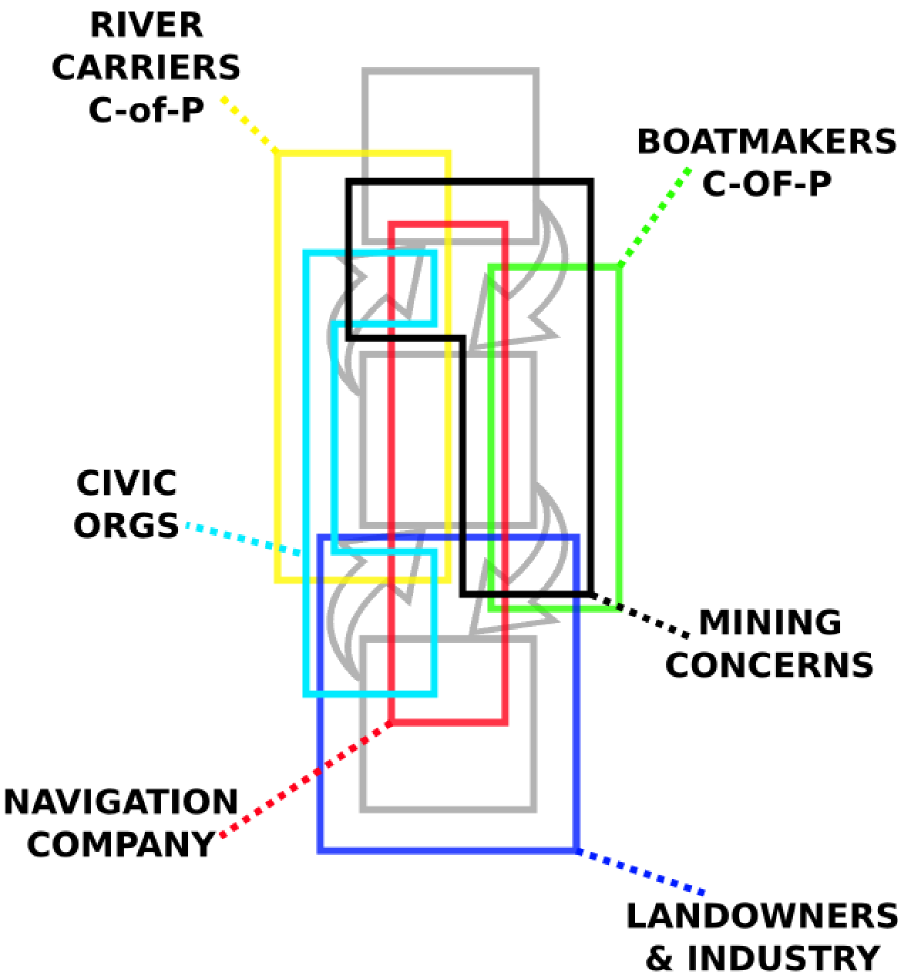

Figure 6.3: Articulated trialectic model for section 6.2 (The Don Navigation)

down to their own wharves on the riverside, so as to take advantage of the ability to get their goods onto the water as soon as possible; avoiding overland carriage entirely cut costs to such an extent that entirely new markets opened up to them outside the local region, particularly for coal, and the sheer volume of their business ensured them a sympathetic ear within the navigation company.

Note that this irregularly-shaped grouping connects to the interface layer, and also to both of the influence vectors between the interface and the protagonist. Mining concerns influenced the vessels they used primarily through their need for ever-greater capacity, but they also influenced service design: in a very early manifestation of what we would now describe as containerisation, mine operators pushed for their coal to be loaded onto ships while still in the trucks that carried it to the riverside, as this would simplify and speed up the loading process considerably (at least from their perspective), and make for easier intermodal transfers further along the journey.

But note further that these powerful protagonists also generated HKJ influences at the same time, through their attempts to secure ever more capacity at lower prices: after the Don company agreed to the more convenient loading procedures and started charging mines by the truckload, it became apparent that the mines had been quietly increasing the standard size of their trucks, necessitating a readjustment of the appropriate tolls (Hadfield, 1972, p80).

6.3 The Sheffield & South Yorkshire Waterways (1840—1900)

If the negotiations and wranglings required to make the Don Navigation a reality seemed protracted, they were nothing by comparison with the internecine disputes which were to come. The next moment in which a fairly stable assemblage might be sketched does not occur until around 1880, but in order to understand that assemblage, it is necessary to cursorily sketch out the extensive conflicts which shaped its constitution.

The 1790s saw increased calls for an extension of the navigation beyond Tinsley and into Sheffield, thus bypassing the overland turnpike and getting goods straight onto the water at their point of origin. This was also the period in which the fad for navigations gave way to full-on “canal mania”, a phenomenon which was as much financial and political as it was technical: as such, what follows is a massive simplification of events by comparison to the actual corporate combat that characterised canal development in general, and canal development around Sheffield in particular.

The increase in the industrial and domestic use of coal within the region meant that coal traffic on the Don and other local systems was actually falling. The arrival of the Navigation had resulted in a profusion of tramways and waggonways connecting mines and quarries directly to the banks of the river; traffic might be sustained if production could be ramped up to meet the demand further afield. This provided the impetus for the development of the Barnsley coalfield, in which the Don Navigation company had a clear and direct interest (in the form of a stake in what would become the Dearne & Dove canal).

A meeting in Sheffield in 1792 saw the first serious proposal of extending the Don Navigation to Tinsley, as well as the plans which would become the Dearne & Dove, but while the Don company's shareholders agreed on the plans, they were frustrated once again by the interests of local landowners. However, the Stainforth & Keadby Canal was launched in Oct 1792, entirely under the control of the Don company, and an agreement was reached with the Aire & Calder Navigation over what would become the Dearne & Dove and the Barnsley canals, and a connection between them; the Aire & Calder's remit stretched roughly between Huddersfield on the Calder in the west and Goole on the Humber in the east (and is not labelled in Figure 6.1 on 124 so as to avoid cluttering). While separate on paper, there was a great deal of overlap of funders and personnel within these organisations; the Stainforth & Keadby and Dearne & Dove "obtained their Acts in 1793 and became separate companies, though with much common shareholding, control and management" (Hadfield, 1972, p208-209); the Stainforth & Keadby started operations in 1802, the Dearne & Dove in 1804.

The Sheffield to Tinsley link stayed on the drawing board for a long time due to the continued resistance of land-owners, and the first decade of the century saw numerous proposals being batted back and forth across the parliamentary net with no success. The idea of a canal connection was revived in 1813, but the Don company had by then cooled on the idea, so an independent company was formed in 1815, and the canal connection finally opened in 1819; the Don company's judgment may have been sound, as "the canal proved expensive to build and only moderately profitable" (Hadfield, 1972, p221).

The 1810s and 1820s saw the first rumblings of railroad competition, with the Don company initially aiming to enter the intermodal game with some branch-line connections of its own, only to dial back its ambitions, rationalise the system it already had, and link the navigation directly to the Sheffield canal. There were also legal and logistical squabbles, such as that with the engineering company Walker's of Mosborough, who would draw on the water supply to the extent that the navigation became too shallow to operate, and were eventually bought off with a doubling of their water fees, as well as the dropping of improvement plans;

also, influential local coal owners "forced the concession that a ton of coal should in future be reckoned as 25 and not 20 cwt." (Hadfield, 1972, p215).

Water supply was a particular problem for canals and navigations alike, and the Sheffield systems often relied on waste water pumped out of coal mines. This source became unreliable and insufficient, leading to clashes such as that with Walkers and other owners of abstraction rights, and eventually to an agreement with the recently-incorporated Sheffield Water Works Company in 1836 (Hadfield, 1972, p274). The 1830s are marked mostly by attempted deals and buy-outs intended to forestall or mitigate the inevitable arrival of the railways. By the 1840s, with railway mania in full swing, attention turned instead to the possibilities of intermodal connections and collaborations, and the Don company absorbed the Stainforth & Keadby, Aire & Calder and Sheffield canals, only to be itself amalgamated into the South Yorkshire Railway and River Don Company in 1850, which was in turn leased to the Manchester, Sheffield & Lincolnshire Railway in 1864.

Despite pressure from the railways (which could compete relentlessly against the canals, due to the lack of regulation on their rates), the canals managed to sustain decent levels of coal traffic (and hence receipts) for the rest of the century—though their modal share of the total traffic by comparison to the ever-busier railways was declining steadily. It is only here at the end of the 19th Century that the articulatory churn outlined above results in a significant shift in the constitution of the infrastructural layer. Likely inspired by the nascent Manchester Ship Canal, plans were floated to upgrade the network, now known as the Sheffield and South Yorkshire Navigation Company, to accommodate seagoing ships, and an Act of Parliament was secured to that aim in the early 1890s. The Act's promoters "were proposing to rebuild the Don and the Keadby Canal to a 300 or 400 ton standard" and "to enable both it and the Dearne & Dove to take compartment boat trains" (Hadfield, 1972, p417).

Unfortunately, the promoters were far from unified, and caught in a national crossfire of infrastructural investment speculation: deals on land, water and shared access fell through, investment failed to materialise, and the Manchester Ship Canal turned out to be less successful than expected, all against the backdrop of by a general decline in the national passion for building waterways. As a result, the Sheffield network was only improved to the extent of being able to handle 110-ton boats (see below); despite efforts at straightening the route, compartment boats could only pass in threes, which represented little or no throughput increase, but the opening of the New Junction Canal did result in a slight increase in tonnage up to the start of the first world war.

6.3.1 Elements

Protagonist

The role of the protagonist remains stable. Indeed, by this point the business of carrying has already formalised to such a point that the instigating protagonist may not actually take any part in the choice of assemblage(s) to be enrolled in the performance, leaving such logistical matters to the organisation performing on their behalf.

Interfaces

By 1900, there are a considerable array of different interface options for the Sheffield waterways assemblage, with the bottom tier still populated by assorted small barges (10—20 ton) and other such craft.

The abortive improvements achieved by the Sheffield & South Yorkshire after finally conglomerating the local waterways came nowhere near its ambition of accommodating 400 ton ships, but it was by this point finally possible for a Sheffield-class Humber hull (110 tons) to sail from Goole to the Sheffield canal basin.

(It bears noting that steam-powered variants of both small and large hulls were in production, and had been in use on the Aire & Calder since around 1830. However, steam-powered boats were still banned from use on the Sheffield & South Yorkshire six decades after that date.)

Compartment boats, meanwhile—also known as "tub boats" or, locally, "Tom Puddings"—were barely boats at all. Little more than an open-topped iron container capable of floating 30 tons of coal, and of being strung together into trains (not unlike pack-horses), these were developed on the Aire & Calder with the aim of completely mechanising coal transshipments all the way from the mineheads of the Barnsley fields to the growing port at Goole. They were a forerunner of 20th century containerisation: highly modular, and accompanied by bespoke wharfage infrastructures optimised for swift loading and unloading of the cargo.

Infrastructure

The final canal link between Tinsley and Sheffield opened in 1820, but was still only suitable for small barges, and went underused due to disputes over ownership, abstraction rights, and competition (whether between different canals, or between canals and the emerging railways). By the turn of the century, however, the Sheffield waterways had been dredged and improved and fitted out so as to accommodate anything up to the size of a Sheffield-class Humber hull (110 tons capacity).

This is in contrast, however, to the constitution of the Aire & Calder waterways—a separate waterways system, but very much interconnected with the Sheffield system due to its commanding position at the end of the Humber estuary. The Aire & Calder had gone down the route of full mechanisation very early, developing the "Tom Pudding" compartment boats and their associated loading and unloading systems around 1860, and subsequently lengthening their locks so as to accommodate seven compartment boats at a time; even by 1900, the Sheffield system's locks could only handle three at most.

6.3.2 Influences

HKJ

The dominant form of HKJ influence still applies, but it bears noting that the Sheffield waterways were oriented toward specialising in coal very early on: other types of goods were carried on the waterways, certainly (not least the Scandinavian logs used as pit-props in the mines) but the exploitation of the Barnsley coalfield provided the initial impetus. Therefore the HKJ influence on this particular assemblage is itself particular, in that it is dominated by a desire for performance parameters that are optimal for the transportation of a commodity with a very high mass-to-value ratio: put simply, bulk capacity with a minimum of intermodal shifts (i.e. transfers between one interface or infrastructure and another) always trumps speed of delivery and delicacy of handling.

DP

Much as with the Navigation, the canal companies published standard fares and tolls (as mandated by the Parliamentary Acts which created them, and by subsequent legislation), and presented as a turnkey carrying service: goods for shipment were given over to the company, which then parcelled out the actual carrying to its own fleet of vessels, and to freelance operators. Alternatively, one might transact with a cross-system carrier company, such as Pickfords, which specialised in point-to-point deliveries rather than regular shipments: that carrier company might then employ the canal company to handle one or more legs of the full journey. Reviewing the tumultuous history of the Sheffield waterways with regard to matters of ownership and responsibility, as outlined above, it seems fair to suggest that anyone who could realistically avoid dealing with the byzantine tangle of canal companies would have good reason to do so; simply turning over your shipment to a carrier company would be a lot less effort than negotiating with a succession of different organisations in order to complete the same shipment. That the organisations in question would have been publicly known to be struggling financially (not to mention feuding with one another) likely did little to improve their public standing. This served to effectively double down on their commitment to coal: of all the possible protagonists in this assemblage, the colliery is the one least able to make an alternative choice of assemblage. Or, more plainly, the waterways were obliged to stick with gratifying those customers who didn't have any other choice.

Or rather that *would* have been the case, were it not for the arrival of the railways in the middle of the century, who were able to provide bulk capacity and minimal intermodal shifts *and* delivery speeds literally unheard of a few years previously—and who were easily able to undercut the canals and the overland carriers, given that the latter were obliged to publish (and stick to) their regulated fares and tolls, while the railways were still savouring the vertiginous thrill of unregulated *laissez faire* business practices. And the problem with going specialist is that, once you're left with only the clients in whom you specialise, the boot is upon the other foot, and suddenly your clients hold the advantage, as illustrated by the successful renegotiation by the collieries of what a ton of coal actually weighed, described above: the DP influence ends up in permanent thrall to the HKJ influence, in other words.

I&I

As before, what passes for the I&I influence in this assemblage is the knowledge of the existence and availability of superior interfaces and infrastructures in operation in neighbouring waterways. But it is clear by comparison with the Aire & Calder that this is not a problem endemic to canals in general: as shown above, the Aire & Calder was experimenting with new iterations of old interfaces (e.g. steam-powered barges) and with genuinely novel inventions (e.g. the compartment-boat system), and was extremely successful as a result. There is little or no data to tell us why the operators of the Sheffield system were content to follow decades behind in the technological wake of other waterways in the region, and then to attempt only watered-down versions of their successful strategies.

But the way in which the system changed hands repeatedly over the course of a half century suggests that they were simply too busy trying to knife one another in the back over ownership (and hence operational and financial control) of the infrastructural layer to lavish much attention (or funds) upon contemporary changes in the interface layer. This undistinguished squabbling, coupled with attempts to either head off new competition from the railways or get into the railway game by the back door, saw the canal companies acting like absentee landlords, the slow decline of their assets being a direct result of their attempts to sweat them over the short term. Superior interface options were always exerting a pressure on the Sheffield waterways to expand, but that pressure failed to outweigh the narrow self-interest of the institutions controlling them, resulting in a "too little, too late" upgrade to the infrastructure at the end of the century.

S&R

By the end of the 19th century, the Sheffield waterways could accommodate the Sheffield-class Humber hulls and, presumably, any vessel smaller than that. This represents a considerable increase in the "bandwidth" of the connection between Sheffield and Goole, with every "packet" shipped potentially five to ten times as large as those shipped 80 years previously. However, it looks rather less dramatic when held up against the Aire & Calder, whose locks could handle more than twice as many compartments at once, and whose wharfage infrastructure was carefully developed to minimise costs related to the loading and transhipment of coal. To oversimplify (but not to excess), the Sheffield waterways system had always lagged behind the regional state-of-the-art regarding its physical standards, and this final half-hearted attempt at upgrade served only to entrench that backwardness. After all, why do your business on a network which is seemingly so wedded to the past?

The regulatory regime likewise reflects what might charitably be described as technological and commercial myopia, with the enduring ban on steam-powered barges on the Sheffield system standing as a synecdoche for the ongoing failure of its succession of owners to move with the times. And it's not as if there weren't clear reasons to change: even as late as 1906, a Humber hull carrying 100 tons and drawing 6′ 6″ would sail up the canal as far as Thorne or Mexborough, at which point they were obliged to take down their sails and arrange for horse-haulage into Sheffield proper, because otherwise they couldn't pass under the bridges (Hadfield, 1972, p423). In terms of the trialectic model, then, the company has failed to mediate between the desires of the protagonist and the affordances of the infrastructure layer: that "signal" of influence needed to be picked up and acted upon, but the opportunity was lost amongst all the inter-organisational horse-trading.

6.3.3 Articulations

The articulatory mapping for this moment is shown in figure 6.4 on page 145.

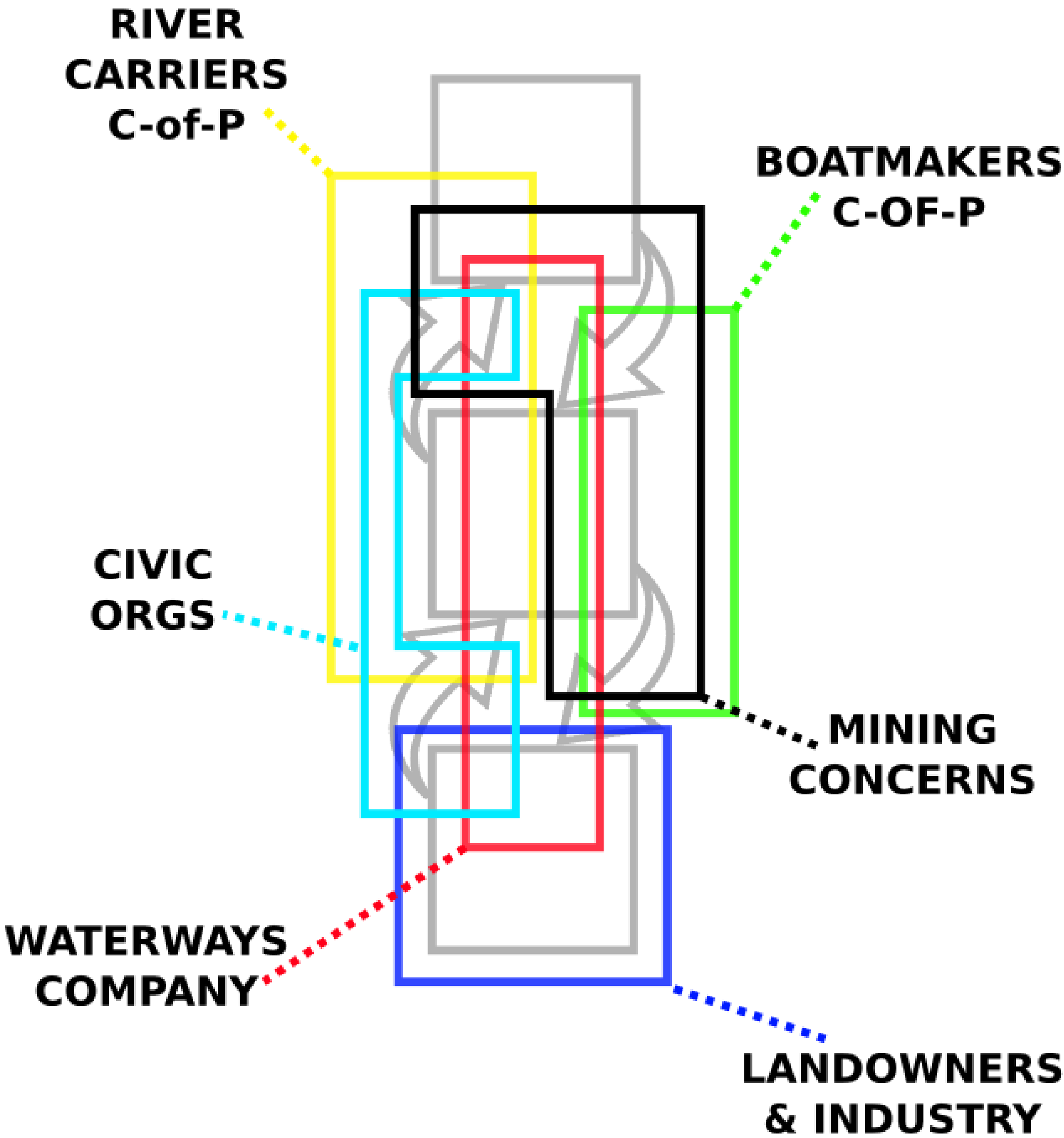

Figure 6.4: Articulated trialectic model for section 6.3 (The Sheffield and South Yorkshire Waterways)

Incumbents: River carriers; Boatbuilders; Civic organisations; Landowners and industrialists; Mining concerns

The majority of incumbent actors are still in play, albeit with some slight rearrangements of relationships.

The Canal Company

The canal company (in this case and at this point the S&SY) inherits the central controlling influence of the Navigation company thanks to its direct control of the infrastructural layer. However, note that its influence over the protagonist by comparison to that of the carrier companies and mining concerns is somewhat diminished: this reflects the greater flexibility of the carrier company's service offer by comparison to that of the canal company, and the controlling influence of a sector which the canal company has specialised in serving.

Recall, however, that while there was at almost every point "a canal company" in charge of the majority of the Sheffield waterways system, there were throughout the 19th century a succession of different organisations taking that role, many of whom have been shown to have been more concerned with blocking rivals (or buying them up) than developing the business itself; furthermore, fragments and subsections of the network fell in and out of the main company's remit over time. In terms of the trialectic, this implies a particular sort of instability, rather akin to that attendant upon a company that replaces its executive management team every year: while the structure of the assemblage stays broadly the same, one central articulatory element is repeatedly swapped for another one. This means that while the other articulatory entities, whose position and relationships have been broadly consistent over long periods of time, develop and retain an institutional knowledge of the assemblage, the crux entity of the canal company is always a late-comer, a new arrival faced with the difficulties of negotiating its way into a pre-established web of relationships while trying to avoid the fate of displacement which befell its predecessor. As a result, the canal company is a weak point in the articulatory web, not in spite of its spinal position in the assemblage but entirely because of it: this is illustrated by its failure to successfully translate HKJ influence into the I&I influence that would have resulted in earlier, more thoroughgoing upgrades to the infrastructural layer.

Implicit

Other Infrastructure Companies

Another implicit articulatory entity—or, more accurately, a cloud of them. As outlined above, the irrational exuberance of the railroad boom created a climate in which companies competed savagely to own, control and extract profit from transportation systems. As such, the canal company is necessarily always looking over its shoulder, keeping an eye on the rivals which could elbow it aside and take its place, and those rivals will always be jockeying for position and advantage, whether over the canal company or one another. This is the other side to the instability and weakness at the centre of the assemblage: not only does a vital central articulatory entity keep changing, but it is surrounded by other entities actively encouraging that rapid turnover in the belief that making this assemblage less stable might make the assemblage in which they have a stake more stable. The problem might be made more clear through metaphor: a young prince surrounded by rivals hungry for his throne necessarily and inevitably spends less time thinking about policy and more time worrying about courtly intrigues.

The account above touches only on the most major events in the Sheffield & South Yorkshire's history, which during this period—much as for other waterway companies—describes an arc that starts with attempts to forestall or protect against the imminent disruption of the railways, through efforts to collaborate with their increasingly evident power, and ends with the waterways as little more than parked assets of the railways, bought up as much for the sake of neutralising their competition with new rail services as for seeking the rents that came from the complete control of established freight systems (and their incumbent and dependent client base, who might then be either sweated on tariffs or encouraged onto a different, more lucrative assemblage). The repeated changes of ownership over what ended up as the Sheffield & South Yorkshire Navigation Company (see Hadfield, 1972, p410-428) to an instability of priorities in that succession of organisations, despite some surprisingly consistent continuities of personnel at the boardroom level: while the running and upkeep of the Sheffield waterways was always on the slate, deals with (and attempts to block) competing systems were evidently a major distraction from the main business.

This was not a phenomenon unique to the Don: all across the country, railway companies bought up canals and waterways, but there was little clarity regarding their continued obligations toward them. On pain of fines and worse, most railways fulfilled their "statutory obligations relating to tolls and keeping the canals in good order", but a kind of malicious neglect was common, which had the advantageous side-effect of pushing traffic onto the more reliable railways (Burton, 1995, p158-159). However, many canals would have gone bust if not for the railways—"[i]n some cases being bought out [...] was the best news shareholders had had since they made their first investment" (Burton, 1995, p158-159)—and decaying canals (e.g. those more minor waterways in the Sheffield region suffering from subsidence, due to being literally undermined by local coal extraction) were only kept up because of the statutory obligation to do so. Legislation in 1845 freed the canal companies to run their own fleets and vary tolls, and the parliamentary Commissions of 1872 and 1883 found that tolls on railway-owned canals were up to five times higher than those on the still-independent waterways, while other figures for the period suggest that the independents were also carrying five times as many tonnes per mile of network than those owned by the railways.

6.4 The Long Decline (1900—present)

The previous moment, as the 19th century gave way to the 20th, was the last substantial reordering of the Sheffield waterways assemblage—and as remarked above, it was too little, too late. As such, there is no new assemblage to model—but it is worth following the story to its end nonetheless, precisely because the Sheffield waterways are unique among the region's transport infrastructures by merit of their nigh-total decline into commercial irrelevance in the context of freight practices.

The first world war saw the Admiralty take control of not only the canals and navigations themselves, but also the majority of the steam trawlers operating between Hull and Sheffield. After war ended, "traffic offered, but many of the canal barges [and] the lighters that had worked in Hull docks, had been sunk"—and those that hadn't sunk were now being used as floating warehouse space "in order to avoid paying demurrage on ships" (Hadfield, 1972, p424-425); as a result, there simply weren't enough interface vessels to make use of the system's capacity, which likely pushed local freight traffic onto the railways and, increasingly, the roads, which were now starting to fill up with early ICE vehicles.

Sheffield City Council had already been considering an upgrade of the waterways system before the war started, and had drummed up support from manufacturers and other local councils; it was proposed that the government effectively nationalise and fund the waterways, though Sheffield "were in principle willing to contribute if the navigation were to be freed from railway interference" (Hadfield, 1972, p423). The plan included deepening the channel (from 6′ 6″ to 8′) as well as widening and straightening, and upgrading to larger locks comparable to those on the Aire & Calder, capable of handling one 300-ton vessel, or three 110-tonners side by side, or a decent train of compartment boats. The government declined to buy the company out, and Sheffield decided not to take the risk on its own; these inactions served to compound the tardy development that had preceded them.

Trade revived somewhat in the years after the war, but the railways and roads were eating into flows of all but the heaviest and cheapest commodities. The system survived by doubling down on its focus on coal, facilitating what flows were still ready and waiting, and cutting away what was already withering; the Elsecar branch of the Dearne & Dove closed in 1928, and the Bradford link in 1934. An ever-narrower focus and failures to invest meant that the writing was on the wall: "Coal traffic had dwindled because old and relatively small mines [close to Sheffield] had been worked out, and new ones sunk further east" and, furthermore, "the canals used smaller barges than the main waterway, which the company thought no longer worth building" (Hadfield, 1972, p426). The resulting mismatch between the infrastructure and interface layers eroded interconnective and multimodal capacity as well as flexibility regarding load types, leading to the fracturing and decline of the broader regional network.

The second world war saw the waterways return to direct state control once again, and the Sheffield and Tinsley sections were badly damaged by bombing. After the end of hostilities, however, "the company found that oil traffic was increasing"—as they had with coal in the 19th century, the canals found themselves becoming part of the fuel distribution subsystems of the assemblages with which they were competing—"and immediate prospects were more hopeful. In 1946, in conjunction with the carriers, they started to collect goods from works in Sheffield, carry them, and see them loaded into steamers at Hull or Goole" (Hadfield, 1972, p426).

The Transport Act of 1947 nationalised all the country's waterways: "[a]ll the canal company fleets went with the canal, and major private operators dropped out," selling their fleets on directly to the newly established British Waterways, which promptly set about dismantling the traditional lifeways (and associated visual culture) of the boat-people (Burton, 1995, p164-165), who had been the subject of sustained campaigns of vilification and Victorian do-goodery for decades (Shell, 2015, pp86-94). In a form of triage, British Waterways prioritised waterway upkeep by assessing networks into one of three categories on the basis of their existing traffic profiles: networks which were good investments, networks which could be saved, and networks worth only selling off; the Sheffield waterways most likely fell into the middle category. But in 1952, the National Coal Board transferred all of its coal and tar traffic outbound from Swinton onto the roads, effectively killing off the Dearne & Dove's remaining traffic source, and leading to its nigh-total abandonment in the 1961 British Transport Commission Act; by 1954, meanwhile, the Sheffield & South Yorkshire was dependent on coal for 84% of its traffic, leaving it vulnerable to a similar fate.

Further minor improvement works—likely little more than repairs and maintenance, with perhaps some more modern secondary infrastructures added to facilitate intermodal transfers—took place in the late 1950s, but in 1960 the British Waterways Board moved the main waterhead of the system to Rotherham, effectively leaving the Sheffield end to wither and die. 1961 saw another proposal for enlargement (though only to 250-ton vessels), and 1966 saw the British Waterways Board submit a plan to rebuild the main line, but it was rejected. A deep decline in tonnage and receipts continued through into the 1970s, with Sheffield Basin ceasing operations as a cargo port at the start of that decade; despite the basin being redeveloped for leisure uses in the 1990s, today the canal experiences little in the way of recreational use, and carries zero freight.

In terms of the trialectic model, the decline of the canals throughout 20th century might best be represented by the shrinkage and outright departure of vital articulatory entities: for example, given the incredible dominance of mining concerns in the preceding articulation (see Figure 6.4 on page 145) the articulation would be considerably weakened when those mining concerns closed up and left the area; likewise, the Sheffield Corporation's decision not to intervene can be seen as a withdrawal from (or decreased engagement with) the assemblage, thus removing another important structural prop which had been a part of the waterways assemblage right from the start. Without these entities being in a position to negotiate and mediate the various vectors of influence, those vectors will redirect themselves toward another assemblage where their influence might have greater effect—and without the vectors to channel influence and bind the assemblage together, the trialectic itself disintegrates, just like the system which it is being used to model.

6.5 The Sheaf

As mentioned at the beginning of this section, Sheffield's second major river, the Sheaf, never saw significant use as a transport infrastructure; by comparison with the Don, it had entirely the wrong hydrological properties, being fast-flowing and shallow, and having a bed of sandstone, clays and coal seams which made dredging all but impossible.

However, the properties that made the Sheaf unsuited to a transport role made it ideal for other infrastructural purposes; and while it played no transport role, its location—in a rocky-bedded valley that provides the shallowest grade of route into the city from the south—meant that it nonetheless played a significant role in the configuration of the city's transportation assemblages. Furthermore, the story of the Sheaf also serves to illustrate some of the influential contextual sociotechnical transitions happening at the same time as the freight transport transitions with which this project is concerned; as such, a brief rehearsal of that story is warranted.

Beginning at the point where the Redcar and Old Hay Brooks meet, the Sheaf descends 120m before it joins the Don in the very centre of Sheffield; this spectacular head of potential power meant that from as early as the 15th century, much (if not most) of the Sheaf between Totley and the junction with the Don comprised a series of dams and millponds, powering a variety of early heavy industries predominantly focussed on the metalworking for which Sheffield had long been known. Indeed, it is estimated that during its heyday, more water-generated energy was being harnessed for industrial purposes along the Sheaf and its tributaries than at any other site in the world (Ball et al., 2006, p xvii) The succession of dams ensured that transportation uses were out of the question: there would have been flash locks and sluices that would have theoretically allowed for the passage of small boats along certain sections, certainly, but to carry any significant load any significant distance would have taken a long time, given the need to wait on the mill-owner's favour before one could pass. Even as far south as Totley, it would probably have been faster to send goods down the valley and into the city centre by loading them onto packhorses and driving them down what would eventually become Abbeydale Road.

It is widely understood that the availability of reliable and affordable steam engines eventually signed the death warrant for water-powered mills. However, less attention has been paid to the timing of this transition as it took place in different locations, and the millponds of the Sheaf provide an interesting example. Newcomen's famed steam-engine was built in 1712, and Watt's refinements thereof started to appear in the mid-1760s, but these earliest engines were huge, inefficient devices, suited only to tasks such as pumping water out of mines (and into canals). Boulton and Watt's "Lap Engine" in 1788 was the first to be installed directly into a mill, thus kickstarting the mechanisation of the cotton industry, and the industrial revolution more broadly; in fairly short order, cotton mills all across the north of England were driven by steam.

Sheffield was never a textiles town, however; its reputation for iron and steelwork, and particularly blademaking, was well established even prior to the industrial revolution. As such, a great number of the mill-wheels along the Sheaf were used to power grinding wheels, on which blades could be sharpened and finished. Sheffield's bias toward finished iron and steel products compared with the raw metal orientation of other "steel towns" was a response to its topographical location: as has already been shown, it was slow, difficult and expensive to transport goods with a high mass-to-value ratio (such as coal or unfinished metal) even a short distance out of the city, while one could actually make a profit shipping out finished goods, which had a lower mass-to-value ratio.

We might therefore reasonably expect steam engines to begin replacing waterwheels along the banks of the Sheaf in the last decade of the 18th century; however, it would be another six or seven decades before any such transition took place. This must have been in no small part down to opportunity costs: if you already had a functioning water-powered mill, replacing it with a steam-powered one would be expensive, and you'd lose production during the downtime for construction; furthermore, given the incredible generosity of the Sheaf's head, steam would have to get pretty cheap (and industry ever more demanding of power) before it could compete on cost with the water power you already had on hand.

But there is another factor which surely contributed, which also contributed to the rapidity of steam's adoption in the textiles industry. Put simply, a steam-powered factory tends to have a steamier atmosphere—and this was an outright advantage if your factory worked with cotton, because a slightly damp atmosphere made it easier to work with the threads. (Indeed, this explains why the very earliest steam-engines were introduced to cotton mills long before they were sufficiently powerful to provide power directly to the machinery: instead, they were used to pump water to turn a water-wheel.) But a damp atmosphere was a huge disadvantage if you were working with iron and steel, for it would cause them to rust. All of these factors combined to stabilise the Sheaf's role—like that of the Upper Don, the Porter Brook and the other lesser rivers of the region—as a power infrastructure, long after steam power is traditionally thought of as having triumphed over water power.

Indeed, there are indications that it could have continued even longer, but for the rise of the railways. In the 1860s the Midland Railway finally built a line that entered the city from the south (starting from just north of Chesterfield), which was to replace the "old road" that looped westwards from Chesterfield through Rotherham and approached Sheffield along the Don valley. The building of the new line was vigorously opposed for many reasons: it necessitated the demolishing of some recently-built worker's housing (a problem that even today's new railway lines can't seem to avoid), and threatened to spoil one of the the Duke of Norfolk's favourite spots (that section of the route was put through a tunnel and concealed with an ornamental garden), but most of all it meant that most of the millponds that covered the valley floor would have to go. Unfortunately for the mill-owners, while the economics of water rights had worked in their favour for a long time, the game was up. Flush with heaps of investment cash at the height of railway expansionism, the Midland railway simply bought up the water rights for the land it wanted along the Sheaf valley and literally built over everything—as a result, the last kilometer of the Sheaf before it joins the Don is almost completely culverted, and runs beneath the concourse of what is now Sheffield Station.

Further south, however, some water-powered mills hung on: Abbeydale Works, now a working industrial museum, supplemented its water-wheels with a steam engine in 1855, presumably having seen the writing on the wall, and struggled on until the turn of the century; likewise the grinding shop at Little London Works lost some of its dams to the railways, but retained enough that it was still operating water-powered tilt-hammers up to 1951.

On the face of it, the story of the Sheaf seems to stand in complete contrast to the story of the Don, with the former retaining a primary role as an energy infrastructure, while the latter became predominantly a transportation infrastructure. But when we consider that the vast majority of traffic carried on the Don was coal (and the materials required for the extraction of coal, e.g. pit props), and that the coal it carried was sold in order to fuel steam engines and household fires, then there is an argument to be made that the Don, along with the Sheffield waterways system, is as much an energy infrastructure as it is a transport infrastructure: in very different ways, they both served to contribute to the flow of readily available power upon which industrialisation floated.

6.6 Summary

This chapter has deployed the trialectic model and methodology in order to perform a historical analysis of the evolution of freight logistics assemblages based upon the waterways network in the Sheffield region.

The analysis has revealed Sheffield's topological isolation in the context of the regional (and hence the national) waterways network: with the impassable Pennines to the west and only the shallow and sluggish Lower Don offering any waterborne connections eastwards, Sheffield was quite literally a backwater for heavy commodities shipping until the advent of the Don Navigation—and even after that, the city struggled with substandard connections to larger, more innovative networks, thanks in no small part to the speculative antics of the owners, investors and directors in charge of the waterways during the frantic cut-throat capitalism of the late 1800s. This may go some way to explaining why the demise of Sheffield's waterways began so early, and took so thoroughly.

In terms of the trialectic model, we observe that the waterways are a partly-open system, in they offered a turn-key freight service to clients, but also allowed subcontractors and carrier firms to integrate the waterways invisibly into their own service offerings. However, the physical affordances of the waterways are rather less forgiving and flexible than those of the roads, and the network (local and regional alike) less densely connected than the roads by several orders of magnitude, even as it trumped them effortlessly on capacity. This initially resulted in a sort of cooperative coexistence between the roads and the waterways, with the former playing the "last mile" to the latter, while the latter picked up the traffic too bulky and inconvenient for the former—but this intersystemic mutualism was unable to survive the twinned pressures of predatory railroad competition and *laissez faire* speculative capitalism.

In terms of the articulation of the assemblage, we note the enduring presence of a spinal entity throughout the evolution of the system, and further witness the way in which such an entity's becoming weak or ineffectual will in turn affect the pass-through of influences from the protagonist and the interface layer, with the result that the infrastructure layer falls behind the development curve, and ends up unable to compete with or even match the performance of other parts of the network to which it belongs, let alone that of an alternative competitor assemblage.

Chapter 7

Historical analysis C—Competition: the evolution of rail

A preamble on sources

As explained in greater detail at the beginning of chapter 5, the narrative approach of this thesis to its blending of data and analysis precludes the referencing of every fact that follows in the manner that might be considered traditional to some disciplines. Therefore any statement of broad or contextual fact in the analysis chapters of this thesis (namely chapters 5, 6 and 7) which do not bear an inline citation should be taken to be drawn from a synthesis of the sources pertinent to the chapter in question; in the case of this chapter, those sources are S. Bradley (2015); Chapman (2013); Gourvish and Anson (2004); Guldi (2012); Hey (2010); Wolmar (2001, 2009) and Wragg (2016) in particular, though some degree of contextual information may have been drawn from or corroborated by those sources with more direct pertinence to chapters 5 and 6. Direct inline citations, therefore, should be taken to indicate the sourcing of a unique and precise detail upon which the analysis is particularly dependent.

The structuring of the subsections serves to assist in the distinction between data and analysis, as much as said distinction is practicably possible in such an approach. The introduction and "Elements" subsections of each historical moment should be considered to represent statements of fact, to the extent that such are possible regarding the period in question, except where the narration clearly indicates a supposition or conjecture on the narrator's part.

By contrast, the "Influences" and "Articulations" subsections of each historical moment should be considered to be predominantly speculative analysis based upon the materials already cited and discussed; where it adds clarity, the introduction of further specific data within these sections is accompanied by a direct reference to its source wherever such is realistically possible.

For a discussion of the epistemological and methodological challenges inherent in this research, particularly in regard to the the availability of and reliance upon pertinent sources, the reader is directed to section 9.4.5 of the discussion chapter of this thesis.

7.1 Origins: tramways and plateways (~1770)

The direct antecedents of the railways were known as tramways or plateways or waggonways, emerging as a solution to the problem of carting coal and other minerals to the nascent canals and navigations. The first recorded (and all-wooden) waggonway in Sheffield dates from 1729, and ran from the coal pits of Park Hill to a coal-yard in the town, and was replaced by what is believed to have been the very first cast iron plateway in 1770; other early examples connected collieries at Tinsley Park and Handsworth to the developing waterways of the Don valley (Chapman, 2013, p4).

At this point, therefore, there is no network to illustrate—but the distribution of tramways and plateways in the region might be imagined by referring to the map of the road and waterways network in Figure 5.4 on page 94, and imagining that the Don Navigation (blue diagonal line, upper center of image) is limned with a series of short tramway and plateway links into the land to either side of it, sticking out from the Navigation like bristles. At this point, tramways are acting as a sort of specialised "last mile" add-on to the waterways, and to a lesser extent the roads.

7.1.1 Elements

Protagonist

As always, the protagonist role is essentially stable. Note, however, the strong specificity of the protagonist in this moment: tramways and plateways are direct adjuncts to the business of mining, and in the case of Sheffield, coal mining specifically. As such, this assemblage has a fairly narrow set of performance parameters to fulfill: it doesn't need to be all things to all comers.

Interfaces

The interface layer consists of some sort of wheeled container or truck, and some form of motive power; the latter may be provided by horses or oxen (whether pulling the trucks directly or through some sort of mechanism), by gravity (loaded trucks descend the grade, thus raising the unloaded trucks at the bottom), or even by very early stationary steam engines (e.g. pumping engines temporarily repurposed to pulling a load uphill by rope or chain).

Infrastructure

The infrastructural layer is fairly crude: little more than a set of rails—wooden for a waggon-way, metal for tram- and plateways—laid along the route, or channels cut directly into the stone, depending on the local geology.

7.1.2 Influences

HKJ

The HKJ influence is particularly pure and simple in this moment: as noted above, the protagonist is almost invariably a mining concern, and as such they're seeking improvements to a specific set of parameters of their freight transportation performance, namely reduced costs and faster bulk handling. The influence is also largely unmediated, given that the protagonist is also the developer of the interface layer: there is no other actor with whom it is necessary to compromise.

DP

Given that the protagonist and the developer of the interface are one and the same, there is no service layer within which the interface is bundled up for access. As such, the DP "influence" over the parameters of the performance is effectively null; there is no agonism to resolve between the performance and the interface, as the latter has been developed very specifically to address the former. In such a case, DP responds as fully to the protagonist's HKJ desire as the state of the technological art permits.

I&I

Considering the interface technologies in play, we may observe that, with the rare exception of those tramways whose trucks were pulled by steam power, they are essentially the same as those available on the roads during the same period:

wheeled vehicles, drawn by animals. As remarked above, pack-horses, carts and waggons would have been employed to move coal from the minehead to the nearest waterway, which was not only slow, but economically inefficient when dealing with a commodity with a high mass-to-value ratio: to carry a load of coal overland a mere ten miles from the minehead was to double its price. The vehicles and animals would also contribute to the further degrading of routes over the peaty soil of the region, or struggle where the going was rocky underfoot.

Much as these difficulties applied pressure for the improvement of road surfacing, the I&I influence thus seeks an improved infrastructural layer which will alleviate the specific difficulties attendant on the use of heavy wheeled vehicles on steep grades. And just as in the upper dyad of the trialectic for this moment, here in the lower dyad we can observe that the interface developer and the infrastructure developer are actually the same actor (which is to say the mining company in question), meaning that the I&I influence is effectively unmediated, and no compromise is required.

S&R

The best way to stop wheels sinking into mud or clattering over uneven rocky surfaces is to put something strong and rigid underneath them, in order to support the weight and guide the vehicle where it needs to go. While different materials were used in various locations (e.g. wooden guide-rails on a waggon-way, channels cut directly into the stone, or iron rails), the basic principle is the same everywhere: the way is exactly as wide as the gap between the wheels of the vehicles to be used. This immediately necessitates a system-wide standard for track gauge and other such physical parameters. But given that there is no agonism or conflict between the elements in this particular moment (because the entire assemblage belongs to and serves only its developer, who is also the protagonist), the only compromises to be made are those that will keep down costs. As such, at least in theory, the makers of tramways in the Sheffield region might have settled on almost any standard gauge; at this point, there was no expectation of systemicity, meaning that thoughts of compatibility between different tramways would been unlikely to occur.

But in practice, pressures for standardisation were already there: for a start, it has already been shown that the shipping of coal on the waterways resulted in the rapid standardisation of truck sizes; furthermore, considering the size and complexity and number of tramways operating at this time not just in the Sheffield region but all around the country, there would already have been a number of off-the-shelf standard designs to pick from, which would have been cheaper than specifying your own permanent way and rolling stock designs to an engineering firm, or hiring an engineer to do so on your behalf. As such, while there may in hindsight be reasons to argue that the widespread adoption of Stephenson's 4'8" standard gauge, as established on the nearby Stockton & Darlington, was not the optimum choice from a technical perspective, it would have been optimal from a pragmatic perspective: put simply, you knew it worked, and you knew you could get the appropriate rolling-stock without too much fuss or expense.

As the resulting assemblage is a closed system, accessible only to the protagonist themselves, there is little or no need for regulations restricting usage, which are predominantly intended as ways of limiting or rationing the capacity of a system which can be accessed by any given user at any given time. If you've built a tramway for yourself, you can use it whenever you fancy it without getting in anyone's way, and you would presumably set it up in such a way as to accommodate the best performance parameters possible with the technology to hand. As such, and much as with the DP vector discussed above, the S&R "influence" is no such thing in this particular moment, because there is no agonism between actors in need of mediation: as with DP above, the "standards" of the infrastructure layer are in this case an accommodation of the parameters made manifest in the interface layer. Or, more simply still: the infrastructure and interface layers develop in parallel under the same engineering aegis, and are thus mutually constituted.

7.1.3 Articulations

The articulatory mapping for this moment is shown in figure 7.1 on page 160.

Mining concern

A tramway system presents us with the most simple articulatory map possible, because all three elements are under the influence of a single actor, namely the mining concern which has built a tramway for itself; it is about as close to a closed system as an infrastructural assemblage can ever be.

Waterways company

But of course it is *not* a closed system: it exists to get coal to the navigation, and other goods from there back up to the mine. And so the waterways company exerts an influence over the infrastructural layer that is primarily to do with location: put simply, the rails have to run to where the barges can be loaded.

But there is also some influence over the interface layer, which reflects the first stirrings of what we now think of as intermodal transport technology. Even at

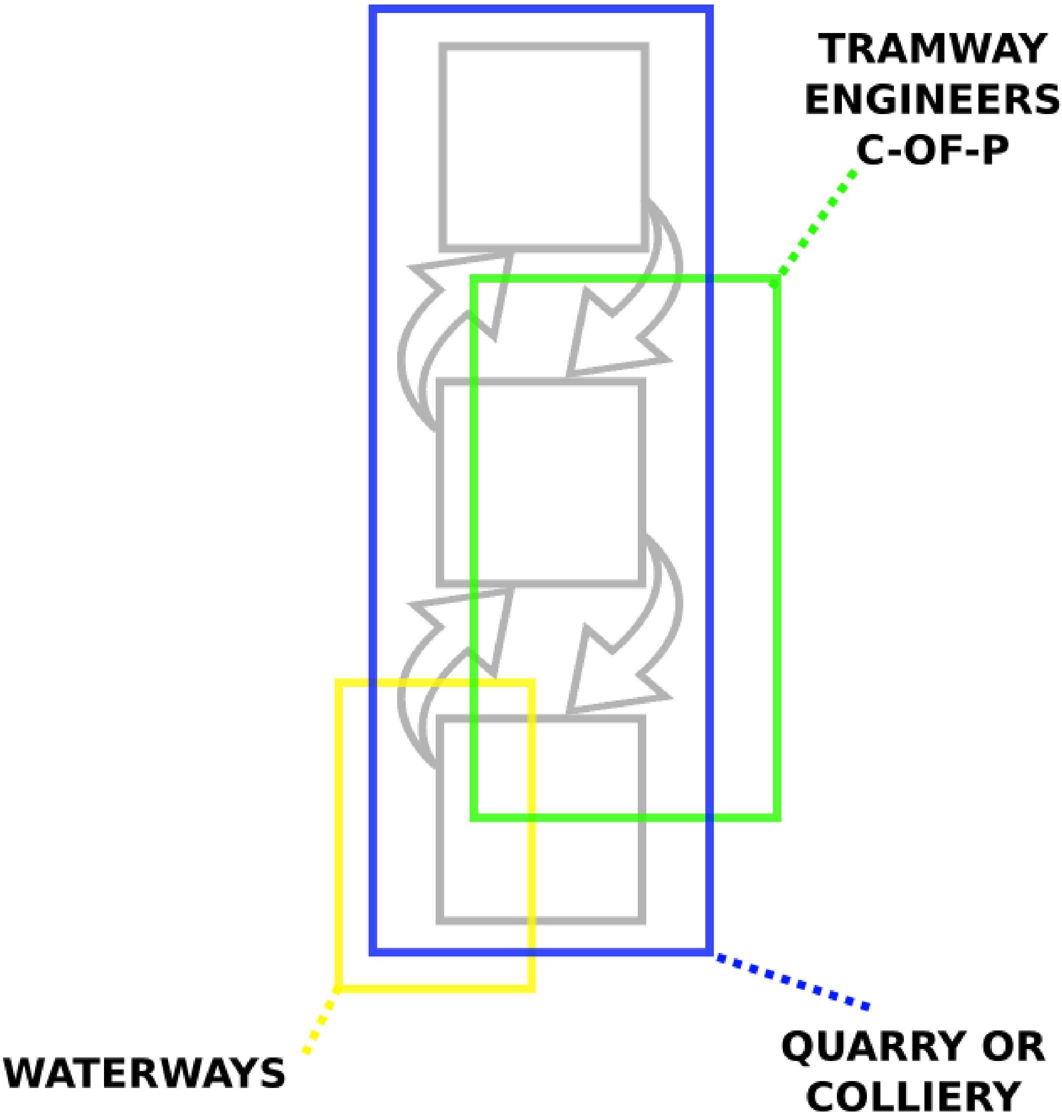

Figure 7.1: Articulated trialectic model for section 7.1 (Origins)

this early stage, some collieries in the Don valley made arrangements for their coal to be loaded onto barges while still in the trucks that had carried it down the tramway; this was great logistics, streamlining the loading and unloading process, but it also helped to standardise load sizes, and thus tariffs. (Furthermore, and perhaps unsurprisingly, we can also observe during this period the first attempts by protagonists to game a standardised system, with some collieries quietly upping the capacity of their "standard" trucks without informing the waterway carriers of the change—a classic example of HKJ in action.)

Colliery engineers community-of-practice

Tramways and plateways had their hey-day during the same period that the turnpiking and waterways booms enabled the self-creation of the civil engineer as a powerful and autonomous expert agent—and they were also nurturing the civil engineer's successor in fashionable expertise, the railway engineer. Restricted in their experiments on more advanced steam engines by the ludicrously punitive patents granted to Boulton and Watt on their early designs, these pioneers retreated to work on the internal logistical systems of mines and collieries, trying to produce a viable self-propelling steam vehicle to replace the animal power still required for moving materials and containers. While they were producing few viable engines during this period, their manufactories were certainly producing hundreds of trucks and miles of rail, thus establishing the economic and pragmatic precedents for certain standards which would be unknowingly adopted by subsequent builders of tramways and plateways. As such, they are shown here to have some considerable influence over both the interface and the infrastructure layers, and both of the vectors which connect them.

But note that tramways and plateways, while effectively small networks in and of themselves, were not yet a network in the collective sense that the roads and (albeit to a less extent) the waterways were: there was no direct communication or exchange between tramway systems, in other words—for what would one colliery want to buy from another? But the evidence for the exchange of standards between tramways and plateways is clear, which in turn implies that tramways and plateways *were* effectively networked, in the sense that ideas and configurations are being exchanged between them even if freight is not, and that the connective tissue of that network is formed by the community of engineers who design and produce the hardware for the systems in question.

7.2 Expansion: the Permanent Way (1850–60)

The first commercial railway to use steam locomotives, the Stockton & Darlington, opened in 1825; a direct evolution of tramways, its purpose was to carry coal directly from the minehead to the coast for onward shipment, but quickly diversified to other loads, including the first passengers. However, much as with both turnpiking and the earlier waterways mania, the Sheffield region got its railroads rather late when considered in the context of the boom more broadly.

The history of the railway boom is replete with failed projects, disputes, hostile takeovers, grudging mergers and high financial skullduggery, and it is far beyond the scope of this project to recount the development of the Sheffield region's railways in full detail. However, brief sketches of the development of the dominant systems in the region are necessary, so as to illuminate the dynamics of the assemblage itself; these descriptions will refer to the map in Figure 7.2 on page 162.

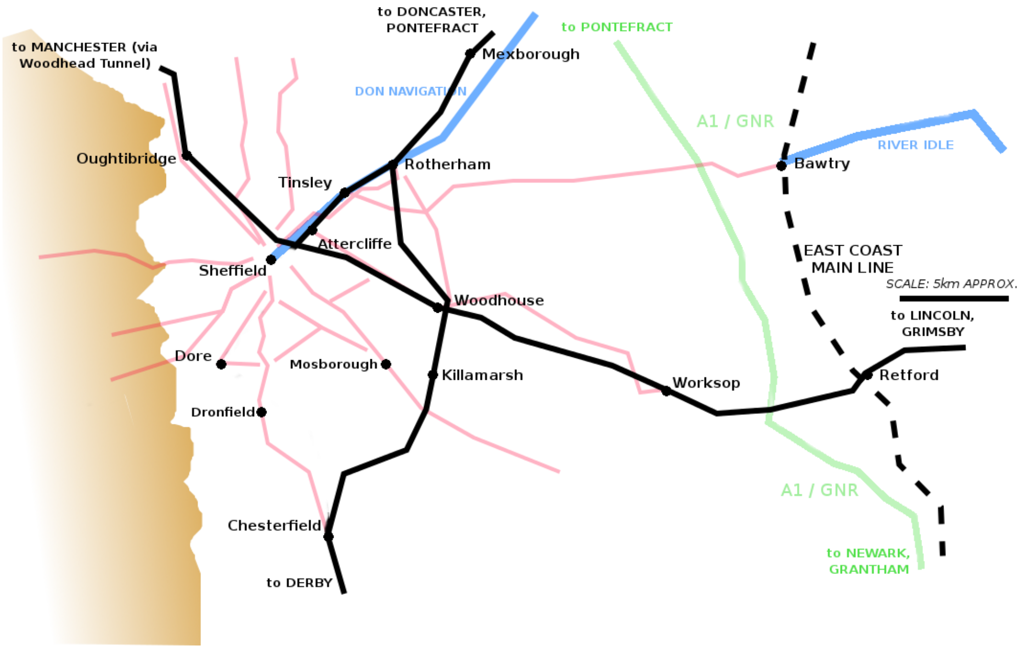

Figure 7.2: Railways in the Sheffield region, 1850—1860

While the Don Navigation company was fending off nascent railway threats during the 1820s, the Sheffield & Rotherham Railway—the region's first line, operating between its two titular towns—didn't open until 1838, and focussed predominantly on passengers until onward connections (to the North Midlands Railways, which crossed the Sheffield & Rotherham Railway near Masborough in 1840) and links to the coal mines at Greasbrough were established. The economic slump of the early 1840s saw the Sheffield & Rotherham Railway struggle with low receipts; eventually it was decided that expansion was the only way to survive, resulting in a new connecting line to the Sheffield, Ashton-under-Lyne & Manchester Railway, which opened the line running northwest from Sheffield toward Manchester via Woodhead midway through the decade. The Sheffield & Rotherham Railway hung on long enough to be sold to, and rolled up within, the newly amalgamated Midland Railway in 1845, thus linking Sheffield to a major north-south rail route, but nonetheless leaving it as something of a topological backwater in network terms.

Rotherham Masborough was, at the time, on the Midland mainline, and so a convenient hub; trains could connect to Sheffield from there, but Sheffield was the end of the Sheffield & Rotherham Railway branch, which required coming off the main line and into a subnetwork. Effectively, this meant that trains for all points south of Sheffield would initially leave the city heading north-east up the Don valley, before joining the Midland network at Masborough (south of Rotherham). The very same hilly topography which made the Sheaf valley an ideal source of power served also to prevent railways running into the city from the south until considerable advances had been made in railway technology, surveying and construction, and even then they would have to wait until the price of land rights in the valley fell with the decline of water power, as described in section 6.5. Before that, a train approaching Sheffield from the south would pass through Chesterfield, curve eastward around Sheffield to arrive at Rotherham, and then take a dog-leg route south-west from there to reach the city—a route still known to railway staff as "the old Road", and occasionally used to reroute trains when improvement works or other factors are causing congestion northbound on the Sheaf valley route into Sheffield.

Construction began on the Sheffield, Ashton-under-Lyne & Manchester Railway in 1838 on the western (Manchester) side of the tunnel through the Pennines upon which it would depend, but the eastern side—connecting Bridgehouses Station in Sheffield (very close to the Sheffield & Rotherham Railway's Wicker Station, where the Don flows north-eastwards out of the city) to the tunnel mouth at Woodhead—didn't open until 1845. After a series of failed or stalled negotiations over mergers and extensions, the Sheffield, Ashton-under-Lyne & Manchester Railway's shareholders agreed to merge with the Sheffield & Lincolnshire Junction, the Great Grimsby & Sheffield Junction, the Grimsby Docks Company and the (as yet unbuilt) East Lincolnshire Railway. This merger received royal assent in 1847, resulting in the formation of the Manchester, Sheffield and Lincolnshire Railway which, as it name implies, controlled track running through Sheffield between Manchester and Lincoln (i.e. running from the upper left corner to the middle right side of the map in Figure 7.2), providing the first straight-through rail link to support the long-established east-west flow of trade across the Pennines.

Many of these lines would be subsumed into the expanding behemoth which was the Midland Railway: founded in 1844, one of its first moves was to buy up the Sheffield & Rotherham, and it slowly bought and built its way southward to London, and southwest to Bristol via Birmingham, and thus gradually bringing Sheffield into an extensive national network of railways with a north/south orientation, of which the major spine was the East Coast Main Line (shown as a dashed black line running top to bottom in right-hand half of the map in Figure 7.2). This was in addition to the traditional and long-standing east/west connections which Sheffield had long enjoyed, as a node on the skein of routes passing over the Pennines between Hull and Liverpool; this included a complex tangle of railways under the aegis of the Lancashire & Yorkshire Railway, reckoned to be the most densely trafficked of all the pre-consolidation railways, whose lines predominantly passed on an east/west axis somewhat to the north of the region illustrated..

In addition to these major railway companies, by the latter half of the 19th century Sheffield and the surrounding areas also featured dozens if not hundreds of smaller railways and plateways devoted to either distributing industrial products directly onto the railways, or supplying those same industries with their raw materials. In network topology terms, then, the Sheffield region is very densely connected.

7.2.1 Elements

Protagonist

As always, the protagonist remains essentially stable. However, by comparison with the tramways before them, these early railways were handling a broader range of freight types, which widens the range of performance parameters that the protagonist may potentially desire to exceed.

Interfaces

Steam locomotion was a developing technology during this period, with the result that there were a wide array of different engine types available, each designed to meet specific needs (e.g. high torque for heavy loads on steep inclines). However, while the steam locomotive is part of the interface layer, in that it is at the head of the chain of vehicles in which the protagonist's shipment must sit, it makes more sense to consider it as part of the infrastructural layer. Beyond the fact that its existence makes the railway assemblage possible, the exact nature of the engine is largely irrelevant to the protagonist, because the affordances of the engine are bundled up in a service: the protagonist doesn't care how the train makes the speed to meet its schedule, so long as it meets the schedule.

Rather more important to the protagonist are the trucks in which their freight is to be carried; this affects their interaction with the service far more profoundly than would a variation in engine type. For instance, one's own goods-outward practices would need to work around the standardised loads implied by the capacity of standard waggons, and any in-house "last mile" tramways or railways built so as to facilitate goods coming in from the railways or going out upon them would need to be a close match so as to minimise transhipment issues—this being less an innovative approach than an extension of the proto-intermodal strategies developed by the operators of the earliest tramways, as described above.

Put more simply: the freight trucks matter more than the steam loco in this trialectic because the trucks are the site within the assemblage where the protagonist has the greatest leverage or opportunity to exert HKJ influences; this is indicated clearly in the previous moment, wherein it was observed that colliers reacted to standardised truck sizes by quietly trying to exceed their capacity without paying more. Admittedly the scope of influence here is limited, and far more so than it was in the previous moment, for reasons which will become clear. However, as limited as it is, the scope is far wider than that which the protagonist might apply to the design of the locomotive; that component is deeper within the assemblage, far removed from direct interactions with the protagonist, and thus largely beyond their influence.

Having made the case for the truck as an important site of contestation in the context of freight performances, it must now be reported that freight trucks don't really change in any significant way during this moment (particularly by comparison to passenger carriages, which underwent a frantic evolution). But while the trucks themselves are fairly stable, the assemblage around them is in a state of flux, as shall be shown.

It this point it bears noting that steam locomotion in fact went through some fairly rapid iterations during this period, as did some particular types of rolling stock. However, these developments were almost exclusively driven by the new demand for passenger transportation which, in addition to being more particular about scheduling (unlike truck-loads of coal, passengers tended to object to waiting on a siding for three hours, or travelling at unsavoury hours of the day or night), also insisted upon smoother, safer, more comfortable and luxurious travel.

The direct link between charismatic and powerful famous locos and passenger ticket sales would reach its apogee in the era of the Big Four (see below), but during the boom years of this moment, passenger rolling stock evolves at a frantic pace in response to safety issues, economics and (perhaps most importantly) issues of social class.

The link between passengers and their rolling stock is far stronger than that between freight protagonists and their rolling stock, for the simple reason that the passenger actually experiences the rolling stock first hand: it directly affects their experience of the service they are paying for. By comparison, the freight protagonist cares nothing for the details and affordances of the trucks carrying his goods: so long as the whole shipment arrives at its destination in good time and good order, the internal sociotechnical constitution of the performing assemblage is anathema to him. Indeed, this "magical" service is exactly what they're willing to part with their money for.

Infrastructure

In a simple sense, the infrastructural layer of a railway—referred to by insiders as "the permanent way"—is much the same thing as a tramway or plateway: a set of rails that guide the engines and trucks of the interface layer along a predetermined route. But where the plateway needed little more than the rails themselves, the increased technological sophistication of the assemblage meant that the permanent way acquired a raft of extra requirements: not just stronger sleepers and rails, but points and sidings, bridges and tunnels, improved drainage, more clearance to either side (which in turn had to be denuded of plant life so as to minimise the risk of trackside fires), and of course fences to keep livestock (and perhaps the occasional Luddite) away from the trains. By the mid-1850s, the permanent way also increasingly featured telegraph cables, which initially served as the nervous system of the railways by allowing communication between stations and signal boxes. The requirement for running a faster communications network in order to coordinate a large logistical network is not novel, of course: carriers and merchants had long used foot- and horse-posts and dispatch riders for much the same purpose. But the near-instantaneous communication across great distances enabled by telegraphy gave the railways an advantage that was hard to beat, and enacted a profound transformation on society that is perhaps best summed up by the introduction of standardised time across the UK—a change almost entirely necessitated by the need to coordinate railway schedules over a nation in which time had heretofore been a largely local matter.

There is also a sort of secondary infrastructure involved with the permanent way, but it has an interesting status by comparison with secondary infrastructures from other assemblages, because of its direct technical relationship with the interface layer. Consider the secondary infrastructure of stables that supported the road carriers (see section 5.2 above): though bolstered by the growth of the carrier economy, this network of animal-power provision was already widely established around the country, allowing the carrier's business to "plug in" to it as and when required. The point being: carriers didn't have to carry their own fuel for the entire journey, as they could "fill up" (or replace their motive units with fresh ones) at multiple stops along the way.

By comparison, the railways had no such pre-existing system of fuel distribution. But at the same time, as has already been shown, the railways were acting primarily as a system of fuel distribution by moving coal around the region, having evolved from the internal logistical systems of collieries. As a result, the railways bootstrapped themselves in a manner which no other infrastructure has quite matched: a technology for transporting coal evolved into a system for transporting coal which was also powered by that which it transported. Because railways started out working with coal, they were capable of taking coal to any location where their tracks would take them—meaning that (at least in the strictly distributive sense) railways in the age of steam acted as their own secondary infrastructure. There was a further necessity for storing coal in the appropriate locations (as well as water and sand, regular supplies of both of which were necessary to keep steam locos working), and the resulting bunkers and water-towers also became part of the permanent way.

As such, in this moment and those following, the locomotive involved in pulling a freight train is considered to be part of the infrastructural layer, as in this context it bears a far more intimate technical relation to the constitution of the permanent way than to the constitution of the rolling stock.

7.2.2 Influences

HKJ

As noted above, the protagonist is essentially consistent in nature throughout the analysis, but there has been a broadening of the potential base of protagonists since the last moment: tramways and plateways were predominantly in-house mining logistics systems, and thus catered closely to the parameters that the miners, their owners and operators, most desired to exceed. Railways, however—even those originally intended for moving coal or other minerals—soon came to offer transportation for pretty much anything.

That said, most early freight types weren't particularly demanding, as they tended to be bulk commodities: a container that didn't spill its contents or slip the rails, as part of a train that made its published schedules, would perform just as well for limestone, slate or grain as it would for coal. Given that freight practices are predominantly performed by proxies, the protagonist has little reason to care about the internal constitution of the assemblage, as they never encounter it directly; they care only about the parameters of the service they are buying, particularly capacity and speed and cost. Therefore the protagonist of a freight performance has little or no influence on locomotive design, except inasmuch as their desires for greater capacity or lower costs might be mediated by the railway companies and channeled into engine improvements.

This stands in contrast to the previous moment, where there is an unbroken and unmediated line of influence between protagonist, interface and infrastructure: the colliery owner could intervene at any point in the tramway assemblage so as to assert their preferences. In this moment, however, the protagonist can take either the service as offered or leave it; only a serious bulk operator, or a collective thereof, would have a chance of dictating technical terms to a railway (and history indicates clearly that most such operators, rather wisely, tended to defer to the expertise of engineers on such matters).

Note also that in Sheffield during this period, there is little or no direct competition between different railways—not least because it had already become apparent that a railway was what economists refer to as a *natural monopoly*, in that there was little logic in two lines competing to cover the same route. If you wanted to ship goods west across the Pennines, you sent them on the Manchester, Sheffield and Lincolnshire Railway, or perhaps on a service using lines shared with or owned outright by the Lancashire & Yorkshire Railway; if you wanted to send northwards, eastwards to the coast, or to the southern counties, those goods would more likely depart on the Midland Railway, heading first north-east up the Don valley on what was previously the Sheffield & Rotherham Railway's line between Sheffield and Rotherham, and then onward via other networks. There is a choice of service providers, in other words, but one's choice is almost exclusively informed by the origin and destination of the goods one wishes to ship.

DP

While the railways may not have been in operational competition with each other, they were very much in competition with the roads and the waterways—particularly with the latter, in the case of Sheffield, given the regional bias toward coal. As discussed above, the railways had no need to compete or otherwise accommodate protagonist desires with regard to rolling stock, because the freight protagonist's desires are not particular in that regard, and furthermore had been largely pre-established by the emergence of de facto regional technical standards regarding, say, truck capacity or axle length.

That means the railways were obliged to compete to offer a more appealing freight service by comparison to that of the road or waterway carriers. The road carriers had the advantage of being able to expedite point-to-point routings, while a railway could only carry goods to other locations with a railway station—and despite the vast capacity advantage of rail over road, the waterways were still way out in front on that particular parameter. The railways had two main advantages, however, besides their undeniable (and influential) aura of excitement and modernity. The first of these is the earliest rail transport moved at what were even then utterly unprecedented speeds, and thus opened up rapidity of supply as a parameter on which businesses might begin to compete. But the second, and perhaps the most important, was their vast reserves of investment cash, and their unrestrained ability to undercut the regulated and publicly-posted rates for road and waterway carriage, effectively making a loss on countless shipments in order to capture as much traffic from other systems as possible—a strategy that survives to the present day, in the form of the "disruptive" taxi alternative known as Uber.

So while the development of such service add-ons as last-mile linkages (i.e. horse-drawn vehicles moving goods between origin and railhead, and/or between railhead and final destination) would have surely sweetened the deal, the most crucial DP influence over the protagonist was that of price: by ruthlessly driving down the cost-to-protagonist of the service within which the rail assemblage is bundled up, the railways attracted even those protagonists who were heretofore perfectly satisfied with the services they'd been getting from other systems, the waterways in particular. After all, if slow but cheap transport is good, faster transport at an even lower price is a deal that's hard to refuse.

I&I

Here we encounter what is perhaps the most important distinction between the railways and the other two transportation systems with which this project is concerned. In the case of both the roads and the waterways, there is a significant organisational separation between the interface and infrastructure layers: with the former, the roads are open to all comers, but each operator is obliged to provide their own vehicles; with the latter, waterway access is parcelled out by the controlling company to a community of contractors and carriers specialising in such operations. But in the case of the railways, following the precedent set by the colliery tramways from which they evolved, ownership of—and hence control over—both the infrastructure and the vehicles to be used on said infrastructure is the norm. Or, to put it another way: the organisation in control of the rolling stock does not have an agonistic relationship with the organisation in charge of the permanent way itself, because they are the same organisation. If they want a certain type of truck, they can insist that the permanent way (which they own) must accommodate it.

As such, the I&I influence at this point doesn't have to "push" at the infrastructure layer, because it's in the railway company's best interests that the relationship between the two layers be as accommodative of one another as possible, albeit within the constraints of the engineering of the time. Furthermore, as already discussed, the late arrival of the railways in Sheffield meant that the centres of technical innovation had already been established elsewhere (e.g Derby, home of the Midland Railway), and *de facto* standards thus embedded—all of which is to say that while the freight rail assemblage is a direct evolution of the earlier tramways, railways in the Sheffield region were effectively built using standard and established designs already in use elsewhere, transplanted wholesale. Or, to put it another way: rather than imagining Sheffield's tramways to have expanded outwards and grown together organically into a region network, it makes more sense to imagine instead a set of isolated systems being deliberately swallowed up and subsumed by a new, larger network which shared many of the same basic physical parameters.

The point being that, as with the tramways, the lower dyad of the trialectic becomes a sort of virtuous circle: with no significant oppositional entities in play, there's nothing other than the limits of contemporary technology (and the company engineering budget) to prevent the relationship between the two layers being as accommodative of one another as possible. That means there's a sense in which both I&I and S&R aren't *influences* in this moment, so much as they are are *mutually constituted and complementary flows of desire* occurring almost entirely within the organisation of the railway company.

S&R

And so, just as if the organisation decided it wanted a certain sort of truck, they could insist that the permanent way accommodate that design, then if the same organisation made a decision about the constitution of the permanent way, they could insist that all trucks conform to that standard. (In practice, both points would be moot, as explained above: with the railways, interface and infrastructure tend to come as a single package, co-developed in parallel—a sort of preassembled assemblage, if you will.)

The downside of this lack of agonism between infrastructure and interface is inflexibility. Through their mutual accommodations of one another, the closeness of the layers makes it harder for any alternative configurations to break through, forming a sort of path-dependency or technological lock-in: when standards are both very tightly defined (as the physical standards of railways were, by necessity of engineering) and rigidly obeyed, there is little possibility of organisational or technical flexibility. This rigidity is a clear advantage in this particular moment, as evidenced by the incredible success of the rail assemblage in spreading across the country. Rigidity of standards meant not having to worry: the assemblage had demonstrated its stability, and could simply be re-applied (with some minor adjustments) to a new spatial context. But it would become problematic further down the timeline, as shall be shown.*

Regulatory regimes are effectively twofold by this point, including as they do both the railway company's own rules and regulations of operation, and the first hints of regulatory pressure from the state in the form of the Railway and Canal Traffic Act 1854. However, both of these regulatory pressures were still very light at this point, and much of the external demand for regulation was principally informed by the growth in passenger numbers (and the regrettable but inevitable concomitant increase in the deaths and injuries thereof); as such, it had little impact on freight operations, except in the more general sense that improvements in signalling and safer shunting practices would have resulted in less disruption to freight services overall.

But as mentioned above, the most important aspect of railway regulation in this period is the absence of regulated fares: they were already considered common carriers in the eyes of the law by this point, but the aforementioned Act of 1854 placed further obligations upon the railways in recognition of their status as *de facto* monopolies, and subjected them to the full regulatory requirements of common carriers: they must take any shipment offered to them, and they must "set and publish the same levels of fares to all in respect of any particular service".

Sadly, setting a law was easier than enforcing it, and the courts were unwilling

*It bears noting that there was in fact a competing standard for both the permanent way and rolling stock in the form of the Great Western Railway, for which Isambard Kingdom Brunel had insisted upon his favoured broad gauge. However, Brunel did so under the assumption that railways would never link up into a national network—a surprising failure of systemic thought from one of the great network builders—and would thus never need to be technically compatible. Events rapidly proved him wrong, but Brunel stubbornly clung on to broad gauge in spite of the growing expense of inter-network linkages and line-sharing deals between the two incompatible standards, and in defiance of assorted acts of parliament in the 1850s which enshrined the regular 4′ 8″ gauge (as established by Stephenson at Stockton) as the national standard; the GWR's final broad-gauge service ran in 1892. (S. Bradley, 2015, p264-267) or unable to get a handle on the railway companies, which by this point were expanding ruthlessly into other peripheral sectors and businesses, and had become very accustomed to the *laissez faire* approach to business that prevailed at the time; it would take a Royal Commission in 1865 and an 1873 Act of Parliament before the Court of the Railway & Canal Commission was created, and order begun to be more successfully imposed. But these ineffective regulations helped establish a pattern of Byzantine complexity in rail company tariffs, whereby they published hundreds and then thousands of fares, each of which would apply to a particular combination of route, load and train constitution—meaning they not only continued to undercut other services quite blatantly, but also began to make their service offer increasingly confusing and complex, which would cause problems later on. Indeed, this could be seen as a precedent for contemporary infrastructural "splintering" (Graham & Marvin, 2001).

7.2.3 Articulations

The articulatory mapping for this moment is shown in figure 7.3 on page 173.

Incumbents: Mining concerns; Railway engineers community-of-practice

The continued dominance of coal traffic in the region ensures that the mining concerns retain their strong influence over the railway assemblage, though it is obviously diminished in comparison with that held over the tramways, which they owned outright.

Likewise the figure of the railway engineer retains an important and highly visible role in the articulation of the assemblage, given their huge influence over the technical parameters of the systems they built and maintained. However, as with the civil engineers who rose to prominence and influence due to their involvement with the early turnpiking projects (and their requisite parliamentary interrogations), engineers are already losing some of that man-of-the-moment glow, increasingly absorbed into the organisations for which they work, which in turn are increasingly identified with the businessmen and financiers who manage them rather than the engineers who build them.

Railway company

It is presumed that the inclusion and placement of the railway company in the assemblage should require no justification. Much like the canal or waterway companies mapped previously, it acts as a central organisational spine, though its

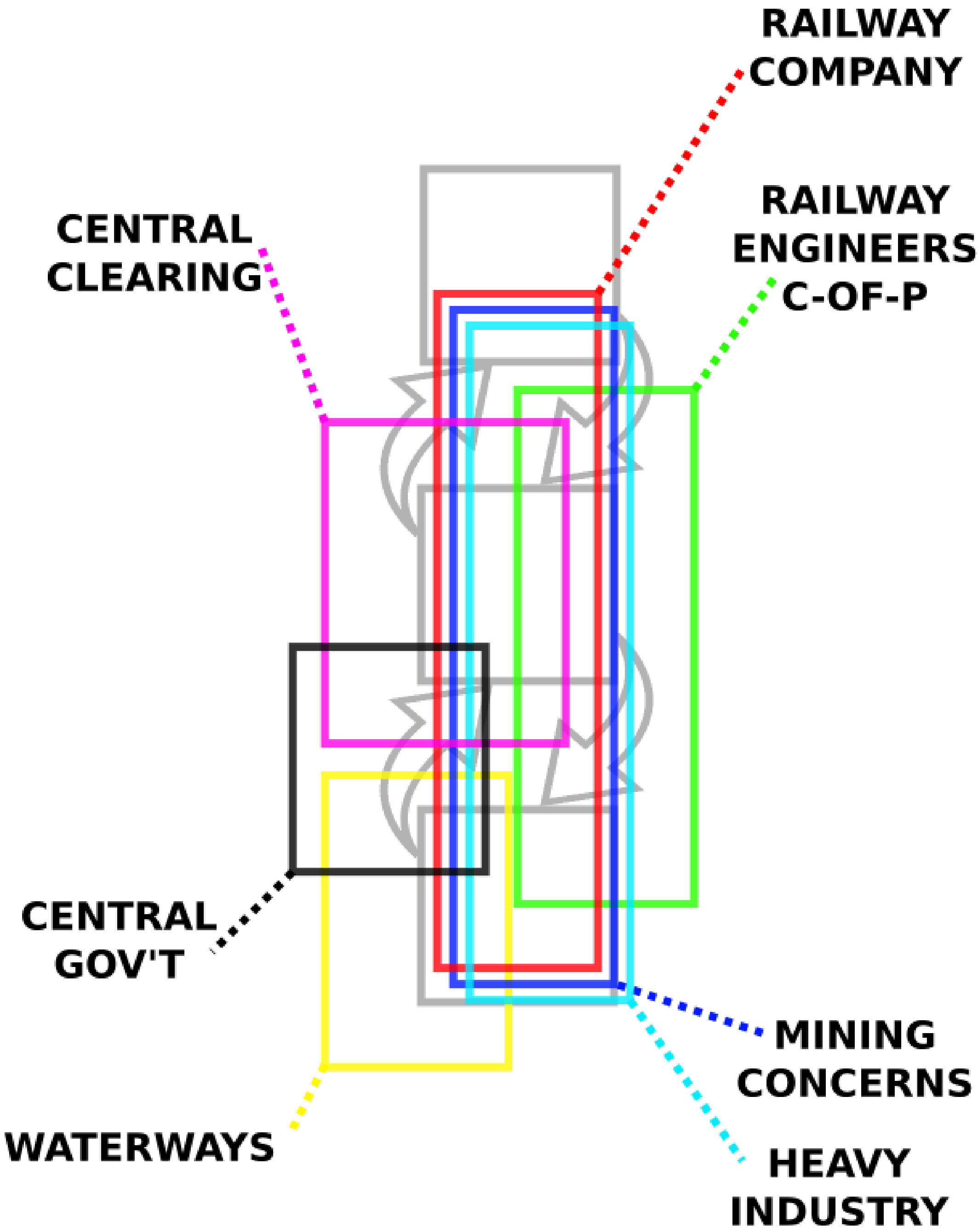

Figure 7.3: Articulated trialectic model for section 7.2 (Expansion)

greater breadth indicates the greater extent of its control over the interface layer, as shall be discussed below.

Heavy industry

By the mid 19th century railways were carrying all sorts of cargo, but traffic in the Sheffield region was always dominated by coal and metal products. As such, the "heavy industry" entity bundles up the influence of this sector as being allied with, but nonetheless distinct from, that of the mining concerns.

Other Railcos / Central Clearing

By merit of their competing within distant manifestations of the same network, all other railway companies would be implicitly involved in any assemblage featuring one particular railway company; there is, in other words, a sort of community-of-practice of railway companies, and during this period it was a lively and fractious one.

But there was also an explicit functional interlinking of the railway companies in the form of what came to be known as Central Clearing, an organisation initially established in 1842 by George Hudson, the nigh-legendary baron of the London & Birmingham Railway, for the purpose of calculating and distributing the appropriate portions of fares and tariffs charged on any given shipment to the operators of the lines on which that shipment travelled. Its remit soon expanded to the provision of universal network-wide ticketing systems, and—perhaps most importantly, in the context of freight—the recirculation of a large shared pool of basic freight wagons, which might be rotated into the operational stock of any given participating railway on any given day, depending on where they were next needed. By the mid 1850s the majority of the significant railways had joined the scheme, but it bears noting that the freight-intensive railways of the north east and east Midlands—including those serving the Sheffield region—were the earliest and most enthusiastic joiners, which implies that they had the greatest need for these interconnective facilities. This compares interestingly with the phenomenon of "back-carriage" in the era of turnpiking, when empty vehicles were incentivised through low or suspended tolls to carry essential commodities on journeys which would otherwise have been made empty: Central Clearing therefore represents the very early emergence of systemic logistical thinking among railway operators, and also presages the centralisations which were to come.

Central government

The building of railways, like most other infrastructures, was meant to require Acts of Parliament, but as the railway boom built up a head of steam (and a reservoir of investment cash), railway companies began to embrace the *laissez faire* spirit of the age by indulging in speculative projects, wherein construction might begin before Bills had been posted or permissions from landlords sought. For example, the short-lived South Yorkshire Railway became notorious for such guerilla expansion, and at one point in the late 1800s decided to run a new line underneath that of the Midland Railway by using an existing underbridge; understandably peeved, the Midland simply ripped the rails up, only for the South Yorkshire to replace them, and then the Midland to rip them up a second time, by which point the South Yorkshire had managed to prove its right of way without recourse to an Act (Chapman, 2013, p13).

The point being: central government is certainly involved in the railway assemblage at this point, but in a very hands-off and distant way, with its most significant non-regulatory intervention of the period being its ban on railway investment schemes, which finally brought the torrent of new railways to an end in the late 1840s.

Waterways

As suggested previously, there is a significant extent to which all other freight assemblages are implicitly present in whichever assemblage with which one is concerned; this is due in no small part to the inescapable fact that all three assemblages are transport assemblages, and therefore to some extent functionally interchangable and interconnected.

But the waterways deserve an explicit position in the rail assemblage of this moment, because they were so closely entwined with the same mining interests who are now enthusiastically dealing with the railways, and because waterways (as has been shown) were often treated as pawns, proxies and cat's-paws in the railway company's game of securing land rights and flows of traffic. The directness of this influence, and the extent to which a well-placed railway could render a canal utterly redundant, can be seen in the closure of the Greasborough Canal, a coal-specific branch of the Don Navigation, almost immediately subsequent to the opening of the Sheffield & Rotherham Railway.

7.3 Consolidation: the Big Four (1920—1930)

Various individuals had been arguing in favour of nationalising the railways almost from their very inception, but it took the first world war, during which the railways were in effect commandeered by central government and managed centrally as part of the war effort, to demonstrate the sort of logistical advantages of a unified system devoid of wasteful internal competition. It was further recognised that an overhaul of the network—which had been needful before the war, but became a clear necessity in its aftermath—could never be achieved by chivvying and wrangling the manifold private-sector railway companies, many of whom had been making heavy losses on freight for decades, into investing money they simply didn't have to spare. The government and the railway companies alike both balked at the thought of full-on nationalisation, however, and so instead the Railways Act of 1921 sidled somewhat in that direction, forcing a series of amalgamations that resulted in the formation of four large organisations with a particular regional remit, all of which were anchored to one or more of the great London termini.

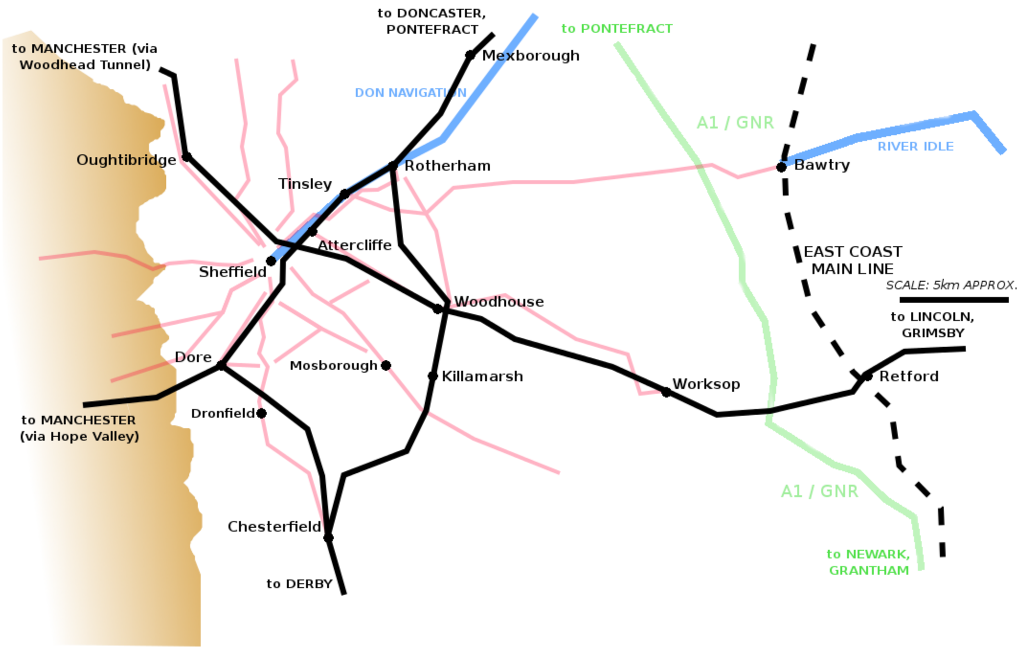

Figure 7.4: Railways in the Sheffield region, 1850—1860

During this period, the railways in the Sheffield region were predominantly under the aegis of the London, Midland & Scotland Railway, but because of Sheffield's liminal position on the eastern edge of this, the largest and most ungainly (but at the same time most successful) of the Big Four subnetworks, traffic in, through and around the area was also of interest to the London & North Eastern Railway, resulting in a fair amount of line-sharing. It bears mentioning that of all the pre-consolidation companies, the Midland Railway—the railway company with the greatest influence over the assemblage in the Sheffield region, and the one around which the newly consolidated London, Midland & Scotland Railway would be based—had been a consistent innovator with regard to both interface technologies and service design (they pioneered the third class carriage, to the ridicule of their competitors), and—more remarkably still—had never failed to turn an operational profit. As shown in Figure 7.4 on page 176 (and discussed in section 6.5), they had also by the late 1870s bought up much of the rights to the riverside land in the Sheaf valley, the acquisition of which property—combined with improved surveying and constructions techniques, and improved engines—allowed them to finally run a line into Sheffield from Chesterfield to the south, which is now part of the Midland Main Line, controlled by the London, Midland & Scotland Railway; the East Coast Main Line, previously the dominant north/-south rail route in the region, is the spine of the London & North Eastern Railway's network. Meanwhile, the Hope Valley line between Dore and Manchester—now the route of the optimistically named Trans-Pennine Express service, and shown in the middle right-hand side of figure 7.4—was opened around 1890 as part of the Midland Railway's network, and was thus accessioned into the London, Midland & Scotland Railway in the course of consolidation.

The fate of the Lancashire & Yorkshire Railway was rather different. Given the reorientation of the national network into what was essentially a star formation centred on London, the original and organic remit of the Lancashire & Yorkshire Railway—a uniquely east/west oriented railway system that recapitulated and strengthened the traditional pre-industrial flows of traffic across the north of England—was hard to accommodate; the new overarching mission of the company was implicitly counter to this older duty. It, too, was largely subsumed into the London, Midland & Scotland Railway—but in the process became something of an annexe to the core of the business, which became ever more oriented around flows of traffic to and from the capital (north/south), as opposed to the historically established flows between the northern regions (east/west), to which Sheffield had always been connected, albeit in a somewhat liminal or marginal fashion.

7.3.1 Elements

Protagonist

As always, the protagonist is essentially stable, and still fairly diverse in terms of the types of goods being offered up for shipment by train.

Interfaces

As before, the railway assemblage for freight practices is encountered primarily as a service: for the more casual client, one simply gave over one's goods for shipment, and gave little or no thought to the technical details of its carriage, beyond supplying a destination address, and perhaps opting for a faster (and hence more expensive) service; the routing of the shipment, as well as the operation of the network on which that routing occurs, is entirely within the remit of the railway companies. Protagonist organisations with sufficient influence or money, meanwhile, could negotiate new services with the railways, up to and including the provision of private sidings and rolling stock; the railways were fairly unified by their enthusiastic accommodation of client needs in the name of capturing flows of traffic, regardless of profitability,

And also as before, while passenger comfort and safety encouraged a continuing evolution of carriages and engines—the era of the Big Four was the apogee of the charismatic locomotive, with household name engines competing for speed records and aesthetic impact alike—freight trucks still hadn't moved much beyond a rather protean form: loose-coupled boxes, with independent braking if they had any braking at all. In short, from the protagonist's perspective, few if any aspects of the service have changed in the last half-century, with the exception of a growing proliferation of highly specific tariffs, and a far denser national network of destination stations.

Infrastructure

In the Sheffield region during this period, the railway infrastructure was almost exclusively oriented around a secondary infrastructure which provided coal as its fuel, as it had been for decades; decisions made during the process of consolidation were to effectively double down on this cheap (and, in the east midlands particularly, readily available) source of motive power.

However, both diesel and electric alternatives were being developed at this time, particularly in Europe, and some experimentation with both forms of locomotion had already taken place in Britain. Indeed, the Midland railway had plans for the electrification of what would become known as the Woodhead line prior to consolidation, and began the infrastructural work between the two world wars, though those plans would not be fully realised until after nationalisation (as shall be shown).

7.3.2 Influences

HKJ

In addition to noting the usual continuity regarding HKJ influences over time, it bears pointing out how limited was the protagonist's scope for hacking or kludging a better performance out of the railway assemblage. As described above, the railways established themselves by giving bulk commodity-producing entities exactly what they wanted: having evolved from the internal logistical systems of such businesses, fulfilling their (admittedly simple) desires was absolutely fundamental to the design protocols of the railways. By so doing, the railways effectively captured and enabled entire industries, which in turn grew to a scale which would be impossible to sustain in the absence of railways for carrying their goods: they were totally functionally dependent on the rail assemblage, in other words.

That's not to suggest that freight clients never tried to pull the operational wool over railway eyes: rare would be the successful industry which never tried biting the hand that feeds it. But the point is that there's no point of leverage, no room for the sort of maneuvering that might wring a slightly improved performance out of the existing system: one might conceivably have tried overloading one's freight trucks, or passing off one expensive-to-ship commodity as something to which a lower tariff applied, but the effort and risk would have outweighed any likely gains. And if hacking or kludging a railway is difficult, then *jugaad*ing one is effectively impossible: negotiation is the only game in town.

DP

That's not to say that the interface layer was incapable of responding to protagonist desires, however; if anything, its willingness to accommodate was perhaps too enthusiastic.

As mentioned above, the railways had responded to early, slipshod attempts to regulate their tariffs by producing an ever-growing list of fares, each specific to a particular type of load on a particular composition of train over a particular route. Many of these fares were in effect cooked up as an agreement between the railway company and a business with particular needs: years of ruthless competition had produced a culture wherein the early capture of traffic flows was a top priority, and this reached its inevitable full expression in the form of railways offering what were in effect private lines and sidings to new industrial start-ups, complete with a sweetheart tariff that, as likely as not, would barely cover the costs of running the service, let alone that of the building the extra infrastructure.

In the Sheffield region, this willingness to accommodate extended still further, as exemplified by highly specialised service offers tailored to the heavy industries which now populated the Don Valley. One such practice, known to railway workers as "hotdogging", involved moving massive ingots of metal, still hot and in the process of being worked upon, between different factories and forges by rail. Hotdogging was sufficiently commonplace that in the 1930s the LMS had an established standard set of procedures for hot ingots up to 80 tons in weight (anything larger needed special permissions), and for transfer routes between works that were more frequently used than others (Chapman, 2013, p37). There had thus grown up in the preceding decades a set of local lines known as the Sheffield District line, largely focussed on these hyperlocal movements of freight. The majority of these lines, and the sidings and secondary infrastructures which supported them, were found within or around the triangle of major lines connecting Sheffield, Rotherham, and Woodhouse; see figure 7.4.

So while there was little opportunity for protagonists to hack an improved performance out of the assemblage, there was also little need to do so: for the most part, the design of the service could be–and was—stretched so as to fit even the most extreme requirements.

I&I

In addition to the consolidation of the Big Four, the Railways Act also brought much needed investment, aimed at replacing exhausted and highly variable rolling stock (including hundreds of different engine types) with a new, narrower range of engines, coaches and trucks. However, while the consolidation that resulted from the Act stands as a clear (and indeed very deliberate) *social* reordering of the railway assemblage, it also stands, with the benefit of hindsight, as a missed opportunity for technological change.

European railway builders were already embracing the opportunities of diesel and electric locomotion in their new networks, but while isolated examples of such alternative technologies could be found scattered around the UK network in the interwar years, the Act did nothing to push for the transition away from coal and steam. The Southern Railway, smaller and more nimble than its northern cousins, was unique in that it already made the bulk of its receipts from passenger traffic rather than freight, and it pushed rapidly and successfully for electrification; by the outbreak of the second world war, it had all but eliminated steam from its networks.

The northern networks, particularly those whose predecessors had effectively evolved as an extension of the coal industry, largely stuck with steam, and for obvious reasons: for starters, British coal was plentiful, cheap and (most importantly) already moving all around their networks, while oil-derived fuels were still scarce and heavily taxed, and effective electricity generation still in its infancy.

But path dependence or "technological lock-in" also plays an important role, as do straitened circumstances: by sticking with steam, the railway companies could avoid the staggering costs (financial and temporal) of replacing the secondary infrastructure of coal with diesel or electric systems. Given that freight protagonists, with their limited exposure to the constitution of the assemblage, would have had no reason to advocate for such a change; and given further that their desires were being effectively met by changes to the design of the service, there is therefore no mediation of HKJ influences through the interface layer which might produce I&I influences. In the short term, at least, it was in the interest of no significant entity in the Sheffield region rail assemblage (other than the Midland Railway itself, and even then perhaps only certain parts of that organisation) for there to be any pressure for change exerted on the infrastructure layer by diesel and electric technologies. And even the Midland's own enthusiasm for new technology would have been dampened by its straitened financial circumstances in the wake of the first world war; it's hard to rebuild and be a pioneer at the same time.

S&R

As a result of investment after the decision to stick with steam, there was an overhaul and enhancement (and a simultaneous simplification) of the physical standards of the railway—but only to the limited extent that was possible within the affordances of a steam-based system. The era of the Big Four is fondly remembered by railway enthusiasts precisely because its engines and rolling stock represented the absolute pinnacle of steam technology; the flip-side of that status is that it also represents the point at which there is no operational headroom left in the steam paradigm, after which further improvements are impossible without a simultaneous (and extremely costly) upgrade of the secondary infrastructure to accommodate new sources of propulsive energy. As there is little change in the physical constitution of the permanent way, its influence over the interface layer is likewise all but unchanged. The accommodative dialectic between the layers, which was established in the earliest incarnation of the railways, has by this point thoroughly ossified: there has been so little substantive change for so long that things have become firmly locked in place, in a manner analogous to a joint seizing up after not having been moved for a while.

That this locking-up of the assemblage was not technologically determined is shown by the counter-example of the Southern Railway's successful electrification project: the steam deadlock *could* have been escaped, had the required resources and political will been applied to the problem. And the claim of absent resources deserves reconsideration in the context of the Big Four's enthusiastic diversification into other assemblages, which saw them buying up local and regional bus companies, overland carrier firms and even early air carriers: much of this can be seen as an attempt to address the railway's "last mile" problem (by making it easier to get people and goods to and from the nearest railhead), but it also suggests that the tendency toward monopolisation demonstrated in networked systems, when restricted or regulated within one particular assemblage, may simply spill over into another assemblage to which it is functionally connected.

For while the consolidation Act made little change to the railway's physical standards, it tightened up the regulatory regime significantly, boosting the power of the Railway & Canal Commission, establishing the Railway Rates Tribunal, and—perhaps most significantly—setting out the rights of railway employees, who to this date (and, in truth, for many years subsequent to it) were the most frequent victims of procedural mishaps and dangerous practices on the rails. However, although these changes undoubtedly affected the manner in which freight was handled on the railways, their effects would have gone largely unnoticed by the protagonist of a freight performance, as they would be mitigated by behind-the-scenes adjustments to the design of the service being offered to them.

7.3.3 Articulations

The articulatory mapping for this moment is shown in figure 7.5 on page 183.

Incumbents:

Railway company

The inclusion of the railway company should, again, require no justification. Note, however, its increased overlap with Central Clearing, which represents the tightening of operational relations between the consolidated companies.

Consider also the change implicit within the Railco entity during this moment. As described above, the London, Midland & Scotland Railway is in no small part an amalgamation of the Midland railway and the Lancashire & Yorkshire Railway; the former had a traditional bias toward north/south flows of traffic, while

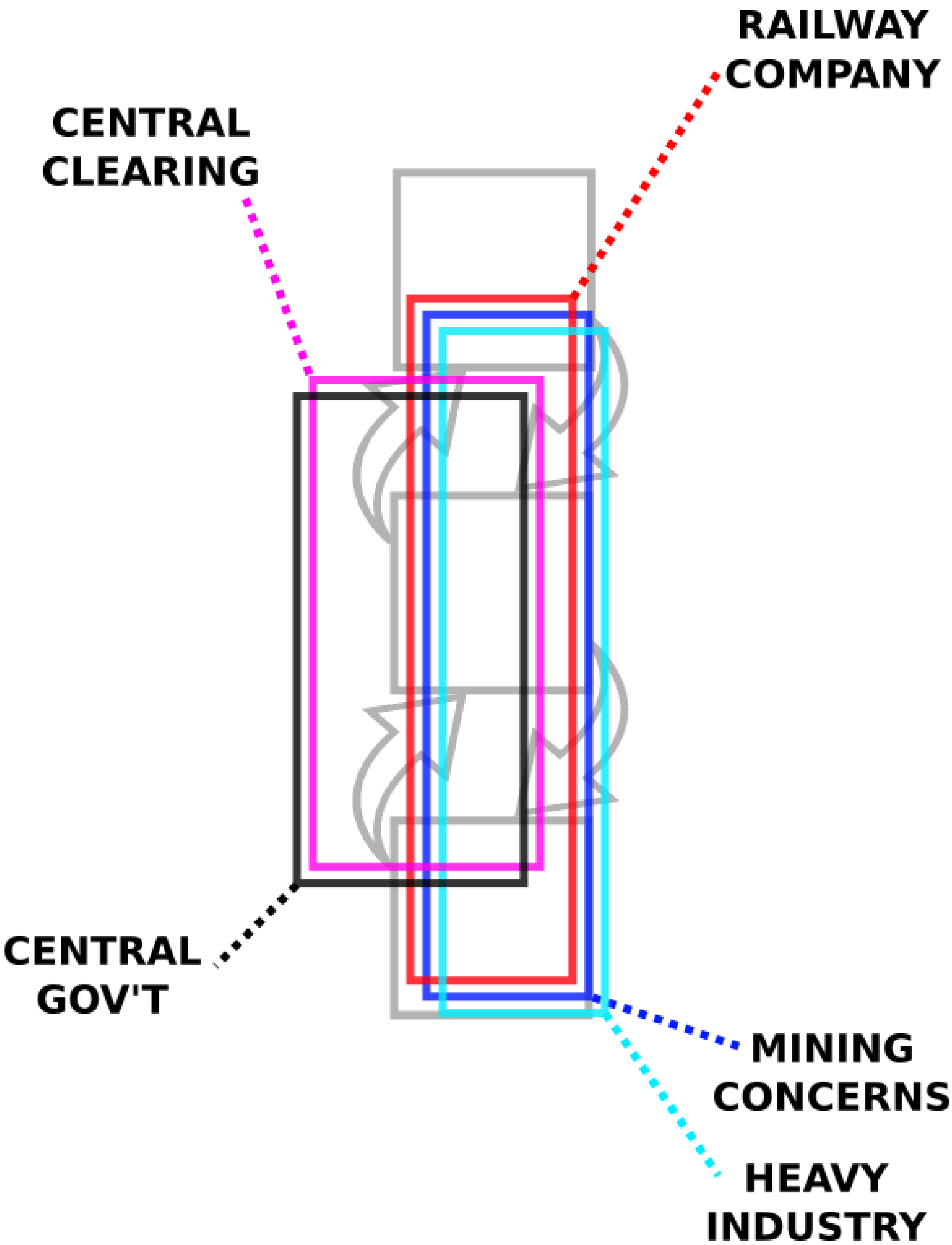

Figure 7.5: Articulated trialectic model for section 7.3 (Consolidation)

the latter had a traditional bias toward east/west. But it was the character of the Midland that prevailed in the newly consolidated organisation, and thus also the biases and priorities of the Midland that prevailed when it came to running this new, far larger network—and the results of this shattering of organisational experience and operational bias would manifest as the slow decline and neglect of east/west traffic in the north of England, in favour of ever greater flows of traffic to and from London.

So while the position of the Railco entity within the assemblage has not changed significantly, that entity's perception of what represents best function for the network under its remit has changed considerably, even though on the most simple quantitative levels it has not changed at all. Which is to say that what seems at first blush to be an organisational continuity is, in some respects, a profound organisational disjunction when considered over the long term.

Mining Concerns; Heavy Industry

The railway's biggest freight customers are still very much in the frame and, what with post-war reconstruction and the first stirrings of nationalisation, increasingly influential; if anything, the role of railways in supporting heavy industry was made more explicit than ever before.

Central Gov't

Central government looms far more largely than before, as is appropriate in this early moment of state intervention. Note its almost complete enclosure of Central Clearing (which, among other functions, served as a convenient point of leverage for regulation), and its increasing overlap with the interface layer; the latter reflects the increasing reach of external regulation over not only operating procedures (i.e. how the railways are run) but service design (i.e. terms and tariffs for shipments).

Central Clearing

The Clearing House is still a very important entity during this period in terms of supporting the nationwide network function—perhaps more important than ever before, given the consolidation down to four companies from well over a hundred, in that the shared rules and practices for which Central Clearing stands as a synecdoche would serve to draw these organisations tighter together; fewer players means fewer opportunities for factions and rivalries, which in turn means fewer opportunities for (or reasons to) differentiate.

Outgoing: Waterways

The waterways have by this point slipped out of the assemblage entirely, even as an external influence, because—in the Sheffield region, at least—they had been effectively written off as a lost cause by anyone with the influence and/or funding to consider their rehabilitation, as shown above.

Implicit: Roads

As the waterways go out, the roads come in—and not as a new host for railway parasitism, but as an implicit parasite of the railways. Note that, as has been explained, the road network was always in the position of supplying last mile connectivity for the railway network, but that provision was essentially non-competitive: in the early days of rail, the roads took over only where the rails couldn't go, and even then, moving anything bulky was a slow and expensive business. But now the arrival of the ICE and tarmacadam have drastically reconfigured the road assemblage in such a way as to make it a viable competitor with rail on capacity, speed and cost on all but the heaviest of bulk commodity flows; combined with the inherent upside of the road network, namely its density and its control over the last mile of a majority of routings, these present a clear threat to the freight-centric railways of the Sheffield region as they attempt to rebuild themselves, yet again, in the wake of war.

7.4 Modernisation: the axe before Beeching's (1965—1970)

The glory days of the Big Four were cut short by the second world war, during which time the railways were once again requisitioned wholesale for the home-front war effort, and all but run into the ground in the process. The nationalisation that happened in the wake of the war was as much pragmatism as socialism: all the problems that had prompted the earlier consolidation had returned in spades, and rebuilding capacity was an absolute priority if the national industrial economy was to be successfully rebooted. It was clear by this point that diesel and electric options would necessarily play a part in this process of rebuilding, and British Rail, formed from the bones of the Big Four through the 1947 Transport Act, set out on a program of modernisation which culminated in 1968, when the last non-heritage steam service was retired.

The Sheffield region benefited from the London, Midland & Scotland Railway's brief pre-war flirtation with electrification, when after the war the Eastern Region division of British Rail dusted off its plan for electrifying what was by this point known as the Woodhead line (previously the Penistone line) across the Pennines to Manchester: the cramped Woodhead tunnel made steam locos particularly unpleasant to work with, and the steep grades up toward Woodhead were presenting a challenge to existing engines. The new line opened in stages between 1952 and 1955, with electrified services running between Manchester and Woodhouse (near Orgreave, approximately halfway between Sheffield and Rotherham), and was even backwards compatible: while steam was banned from the Woodhead tunnel, there was nothing to prevent steam locos using the line between Woodhead and Sheffield, which was still a very busy freight corridor thanks to the proliferation of heavy industries along the Upper Don Valley (which, the reader will recall, was never navigable, but which provided water and power in much the same manner as the Sheaf, as well as somewhere to dump one's unwanted industrial byproducts).

While British Rail arguably did sterling work in rebuilding the nation's shattered network, it was losing money at a rapid rate, and reported its first operating loss in 1955, the same year the electrified line to Manchester went into full operation. A succession of reorganisations and plans for modernisation followed, with a focus on further electrification of main lines (particularly in the Eastern region), continued dieselification, improved rolling stock for both passenger and freight service, improvements to signalling and to the constitution of the permanent way, modernised freight marshalling yards, and an unspecified number of line closures. The 1958 reorganisation saw the Sheffield District of British Rail's Eastern Region inherit responsibility for all infrastructure east of Woodhead and between Chesterfield to the south and Darfield to the north, which resulted in a lot of redundancy: multiple engine sheds, goods yards and control centres, within many of which the old traditions, loyalties and rivalries of the Big Four (and in some cases their predecessors) were maintained.

At the same time, the Sheffield district was reckoned to be the busiest stretch of freight railway in the nation, if not perhaps the entire world at the time, with a British Rail Board report claiming that 10% of national freight traffic originated there. According to Chapman (2013, p27), a 1963 working timetable for the district shows over 800 freight services running every 24 hours, of which "more than 240" were "local trip" movements between private sidings; these latter movements were identified as being inefficient, as were the numerous goods yards and sidings through which they would pass.

As a result, the Sheffield District got its own rail rationalisation plan in 1960, four years before Dr. Beeching would swing his infamous axe at regional passenger services. With regard to freight services, the important features were the consolidation of freight handling sites, with dozens of small goods yards across the region giving way to a sundries and transshipments terminal at Grimesthorpe, a terminal at what was once Rotherham Masborough for what would later become the Freightliner intermodal/containerised services, and a vast automated marshalling yard optimised for waggon-load freight at Tinsley, which Dr. Beeching opened with great ceremony in 1965.

7.4.1 Elements

Protagonist

The protagonist, as always, is essentially stable. However, it is worth recalling the particularity of freight protagonists in the Sheffield area in the light of previous moments, and noting the extent to which these predominantly heavy industries had effectively become completely dependent on the railways not only for bringing in raw materials and shipping out finished goods, but in some cases of moving around materials which are still in the process of being worked upon. To put it another way, while there was a clear distinction of organisation and ownership between British Rail and, for instance, a major steelmaking firm, the functional distinction is made very unclear by practices such as hotdogging (see section 7.3 above), which represent the extent to which the railways had become embedded within the industries they served, and how accustomed those industries must therefore have been to that level of accommodation of their desires.

Note further that this is not only an issue for the very biggest firms working with heavy commodities: the proliferation of private sidings and the flexibility of service that the railways had provided for decades meant they were also absolutely integral to the business of much smaller, specialist manufacturing firms, if not perhaps more so. So while the protagonist's desires are stable, they are also historically accustomed to being accommodated by this assemblage: the relationship between rail freight and heavy industry was hegemonic, in other words.

Interfaces

Freight rolling stock started to change quite rapidly during this period, even if one aspect of its mutation was in fact to return to a principle established on the tramways, namely that of what we now call containerisation. The rise of the intermodal container, more commonly referred to as the shipping container, was consolidated by the United States armed forces using it as the basis of the international logistics operation in support of the war in Vietnam, and the international ISO standards for containers were established soon after in the late 1960s.

However, the basic principle went back centuries, as shown above, and was already showing the potential to unlock the economies of scale necessary to support the expansion of Western consumerism; as with paved roads prior to the turnpike era, the untapped potential would have been obvious to anyone engaged in the business of logistics. British Rail's intermodal containerised service, dubbed Freightliner, began in 1968, but was initially oriented toward connections between ocean-going freight services.

There were some technical changes to freight trucks in this period which have some bearing on the way they were bundled into services. These technical changes are mostly to do with braking—more precisely, with braking simultaneously along the entire length of a train, or "continuous braking". Passenger rolling stock had mostly been switched over to continuous braking by the era of the Big Four (thanks in no small part to some horrific accidents and the subsequent safety campaigns), but freight stock—some of which still dated back to the days before the Big Four—was more poorly covered.

This was not simply laziness or cost-saving, but reflective of the freight services on offer, which can be simplified down to two basic types: unit-train, and waggon-load. A unit-train (or block-train) consists of trucks of the same type carrying the same commodity, all of which are going from the same origin to the same destination; a unit train therefore doesn't get fiddled with along its journey. Waggon-load freight, as the name implies, involves the protagonist buying the use of one or more single waggons for a particular commodity type, each of which may have a different origin and/or destination; a waggon-load train therefore needs to be broken down at each station along its route, in order that waggons for that destination are switched out, and waggons outbound from that destination are switched in. (Also available was part-waggon-load, wherein you booked an allocation of volume or mass on a truck devoted to small individual shipments, and those shipments would be loaded onto and off of those trucks by porters at the goods yard of each station.)

Infrastructure

As sketched above, upgrades in the Sheffield district led to a mixture of coal, diesel and electric secondary infrastructures, with coal fading away by the end of the 1960s. But as previously discussed, the choice of locomotive has a fairly limited impact on freight services; the relevant implication here is that of a considerable increase in the complexity of the system being managed, and the options available within that system.

The most important infrastructural shift is therefore the move toward centralised freight-handling sites. To reiterate, the Sheffield district was perhaps the busiest freight railway network in the world during this period, and had as such evolved a complex and wide-spread network of goods yards, depots and private sidings through which waggon-load and part-waggon-load freight would move. The district rationalisation plan aimed to address by devoting a location at Grimesthorpe to transshipment freight (i.e. the sorting and routing of discrete parcels and part-waggon-load freight), devoting another at the site of Rotherham Masborough to containerised freight (i.e. what would become the Freightliner intermodal service), and building a state-of-the-art marshalling yard at Tinsley, where the slow (and still dangerous) practice of manual shunting would be taken over by automated systems. Sheffield Victoria station would close in 1970, as the diminishing fortunes of the Woodhead line—and freight traffic more generally—were absorbed and compensated for with cutbacks and closures.

7.4.2 Influences

HKJ

As always, the HKJ influence is essentially stable. Note however that the the willingness of protagonists to push for improvements in the services provided by the rail assemblage has by this point diminished considerably, due to their newly accommodative relationship with the road assemblage (see section 5.5 above): not only were the roads significantly upgraded with the specific aim of capturing freight traffic, but the point-to-point flexibility and speed of road freight made it an appealing alternative for the sorts of businesses that were previously reliant on wagon-load and part-waggon-load freight services. Bulk producers and consumers in the region (the former still predominantly coal) were more likely to be running unit-trains, and thus less affected by changes in the interface layer—not least because, like the railways themselves, many of them were nationalised industries whose upkeep was considered utterly fundamental. In a sense, this is the last moment in which the alignment between industry and the rail assemblage remains close and accommodative, just as it was in the era of the tramways.

DP

The difference between unit-trains and waggon-load trains deserves a little more unpacking in order to understand how they influence the design of the services in which they were bundled up. Waggon-load freight trains were continually being broken down and reconstituted in shunting yards, while a unit train, as its name implies, worked as a single unbroken unit. As such, in order to apply continuous breaking over the whole length of a waggon-load train (in line with safety regulations which permitted trains thus equipped to go at faster speeds) it would be necessary for all waggons on that train to have compatible braking systems.

However, there were numerous variations of four basic types of braking in use, and one could never be sure quite what sort of truck the central clearing system might present you with at any given location; and even by the mid-1960s, a waggon-load train might well have few more than half of its total number of trucks fitted with any braking at all. In practice, trucks with better braking would then be clustered nearest to the locomotive, with the poorer or unbraked trucks to the rear, but putting a waggon-load train together therefore took experience, skill, and—perhaps most importantly—time.

As indicated by the construction and outfitting of the new marshalling yard at Tinsley, the Sheffield District Rail Rationalisation plan aimed to accommodate waggon-load freight services at sustained levels for many years to come: given that on the date Tinsley was opened, the Sheffield Division of the Eastern Region was generating more than 24 million tons of originating freight per year, much of it (~70%) from around 150 private sidings scattered around the network, and that a majority of said traffic not only had a local origin but also a local destination (Chapman, 2013, p27, p33), this decision was understandable—even though it would turn out to be fatal.

I&I

Perhaps the most significant invention or iteration in this particular moment is that of the intermodal shipping container, the early versions of which were already exerting an influence on global shipping practices—but it is telling that this invention exerts its pressure from entirely outside the railway assemblage, by way of the rail assemblage's connections to international shipping via British port connections, rather than from within. Much as the collieries of the 1700s had understood the potential in standardising their trucks for transfer onto the waterways, containerisation offered an obvious path for scaling freight services over long distances, and thus exerted an influence upon the infrastructural layer in the form of trucks with a wheel-base sufficiently long to accept standard container sizes.

Otherwise, little has changed since the previous moment: the same old mismatched trucks were being formed into waggon-load trains (or into short blocks to be dispatched on hyperlocal "trips" between private sidings), and the expectation that such traffic would continue at mid-1960s levels provided the push for improved facilities for waggon-load freight.

S&R

The response to that push is best represented by Tinsley marshalling yard, though with hindsight it seems an obvious error, particularly when paralleled by the simultaneous moves toward centralised logistics, unit-trains and containerisation: at a national level, rail freight began losing what would have been waggon-load traffic to the roads in the late 1950s, and have never significantly regained their modal share.

However, as mentioned above, Sheffield was still producing a vast amount of waggon-load freight, much of it of local origin and destination; hence the decision to maintain waggon-load services, as made manifest by the construction of Tinsley marshalling yard. But at the same time, the district's network of goods yards and private sidings was rationalised down to a few major sites, which effectively made decades of procedural precedents and institutional knowledge redundant overnight: with fewer nooks and corners to be found the district network, and with increasing flows of larger freight trains and passenger services alike, practices which were highly accommodative of the industries which produced local freight traffic, such as "hotdogging" (see above) became increasingly untenable.

Furthermore, and despite the deployment of what was considerably cutting edge technology at the time, Tinsley was dogged by technological complexity and a savage maintenance schedule, and (perhaps most importantly) could not automatically handle trucks with a longer wheelbase, which therefore had to be hand-shunted—which was totally counter to the purpose for which the marshalling yard was intended, namely the automation of shunting and waggon-load train formation. These insufficient physical standards inevitably pushed longer wheelbase traffic and early container freight toward the freight depot at Rotherham Masborough, thus beginning a marginalisation of the Sheffield region in terms of the national network of bulk freight. And as a response to the 1968 Transport Act, the sundries division of the freight terminal was handed over to a new state-run haulage company, National Carriers Limited, which was strongly biased toward road vehicles. As such, small-consignment traffic "for depots outside of Sheffield, previously moved by rail to and from Sheffield, [were] conveyed direct by road motor vehicles based at the new terminal" (Chapman, 2013, p30), thus removing the rationale for sundries and part-waggon-load freight services on the rails, and in turn encouraging such customers to turn to the use of point-to-point road freight services instead. This, in combination with the increasingly unaccommodative nature of waggon-load services, began to push smaller industries off the railways and into the arms of the road carriers, while encouraging the proliferation of unit-trains which predominantly carried coal or steel.

Less well known was a fundamental change in the regulation of the railways, ushered in by the 1962 Transport Act: in exchange for the Treasury taking on the debts accrued by the operational losses of the 1950s and the failed modernisation plans of the 1960s, it was decided that British Rail was obliged to run the railways in such a manner that operating profits redeemed all running costs, and more specifically that each separate service should pay its own way, or at least show the potential to do so. Furthermore, the yoke of common carrier status was removed, effectively allowing British Rail to compete in the same marketplace (and on the same terms) as other private carriers, and redefining its primary duty as the quest for "efficiency, economy and safety of operation". Crucially, the suspension of common carrier status removed the obligation to accept any commission offered at published rates, which in turn permitted British Rail's gradual turn away first from sundries freight, and then from waggon-load freight.

7.4.3 Articulations

The articulatory mapping for this moment is shown in figure 7.6 on page 193.

Incumbents:

British Rail

Not strictly an incumbent, in much that the same way that the Big Four were not strictly an incumbent, but British Rail is the clear inheritor of the central controlling position at the heart of the rail assemblage. And much as with the consolidation, the result is a vast improvement in the possibilities for integration and modernisation of the entire national system, counterbalanced by a process of ossification wherein the earlier sources of new technical ideas for railways, namely the railway engineers community-of-practice, have been subsumed not just into the assemblage, but into the dominant entity of the assemblage.

To put it another way, there are no longer any significant outside influences for technological change who might disrupt or distort the vectors of influence with new ideas (or iterations of old ideas): this makes for a stable assemblage, certainly, but also creates the preconditions for a sort of sociotechnical myopia, in which new ideas are assessed only within the context of the organisation and its goals, rather than within the broader context in which the organisation is operating. In combination with the 1962 Transport Act's reorienting of British Rail's mission toward efficiency and profit rather than the provision of a service to the nation, this myopia ensured that, while the formation of a monolithic national monopoly rail company offered the possibility of solving the worst problems carried over

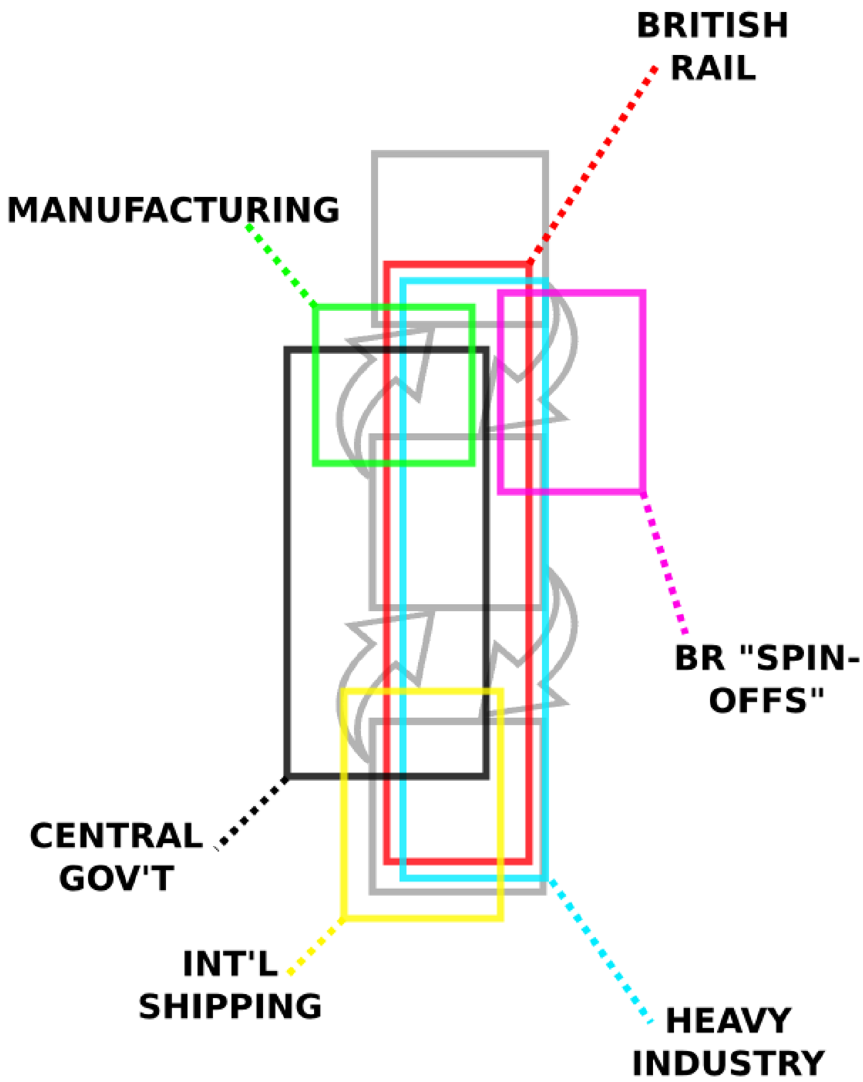

Figure 7.6: Articulated trialectic model for section 7.4 (Modernisation)

from the railroads of old, it could only even consider doing so if taking action would show a quick return on investment—a situation which, as history shows, would rarely pertain.

Mining Concerns & Heavy Industry (Nationalised)

In light of the post-war nationalisation projects, and in recognition of the closeness and scale of the coal and steel industries, these two entities have been merged for the sake of simplicity, and so as to highlight the growing schism between such heavy bulk industries and the smaller enterprises working around them.

Manufacturing

The scale of the industries comprising Britain's industrial base increased very rapidly through the late 1960s, so that while smaller industries also enjoyed a period of strong growth, they were gradually outstripped in terms of their ability to retool their logistics in order to take advantage of the new economies of scale being offered by British Rail's modernised freight service offering. At this point they are still being courted by British Rail, as indicated by the provision of Tinsley for waggon-load freight and the transshipments terminal for sundries and parcels—but at the same time, the centralisation of goods handling mandated by the District modernisation plan began to make trip runs and other special services even more inconvenient and inefficient than before. But much like their larger counterparts, these smaller businesses are nonetheless completely entangled with the railway assemblage: even the latest advances in road freight couldn't beat the co-evolved utility of private sidings and bespoke local railway trips.

Central Gov't; Roads

As a nationalised industry, British Rail is effectively an annexe of the British government by this point, thoroughly regulated with regard to both internal procedures and dealings with protagonists: hence the extensive reach of the governmental entity within the rail assemblage in this moment.

Incoming:

Unions

Nationalisation meant a huge strengthening of labour unions, which in turn meant that the unions could exert some considerable influence upon operational practices relating to the infrastructure layer: for instance, British Rail's keenness to move away from old-fashioned manual shunting (a practice which even in the 1960s could involve a lone shunter running alongside moving trucks in the yard, holding a long pole with which to nudge them at the appropriate moment) can be attributed at least in part to increased pressures from unions regarding worker safety. However, unions tend to resist technological change rather than agitate in favour of it, and as such the rise of the unions likely contributed to the ossification of the assemblage. Put simply, there is a huge reservoir of path-dependency in one's employees, and when empowered to influence the assemblage, they will therefore tend to influence it in favour of stasis rather than flux, because flux in large organisations tends to be accompanied by redundancies.

Due to the rather nebulous and plural nature of the unions entity, it is not mapped explicitly onto the articulation—put plainly, it's not found in one clear position. Instead, it should be thought of as being diffused throughout the spaces in the articulation where the state (in the form of central government) overlaps with industrial entities such as British Rail or nationalised mining concerns.

British Rail spinoff firms (e.g. NCL)

Embedded entirely within British Rail at this point are various logistics operations "spun off" from British Rail's main rail business; the exemplar in this case is NCL, the road-oriented courier firm given control of the Sheffield sundries and transshipments terminal. Note how NCL's closeness to the roads drags their influence closer to the heart of the rail assemblage: in effect, NCL represents a tacit admission by the railways that there were certain sorts of job that the railways were no longer best at, and indeed that they would no longer even attempt to compete on.

Ocean Shipping

The ocean shipping assemblage gets a marginal appearance in this assemblage, as the first stirrings of containerisation spread their influence via ports and ocean-going freight services. As mentioned above, intermodality was to a greater or lesser extent a feature of many freight assemblages prior to this date, but it would take the incredible top-down influence of global systems (and indeed global trade) to impose a new universal standard across the national network; here, that process is just beginning.

Outgoing: Central Clearing

Central Clearing didn't really disappear so much as it became a major organ within the greater entity of British Rail. The duties of the Clearing House were much reduced during the wars, and following consolidation and nationalisation, its membership roster had dropped to four companies and then just one, the British Transport Commission. Most of RCH's responsibilities were transferred over to BTC, and the RCH was formally dissolved in 1955 (although BTC continued performing most of the Railway Clearing House functions under the name Railway Clearing House, in yet another example of a seeming continuity which is anything but).

Implicit: Roads

It is now the turn of the railways to experience full-on intersystemic traffic parasitism, thanks to the role of the roads assemblage as an implicit articulatory entity in this moment. Recall that the government is during this period binding itself ever more closely into the roads assemblage, which since the early 1950s has been increasingly parasitic upon the railway's bread-and-butter metabolic flows—and that the government's choices of both grand strategy and personnel for the management of roads and railways alike do little to dispel accusations of deep-seated but carefully concealed favouritism toward the roads assemblage among politicians of the period, even if that may have been a simple matter of them gravitating toward that which they found easier to understand:

"The frequent interventions of government, notably in 1962 when the [British Transport] Commission was abolished by Ernest Marples, and after the Transport Act of 1968, when the [British Railways] Board was encouraged to function as a top-level planning body along the lines advocated by [management consultancy firm] McKinsey, were a response to a firm belief in Whitehall that railway managers were inbred, inward-looking, and resistant to change. This belief was contentious, though there was some truth to it; but in any case, organisational change could never address the deep-seated confusion about what the railways were meant to achieve in a mixed economy [...] The Board often displayed a siege mentality in an environment in which the motor car and the roads-building programme enjoyed clear priority, a situation barely disguised by civil servants amd a succession of transport ministers." (Gourvish & Anson, 2004, p2, p6)

What is indisputable, however, is that for both assemblages during this period, the British government had as much control over their configuration as it chose to exercise—and the exertion of that control was very much to the advantage of the roads assemblage.

7.5 Rationalisation: the containment of rail freight (1980—1991)

While rail freight traffic had been in national decline since the 1960s, the global economic slump of the 1970s served only to depress it still further. The Beeching report had recommended that only one cross-Pennine passenger connection be maintained, and that the connection in question should be the Woodhead line, but local opposition to the closure of the Hope Valley Line, combined with the advent of the huge coal-fueled Fiddler's Ferry power station in Cheshire, meant that the Woodhead line kept all the freight traffic, and all cross-Pennine passenger traffic went via the Hope Valley as of January 1970, at which point electric loco services between Sheffield and Woodhead were suspended, to be replaced with diesels. Not much more than a decade later, the precipitous decline of coal traffic saw the route effectively closed down, though the tracks between Penistone and Sheffield were retained so as to maintain some minimal local passenger and freight services.

Nonetheless, Sheffield district freight traffic was still holding, thanks to a minor local boom in the production for export to Europe of specialist stainless steels in the 1970s, as were more national flows of freight. However, the latter were increasingly routed right around the district, which as a result began to revert to being a backwater sub-network, rather than the important national freight node it had once been. At the same time, British Rail was developing the Speedlink service, which was to be a modernised successor to the old waggon-load services; Tinsley yard, already obsolete in many ways, was not to be a major node in the Speedlink service, and instead handled the remaining class 7 and 8 waggon-load freight trains comprised of older rolling stock. Speedlink's generous speeds and regularised timetables proved something of a success, and the service was well established by the early 1980s.

But the 1980s began with a drastic national recession, and featured the lengthy tenure of a government which was nakedly hostile toward the old heavy industries of the north, particularly coal, and furthermore to nationalised industries such as British Rail. At the same time, having established the more modern Speedlink service, British Rail moved to finally get rid of all the remaining loose-coupled and/or unbraked trucks and waggons in the system. Later still, in 1991, Speedlink would be rather suddenly closed, leaving only the intermodal Freightliner service, plus a few lingering specials to sustain what little remained of Sheffield's heavy industry after Thatcher's campaign came to an end.

7.5.1 Elements

Protagonist

The protagonist's desires, as before, remain essentially stable. Note however the growing schism of scale between national and international industries, and smaller local businesses: while their desires for improved performance are essentially the same, they express themselves differently depending on the volume of goods they are shipping, with the bulk operators willing and able to spend on consolidation and last-mile connectivity in order to reap the efficiencies of unit-trains, while smaller manufacturers remained utterly dependent upon services and practices that British Rail was keen to abolish.

Interfaces

After decades of minimal changes to freight rolling stock, the 1980s saw a sudden profusion of new truck and waggon types.

A lot of elderly rolling stock was still in play at the beginning of the decade, and in particular the classic 16-ton loose-coupled mineral waggon, the direct descendant of the tramway trucks of old. Tough to maintain, prone to derailment, mismatched or unfitted when it came to braking, and increasingly undersized in the context of both traffic flows and engine power, British Rail saw these vehicles as a hindrance to the modernisation of the service in keeping with the efficiency dictum of the 1962 Transport Act. However, they were also the vehicles around which the majority of waggon-load freight services were constructed, as shall be shown.

British Rail's 1970s like-for-like replacement for old waggon-load rolling stock and locomotion came bundled up in a new branded service called Speedlink: they designed a new diesel locomotive specifically for high-speed heavy freight, and accompanied it with new trucks and waggons (including a coal hopper optimised for rapid loading and unloading) which had a longer wheelbase than earlier rolling stock, and networked air-braking as standard—the idea being to optimise waggon-load shunting and marshalling by ensuring all waggons shared the same standards. Speedlink was also something of a revolution in rail freight service design: rather than providing bespoke routes and tariffs, Speedlink charged standardised rates and ran to a regularised timetable like that of a passenger service, thus offering a more reliable estimate of when goods might arrive at their destination.

Finally, the 1980s saw the rise of the Freightliner service. Established in 1968 in response to growing international interest in intermodal container shipping, Freightliner combined powerful locomotion with long flat trucks large enough to take a full-size standard shipping container. In effect, Freightliner attempted to compromise between the logisitical efficiency of the unit-train and the flexibility of the waggon-load approach, and dial it up to a scale which would match with the emerging infrastructure of global automated shipping.

Infrastructure

The railways of the 1980s were characterised by systemic underinvestment, with the Thatcher government doubling down on the decisions made in the days of Beeching and Marples and pivoting the British economy ever more closely toward road freight. The Sheffield district suffered particularly, not least due to the evisceration of the coal industry, which—as has been shown—was a crucial actor in the regional rail freight assemblage for two centuries.

The geographical placement of service-specific infrastructures bears further consideration, though.

Originally intended to automate (and thereby economise on) waggon-load shunting, Tinsley marshalling yard was sited centrally within the organisational context of the British Rail's Sheffield District. But as noted above, despite being hailed (fairly accurately) as Europe's most advanced marshalling yard when it opened in 1965, by the beginning of the 1980s it was already obsolete, struggling to handle the more modern rolling stock, and hence became what might be thought of as "the yard of last resort", where the grubby and dangerous old rolling stock was shunted into diminishing waggon-load trains of predominantly local origin and destination. Meanwhile, the parcels and transshipments freight terminal located at Grimesthorpe near Brightside (almost halfway betwixt Sheffield and Rotherham), which had already been turned over to the road-centric NCL (see above), burned down in 1984, never to be replaced: part-waggon-load and sundries traffic had diminished to such a point it that it was considered redundant.

Tinsley was also given an allocation of Speedlink rolling stock, particularly the special coal hoppers. But as noted above, the automatic systems couldn't handle the longer wheelbase truck of the Speedlink service, meaning they were shunted manually on their own subsection of the yard. Furthermore, Tinsley was never to be a major node on the Speedlink network; with the closure of the Woodhead line across the Pennines, the Sheffield district had become a freight backwater in which the main routes in and out were all to the north-east, and thus a poor site for a major node in the national service.

The same applied to the Freightliner service, whose closest terminal was at Rotherham Masborough. This meant that for a Sheffield based protagonist, accessing its economies of scale meant first getting one's goods to the depot—and as only Freightliner could handle full-sized containers, that meant last-mile connections and time-consuming transshipment work, all of which would erode the efficiencies to be gained by using Freightliner in the first place. In essence, then, we might say that the topology of the Sheffield district freight rail network had reverted from the hyperconnectivity of the late 19th century to the comparative isolation and limited outward connectivity that had prevailed in the earliest days of the railways: if you wanted to send stuff in bulk by rail in any direction, you'd probably have to send it north-eastwards toward Rotherham first.

7.5.2 Influences

HKJ

As noted above, there is a schism in the protagonist during this period, between big bulk-shipping businesses and smaller firms working with smaller quantities. The bulk shippers seek further marginal gains on economies of scale: if every truck goes a little bit faster and costs a little bit less, the savings soon start adding up when you're dispatching and/or receiving hundreds of them every week. And big firms have money to spend on lobbying, as well as on infrastructure of their own that might enhance efficiency further; as such, these large businesses were much better able to influence the assemblage into which they were connected.

But, as mentioned above, the smaller firms were effectively captive to the waggon-load services, with which they had co-evolved: these businesses depended on exactly the short local "trip" journeys and bespoke practices which the district rationalisation plan had been so keen to get rid of. As a result, after years of recession and industrial unrest they had no one to turn to or exert influence upon when those services were changed or reduced, and insufficient financial flex to retool themselves in sympathy with the shifting assemblage.

DP

Service design and actual physical interface design draw closely together during this moment. As noted above, British Rail was particularly keen to retire all the classic 16-ton mineral waggons still on the network. This decision turned out to have a particularly strong effect in the Sheffield district, as the dominant users for that particular wagon type were scrap merchants all across the nation, who would use them (via a waggon-load service offering) to send scrap steel to the forges and furnaces of Sheffield for recycling (Chapman, 2013, p33). British Rail took the position that any such client would need to purchase their own replacement rolling stock in order to continue to use waggon-load services but, for the majority of the smaller businesses in question, such a move was financially untenable, and led to something of an uproar.

The deadlock was resolved in 1984, when a leasing deal was set up to build and provide for rent nearly 300 new 51-ton air-braked box-waggons to waggon-load customers, thus sustaining a significant amount of that local traffic—but many smaller businesses were forced to turn to the road carriers, or to close down entirely. Recall that most such businesses, particularly those of the Sheffield district and the Don Valley, were linked intimately to coal and steel, and that those industries were being very purposefully driven into the ground by the government during this period: by 1984, the majority of local freight was steel and scrap, with some sundries and part-waggon-load work still passing through the not-yet-burned-down freight terminal at Grimesthorpe, and fruit deliveries running to Parkway Market near Darnall (Chapman, 2013, p33).

Meanwhile, as already noted, Speedlink appeared to be doing fairly well as a service offering, but this was of little benefit to businesses who had previously relied upon the intimate local network that had once spanned the city region, as the efficiencies of using Speedlink would be countered by the costs in making up the last mile connection to the nearest depot. The same applied to Freightliner, if not more so: unless you were a big player, the ante was far too high.

The *coup de grace* came in 1991 when the British Rail subsidiary running Speedlink announced its termination, citing massive operational losses. Speedlink waggon-load customers could either switch over to Freightliner (which would require investment and increase overheads, particularly in a smaller firm), or save up their waggon-loads in order to send a less frequent unit-train (which would have meant considerable cost in either renting or buying the required rolling stock). The essential but much diminished scrap steel traffic was handed over to another British Rail spin-off firm, but for most other protagonists, the new service offerings effectively influenced them right out of the rail assemblage and into the arms of the road carriers.

I&I

Due to both Speedlink and Freightliner having been in operation since the 1970s, that aspect of the I&I influence which we might think of as positive—which is to say, encouraging of infrastructural enhancement—has already had its effect, which is manifest in the new centralised freight terminals and marshalling yards already described. But there is also a negative aspect to that influence, which applies pressure in favour of the removal of redundant systems. As Speedlink and

Freightliner became not only more popular but more remunerative for British Rail, the old waggon-load practices looked ever more slow, costly, dangerous and antiquated. And as waggon-load freight diminished still further through the decade (a mere 5,000 waggons per week passed through Tinsley at the start of the decade, and that number was reduced by half in the wake of the 1984/85 miner's strike), the business case for keeping the old waggon-load services declined in sympathy, making British Rail's decision to force an upgrade of waggon-load rolling stock understandable in the context of its duty to efficiency. With that achieved (and having in the process jettisoned the majority of small-business protagonists, who might have continued to influence the rail assemblage somewhat in their favour), the relative absence of traditional waggon-load traffic sends a signal to the infrastructure layer that it need no longer support such services, while the increasing traffic on Speedlink and Freightliner services sends a simultaneous signal that the infrastructure layer should optimise toward those services.

S&R

As has been the case almost throughout this analysis of the rail assemblage, the relationship between the interface and infrastructure layers has been predominantly mutually beneficial, and this is in no small part due to the fact that both layers are effectively under the control of the same organisation, and hence not competing for advantage over one another (as was the case with, for example, the contestation between wainwrights and the early roads). This is not to say that the two layers do not influence one another: indeed, that mutual influence is inescapable, given the intrinsic need for technical compatibility between an interface device and the infrastructure to which it connects. But it is to say that the S&R and I&I influences in the rail assemblage might, as suggested earlier, be seen as a sort of virtuous loop, devoid of technical or economic agonisms: when one organisation dominates both layers, it has a fairly free reign to develop either or both in whatever manner seems most appropriate. As such, during this period the standards of the infrastructure layer do not actively push for change in the interface layer so much as they *imply the potential for change*, and the same goes for the flow of influence in the opposite direction: as has been shown, when an assemblage is strongly aligned vertically around a few actors, those actors can effectively impose their will upon the assemblage and force its reconfiguration, unless there is a sufficiently strong pressure from another actor (or actors) to encourage the maintenance of the status quo. In this case, said actor(s) would have been the smaller firms who relied upon traditional waggon-load services—and they were effectively ejected from the assemblage, first by British Rail's scrapping of the older rolling-stock used by such firms, and then by its consolidation and simplification of the freight service offer in the Sheffield district.

7.5.3 Articulations

The articulatory mapping for this moment is shown in figure 7.7 on page 204.

Incumbents:

British Rail; Unions; Heavy Industry

British Rail still clings on at the heart of the assemblage in 1991, though much weakened by underinvestment and poor economic circumstances, and undermined in the public eye by the relentless discourses of privatisation and union-bashing that characterised the Thatcher administration and its successors. Histories of British Rail during this period are quite spectacularly partial, and plentiful evidence exists to support not only the narrative of a profligate and hide-bound national industry pouring the tax-payer's money into the pockets of Marxist trade union members, but also the narrative of a much-loved national institution which not only completed the long process of modernisation (on trunk routes, at least) but also developed some respected rolling stock (such as the feted Intercity 125).

But much of that history is understandably focussed on passenger services, given that the modal share of freight traffic going by rail had begun its national decline in the late 1950s, never to recover significantly. As noted above, traffic levels stayed high in Sheffield due to the unique concentration of mutually-supportive industries in the region and, crucially, to the network's historically accommodative relationship with those industries. This moment sees that accommodation suddenly restricted to only the largest businesses, who can be relied upon to provide work for the network that is both simple to manage and lucrative: hence British Rail's closeness to and overlap with Heavy Industry in the articulation, and its separation from Manufacturing.

Central Gov't; International Ocean Shipping

Though British Rail had a fair degree of autonomy, it was still nonetheless a state property, and central government was not as shy of intervention during this period as it liked to make out, even if such intervention consisted chiefly of briefing journalists about wasteful practices on the railways and then claiming nothing could be done because of the unions. While this project cannot show any explicit influence from the government in favour of running down the more granular freight

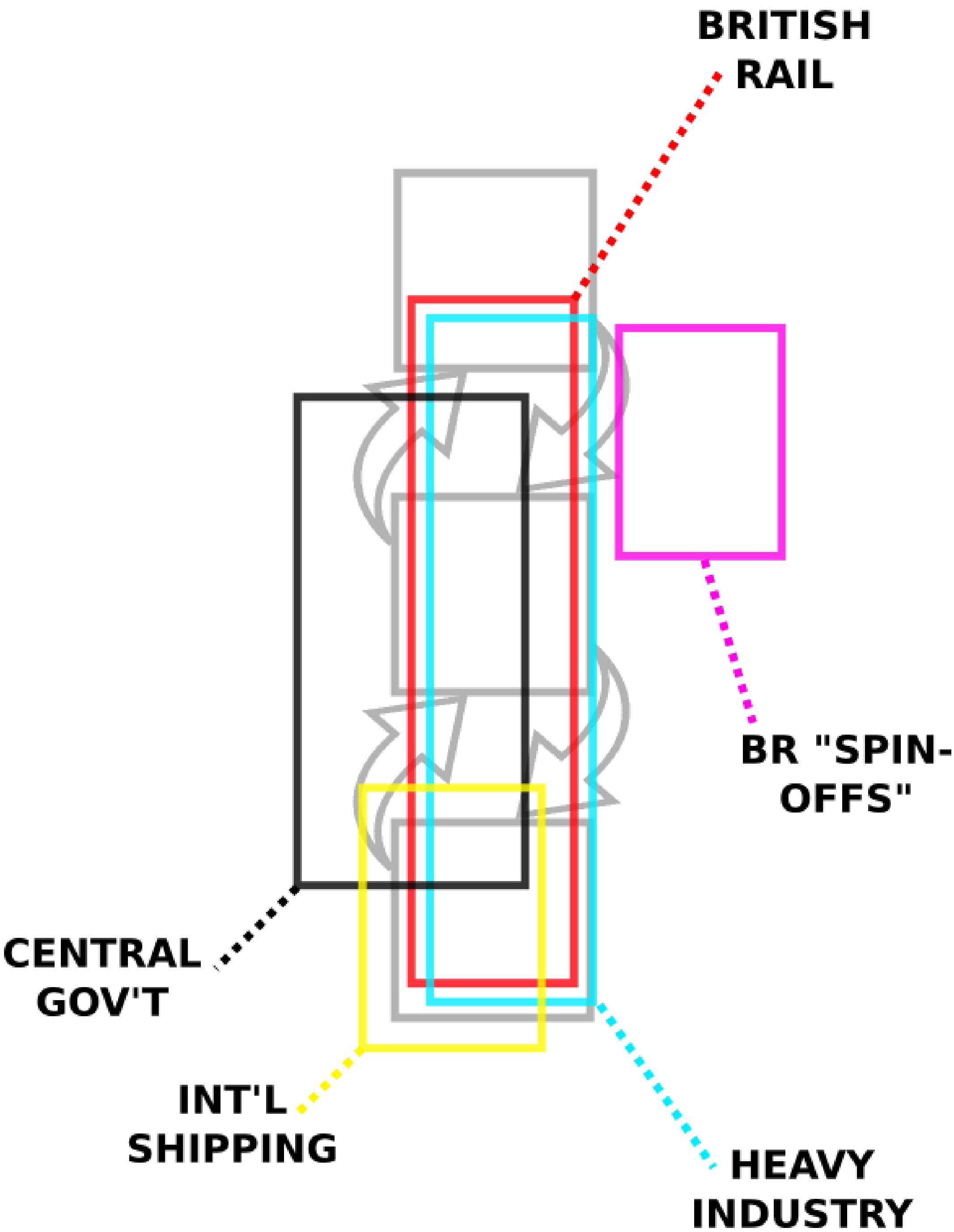

Figure 7.7: Articulated trialectic model for section 7.5 (Rationalisation)

services provided by the railways, the Conservative road-building projects of the late 1980s and early 1990s are evidence of a strong bias in favour of an alternative assemblage—see again Gourvish and Anson (2004, 2-6)—which amounts to much the same thing, if only tacitly so.

Likewise unpopular changes to working practices and wharfage technology at British docks, which sought to both adapt to the rapid growth of containerisation and break the power of the unions. Indeed, if there can be said to be one dominant technological vector that propagated the phenomenon we have come to refer to as "globalisation", the shipping container (and the ISO standards which specify it) is surely the best candidate. Since the closure of Speedlink in 1991, rail freight in the UK is almost exclusively containerised traffic flowing between major ports and cities, over a network in which Sheffield is no longer a node; with the exception of the occasional unit-train of coal, oil or cement, all freight in the region now moves by road.

British Rail spinoff firms (e.g. NCL)

The success of British Rail's spin-off logistics firms were likely another strong influence in favour of the withdrawal of granular freight services: after all, if you can see on your own balance sheets that the margins are better when you use a different assemblage, it will be hard to justify sustaining a loss-making service, particularly under conditions of austerity. Not at all incidentally, many of these firms were subsequently privatised, along with British Rail itself, in or around 1997, and went on to become incredibly powerful and successful businesses: NCL, for instance, is now known as Exel Logistics.

Outgoing: Manufacturing

Lighter industries as exemplified by Manufacturing have now exited the assemblage, in illustration of the rapidity of the severance represented by the elimination of the old loose-coupled waggon-load services. But note how the entity is contorted toward the interface layer by comparison with its earlier, more distant relationship: this illustrates the sudden requirement for such businesses to rent or purchase their own rolling stock rather than have it provided as part of the service, which is a unique articulatory configuration in the history of rail freight as outlined here.

Implicit: Roads

Far less implicit than in the moment before, in truth, the roads assemblage still haunts the railways during this period, during which almost all rail freight other than intermodal containers vanished, snapped up by the ever-hungry carrier firms. This looming and parasitic closeness is further implied by the lurking influence of NCL, which represents a direct connection to the alternative assemblage, as well as a tacit admission on British Rail's part that the roads had triumphed.

7.6 Summary

This chapter has deployed the trialectic model and methodology in order to perform a historical analysis of the evolution of freight logistics assemblages based upon the waterways network in the Sheffield region.

The analysis reveals yet again the topological marginality of Sheffield in terms of freight transport networks—though in the case of railways, it is more a matter of being caught in a liminal location where two or more railway companies have local influence, and the city inevitably being obliged to cleave more closely to one or the other (though that choice may not be the city's to make). It further reveals that there can be a separate topology of service availability atop the base topology of the network itself, meaning that even a seemingly well-connected location might nonetheless find itself cut off from affordances or services which are readily available elsewhere on the same network. Or, more simply: just because you're near a station, doesn't mean that the service you need is necessarily is going to stop there.

In terms of the trialectic model, we observe the railways to be a predominantly closed system—which is to say that the railway company has dominant control over both the interface and infrastructure layers, and hence the complete freedom to reconfigure the service offer or redesign it from scratch, while a competitor literally can't even get themselves onto the network without going through the railway company which controls it. If the roads are a protocol, a set of rules and affordances within which third parties can build service offerings, then the railways are a platform: a suite of predefined and scheduled services within which the powerful affordances of a closed system are bundled up and concealed.

In terms of the articulation of the assemblage, we observe that a closed system is far better able to optimise its service offer through the reconfiguration of the assemblage, because many (if not all) of the contestations of influence which prevail in more open systems are here negated. Put simply, the railway can force the interface or infrastructure layers in any direction it likes, because it is able to resolve any agonisms between those two layers without recourse to negotiation with external third parties; it's all very much an in-house decision. This makes for a potentially powerful and purposeful organisation, but may also serve to make it narrow and inflexible, incapable—or perhaps simply unwilling—to accommodate the marginal, deviant performances which are the seeds of systemic change.

Chapter 8

Analysis: Speculative Mode

Introduction

In this chapter, the second, speculative mode of the methodology (described in section 4.3) is applied to the findings generated by the first, historical mode of the methodology (whose application is described in the preceding chapter). This is in fulfillment of Research Question 2, whose objective is to use the findings generated by a longitudinal historical analysis of sociotechnical change as the basis for an extrapolative exploration of potential future infrastructural assemblages.

In the first section, self-driving vehicles are identified and characterised as an exemplar disruptive technology with regard to freight logistics practices; this exemplar technology is then introduced to the trialectic model, the iteration of which determines the vectors of influence which will be "in play".

In the second section, a simple quadrant matrix is used to generate a suite of four divergent futures, with parameters pertinent to infrastructural deployment defining their sociopolitical and economic contexts.

In the third section, the vectors of influence identified in the first section are combined with the parameters of each scenario in order to create a "deployment sketch", a top-level narrative summary which describes how an attempt at deploying the exemplar technology might play out in each given context.

Finally, the conclusions section gathers together the dominant challenges to the deployment of self-driving freight vehicles as depicted in the four prototypes, and outlines a claim for the unique capabilities of the narrative prototyping process.

8.1 The exemplar technology: self-driving vehicles

In this section, the exemplar technology—in this case, self-driving vehicles—is examined more closely, before being introduced into the relevant trialectic model so that the vectors of influence can be explored. This iterative approach to the model ensures a thorough appraisal of the exemplar and its prospects for deployment.

8.1.1 Concretising the exemplar

The first task is to concretise the exemplar technology: to unpack the concept a little, and consider what lies behind the label. This is particularly important when dealing with a concept such as the self-driving vehicle, which is not so much a novel technology or innovation in its own right, so much as it is a bundling-together of multiple extant technologies of a certain maturity: advanced vehicles, cellular data connectivity, cloud computing, global positioning. The self-driving vehicle further represents an intensification of the linkage between mobility infrastructures and telecoms infrastructures.

These intersystemic linkages mean that, while this project is primarily concerned with a specific practice-as-entity, namely freight logistics, this speculative phase must incorporate some consideration of the contextual influence of those infrastructures and assemblages which may appear, at first glance, *not* to be implicated in the mobility of goods. The historical analysis provides some precedent for this approach: the carrier networks of the 18th century were dependent on inns and stables as a communications network and a fuel distribution system, for instance.

More importantly, communications technology has been explicitly embedded in transportation systems ever since the earliest railway signalling systems mutated into telegraphy, before spilling out of the railway assemblage and becoming an infrastructure in their own right. As such, the current ubiquity of networked IT systems should be considered to be paradigmatic, and there is little sign of the trend for entanglement slowing, let alone reversing. However, introducing all such systems into the trialectic diagram would merely make them more cluttered. For the purposes of analysis, it suffices that their relevance is acknowledged and considered as a feature of the articulatory context; depiction is unnecessary, much as with the implicit articulatory entities encountered during the historical analysis.

8.1.2 Imagining infrastructural impacts

Having clarified the essential nature of the exemplar as being a convergence of existing technologies and systems rather than a technology in and of itself—

recognising, in other words, that the object of enquiry is not "the self-driving truck", but "self-drivingness", which is to say "the potential capability for *any* sort of currently human-controlled vehicle to be fully automated"—the exemplar is now introduced, in a speculative manner, to the three infrastructure types identified in the historical analysis as being enrolled in freight logistics practices: railways, rivers and roads.

It should be noted that the following speculations have avoided considering the potentially disruptive impacts of Unmanned Airborne Vehicles (UAVs), more commonly referred to as "drones". This is in part because the historical analysis which provides support for the speculative mode did not consider air infrastructure, and hence there would be little or no precedent on which to base any speculation; furthermore, it might be reasonably argued that the application of air transport technology to date, particularly in the UK, has been focussed on long-distance bulk haulage, with a distribution of nodes far more sparse than even that of the railway network. To put that in context: it would be all but impossible to explore the history of air freight in the Sheffield area, because there hasn't really been any; airfields have certainly operated in the vicinity, but they have little or nothing to do with the distribution of goods and materials within the region. This is not to discount the role of air transport in modern infrastructural configurations, but rather to note that the situated focus of this particular project means that it is beyond the scope of this analysis.

Still, the argument might be made that UAVs, being significantly smaller than traditional aeroplanes and thus more suited to localised distribution work, might be considered as a potentially imminent disruptor of local and regional freight distribution. Indeed, that argument has been made, more or less explicitly, by the increasingly ubiquitous global retail-and-distribution corporation Amazon, by way of a number of demonstrations aimed at portraying the deployment of drone-based delivery as being "just around the corner", both temporally and spatially (Westcott, 2016)—though it bears noting that the drones being used in such experiments are almost exclusively piloted remotely by humans rather than operating autonomously, and as such should really fall beyond the remit of "self-driving" vehicles.

However, there are reasons to believe that these demonstrations, while arguably confirming the purely technological feasibility of drone-based delivery, go some way to obfuscating the economical, logistical and political obstacles to it being anything more than a publicity stunt for some time to come. The first issue is technological, and relates to the limitations of the electric power-train used in current UAVs:

> "For a 30 minute flight [at speeds necessarily and significantly lower than 40 miles per hour], a drone's overall weight [...] must be twenty times that of the package alone. The batteries' weight accounts for most of that [...] The drone will not be able to fly for more than 32 minutes, and at that time, it will not be able to carry any package whatsoever." (Solomon, 2016)

These limitations mean that the distance between the drone-distribution centre and the destination of the package could be no greater than 16km, even for packages of just over 2kg in weight, unless there were a significant improvement in both battery capacity and electric motor efficiency, both of which have remained stubbornly stable for the last couple of decades, despite considerable research and investment (Solomon, 2016). The matter of the dropping-off of the package is also non-trivial, particularly if the "dropping" is literal, as this would present risks not just to the package, but also to property and people, even in such circumstances as the recipient has a garden or similar open space to receive it. Solutions to this problem involving "special landing zones" or delivery to smart lockers have been proposed (Kobie, n.d.), but these merely serve to highlight the need for drones to compete with terrestrial delivery systems which already make use of such facilities (and do little to remove the social challenges presented by people choosing to attack or steal from a drone mid-mission).

Even assuming these problems can be surmounted, the economics of drone delivery is nowhere close to scaling up to a level competitive with existing options; claims of cost parity with "existing technology" tend to use bespoke one-shot services such as motorcycle couriering for comparison, which are considerably more costly than regular mail services and bulk delivery runs (Kobie, n.d.). The economics of the "last mile" are governed by two factors, namely route density (the number of drops on a vehicle's route) and drop size (the number of packages delivered per stop on the route), and drone delivery does poorly on both: "current prototypes [...] usually carry just one package, and after the drone makes its delivery, it has to fly all the way back to its homebase" to recharge and reload (Wang, 2015). With further investment and development, an increase in distribution centre coverage, and the training and hiring of pilots capable of running multiple UAVs at once, drone delivery might yet come to compete with road vehicles in urban and suburban areas, but at present it is only realistically viable for urgent deliveries where all other options are slow (e.g. replacement components flown out to oil rigs), or for the delivery of high-value low-mass products (such as medicines) in rural settings with sparse populations and poor existing terrestrial infrastructure (such as the Australian outback, or parts of sub-Saharan Africa)—and even these applications would require a significant increase in range to transcend the limitations set out above.

Finally, there are the regulatory issues. Despite the UK's regulatory environment being more conducive to drone experimentation than that of the US or the EU (hence Amazon's pilot programme, mentioned above), there are still plenty of restrictions in place: exceptions can be applied for, but for the most part they are restricted to line-of-sight operations (within 500m of the pilot) with a 400-foot flight ceiling, and effectively forbidden from operating in crowded or built-up areas (*CAP 722: Unmanned Aircraft System Operations in UK Airspace – Guidance*, 2015); provisions exist in theory for operations beyond line-of-sight (BLOS), but these "will require an approved method of aerial separation and collision avoidance" judged equivalent to that of a regular piloted aircraft (*CAP 722: Unmanned Aircraft System Operations in UK Airspace – Guidance*, 2015, Section 3, articles 1.4-8), which in turn implies the inclusion of a significantly complex and powerful package of sensors, communications and control systems—which is not an insurmountable technological obstacle, but would make each drone considerably more expensive. As for genuinely autonomous UAVs, the regulations make provision for the potential certification of such by holding them to similar standards as applied to BLOS operations, but note that there are "no UAS related systems that meet the definition of autonomous" (*CAP 722: Unmanned Aircraft System Operations in UK Airspace – Guidance*, 2015, Section 3, article 3.2). In summary, while the technology may be bordering on the possibility of drone-based delivery, it's a long long way from being autonomous, and even piloted services "have countless issues to overcome, particularly around infrastructure, privacy and security, and avoiding interference with the package" (Calder, 2018). As such, and considering their position outwith the scope of this project, it seems reasonable to exclude drone delivery from consideration as a serious competitor in local freight systems in the Sheffield region, at least in terms of the proximal future.

Rail

The railways are theoretically amenable to automation and driverless operations; the Docklands Light Railway is testament to the fact. Indeed, partial (human-overseen) automation is increasingly commonplace in light passenger rail contexts, but the complete automation of mainline passenger rail is considered a non-starter in the absence of specially-designed infrastructure to support it (as might be put in place in a project such as Crossrail, for instance). This means that the UK's extensive legacy rail infrastructure actually acts as a constraint to automation (Brown, 2014), especially in a context of under-investment like that of the Sheffield region. Freight is arguably more amenable to automation than passenger services, as there are fewer unpredictable human actors in the frame; nonetheless automated rail freight is still surprisingly rare, with arguably the first truly automated service being the recent trials of a Rio Tinto ore train in the remote Pilbara region of Western Australia (Sankaran, 2018). But this is a rare context—isolated, thinly populated, flat, long distances between stops—in which the standard obstacles to automation, namely obstacle detection and emergency stoppages, are reduced to a minimum; by comparison, the Sheffield region's railways are twisty, involve frequent stops, and cut through densely-populated areas.

Of course, it would be *technically* possible to build new freight lines with automation-friendly infrastructure "baked in"; but there is little appetite, funding or political willpower for the construction of new freight lines in the country more broadly; in the Sheffield region in particular, the ultimate failure of the district rail rationalisation project, as represented by the short, fading life of Tinsley marshalling yard (see section 7.4) will serve as an augury against any such investment for decades to come.

Indeed, the reconfiguration of freight around unit-train and container services in the same period effectively innoculated the district against a revival of the sort of freight traffic that might benefit from automation, namely waggon-load traffic. The bulk of contemporary rail freight in the UK is effectively containerised, reliant on economies of bulk scale across long, non-stop point-to-point routes, and ruthlessly optimised; while there might be other reasons for wanting to remove loco drivers from the picture, there is little prospect of self-driving technology making any measurable difference to the cost or speed of these services—which in turn means there's little point in antagonising the railway unions by proposing it. Meanwhile, self-driving freight trains might make more sense on a district network devoted to shuttling components between local businesses, as once prevailed in Sheffield: small, loose or specialist loads; highly variable local and regional itineraries, and one-off special runs. But that sort of traffic is long gone, as is much of the infrastructure that once supported it: not just the permanent way itself but the secondary stuff like sidings and engine sheds, which took with them the multitudinous specialised practices that they once played host to. As such, it can be concluded that we are unlikely to observe much impact from self-driving technologies in the freight rail assemblage; the results would not be sufficiently desirable to encourage the infrastructural reconfigurations required.

Waterways

Likewise, there's little to no chance of self-driving technologies causing radical disruption to the waterways, if only because that network is effectively moribund nationally, and particularly so local to Sheffield: there's simply no traffic to optimise, and no journey time to trim. Nonetheless, the unused capacity of this legacy network is still relevant, and should not be discounted: it still represents the *possibility* of alternative performances for freight logistics, as do the remaining mothballed district rail routes. The question is one of *plausibility* rather than *probability*: the more marginal possibilities should not be discarded too early in the process.

Roads

It is thus the road networks where self-driving technologies are most likely to make their disruptive mark—and where the majority of proposed interventions are targetted.

There are a number of problematics around self-drivingness, and around freight in particular, in terms of realising a successful deployment. In Borenstein, Herkert, and Miller (2017), the authors catalogue "some of the key system level issues that need resolution" if self-driving freight vehicles are to become a functional reality:

> "... if vehicle-to-vehicle communication becomes the norm, will there be sufficient standardization in the design of different makes for the cars to communicate effectively with one another? Will drivers in hybrid human/autonomous vehicles be permitted to out-maneuver fully autonomous vehicles by switching in and out of autonomous mode? Possible responses to such complexities include the development of safety and interoperability standards, sophisticated vehicle-to-vehicle communication systems, and technologies for centralized system control (e.g., centralized intersection management). Each of these responses, however, raises a new set of system complexities, regulatory needs, and ethical issues. [These] scenarios only take into account a relatively finite number of vehicles; in the future, engineers, city planners, and others may have to predict and manage the behavior of hundreds, if not thousands, of self-driving vehicles along with any other automated technologies (such as light rail) or entities that may interact with those vehicles." (Borenstein et al., 2017)

Likewise, Farah, Erkens, Alkim, and van Arem (2018) note that the biggest challenge is the integration of self-driving freight into existing transportation systems, rather than the technical obstacles of self-drivingness in and of itself, and furthermore that road operators and policy-makers are starting to raise questions about how this will work out; their survey reveals that while research on the digital infrastructure capabilities and capacities required to support self-drivingness is plentiful, research on the existing capabilities and capacities of the "legacy" physical infrastructures—which is to say the roads themselves, and the associated systems—is rather scarce. And what little there is suggests that there's plenty of problems to be overcome, particularly in the early stages of any transition to automation—for instance, the potentially detrimental effects on road surfaces: "... in the absence of appropriate control, specifically by repeatedly positioning trucks in the same location, the amount of damage could be highly detrimental, and noticeable influences may occur at autonomous truck volumes as low as 10%" (Noorvand, Karnati, & Underwood, 2017). The news on the self-drivingness side is far from exclusively positive, either, as developments there are mired in ongoing international and intersectoral disputes about standards and regulations for vehicle-to-vehicle communication systems, bandwidth allocations, and more (Uhlemann, 2017).

The social issues surrounding self-driving vehicles are frequently downplayed or overlooked in popular discussion (and promotion) of the technology—and it bears noting that this nay-saying is not exclusive to regulators or critics of technology. For instance, recent qualitative research indicates that people within the German and Swedish freight sectors appear to be well acquainted with the non-technical barriers to self-driving freight vehicles: interviews with sectoral actors (including transport firms, clients, consultants, developers and OEMs) revealed that *all* participants saw the state of existing infrastructure as a barrier to adoption, and the majority highlighted ethical and social concerns, with some explicitly mentioning the risk of job losses, and others highlighting legislative and political obstacles to adoption; furthermore, the role of human drivers in vehicle security, communications, "load securing", document management and customs practices was highlighted, as well as the question of legal and moral responsibility in the case of accidents (Neuweiler & Riedel, 2017, pp38-9; it further bears noting that the condition of both road infrastructure and social safety nets in both Germany and Sweden is considerably less parlous than in the UK at time of writing).

In a similar vein, Richardson, Doubek, Kuhn, and Stumpf (2017) reports that "[drivers and fleet managers] are found to be the most concerned about legal liability issues and the general safety and reliability of [self-driving/automated freight vehicle] technology", and Dougherty, Ellen, Stowell, and Richards (2017) notes a general anxiety among people who drive for a living about having to avoid autonomous vehicles: "the nearest-term autonomation [sic] technology with significant efficiency improvement, truck platooning, triggered negative responses in a portion of the study participants instead of reducing the perception of risk. If individuals have their first exposure to autonomous trucks in the form of platoons, it may lead to broader opposition than individual autonomous trucks would have generated." Finally, an extensive quantitative study of the UK context observes that "automated driving in commercial applications such as taxis or trucks is likely to face some political opposition because of the potential for large-scale unemployment among commercial drivers", and concludes that it "appears more likely that high automation in restricted environment (e.g. motorways) will be available before full automation in urban environments because of the complexity of urban driving, and mainstream automakers appear to favour this approach" (Wadud, 2017). This bias against non-trunk routes is reinforced by the poor availability of mobile telecomms bandwidth: *Connected Nations* (2017) reports that, as of 2017, only 58% of A and B class roads in the UK have in-vehicle mobile data coverage.

Given these data, it seems reasonable to assume that self-driving freight will:

1. necessitate a substantial investment in new communications infrastructure on and around those routes where it becomes an option;
2. necessitate interventions in the "legacy" roads infrastructure in terms of both capability and capacity;
3. necessitate a substantial body of legislature, technical standards and insurance precedents before anything more than limited trials can be put into action;
4. most likely be instigated as a segregated option on motorway trunk routes long before being available on urban or more minor/rural routes.

At the risk of belabouring the point, these obstacles are far from insurmountable; however, they are costly, time-consuming, and fraught with difficulties due to their social and political nature. Only if there is the prospect of considerable cost savings to fleet operators are they likely to invest in the technology—and only then if there is a solid prospect of the necessary infrastructure being in place prior to investment, which implies either state-led investment, or the sort of private (and speculative) investment in radically new infrastructure that hasn't been seen in the UK since the Victorian railways boom. All of these things *could* happen—but the likelihood of their happening is highly sensitive to the social, political and economic context. It is this sensitivity to context, as well as to location, that the prototyping process is intended to explore: absent any proleptic knowledge of what *will* happen, we turn instead to deliberately drastic examples of what *might* happen.

Given this project's focus on freight practices, it makes sense to focus on the impact of self-driving technologies on freight-focussed vehicles. However, it also bears noting that self-drivingness is essentially "vehicle agnostic", which is to say that it might just as easily be applied to non-freight vehicles as to freight. Furthermore, the distinction between freight and non-freight vehicles is primarily regulatory, in that non-freight vehicles are often capable of performing (light) freight logistics, even if their design protocols must be circumvented to do so. In other words, the possibility of non-freight vehicles being made driverless must be factored into the following speculation, as must the possibility of non-freight vehicles (self-driving or otherwise) being "hacked" so as to perform freight roles, in defiance of both their design and/or the prevailing regulatory framework.

With that said, it is clear that the most important assemblage with regard to the potential disruption of freight practices by self-drivingness is that of freight-specific vehicles running on the road network. As such, the final roads trialectic from the historical analysis (see section 5.5, reproduced below as figure 8.1) is the starting-point model for the speculative process, and will inform the speculations to follow.

8.1.3 Vectors of influence

During the historical analysis, tracing the vectors of influence traditionally begins with HKJ; this is predominantly an aesthetic decision on the part of the author, intended to emphasise the project's orientation toward practices, which is to say *toward people doing things*. However, the trialectic model is not concerned with causality, and hence the analysis may begin with any of the four vectors.

When dealing with proposed speculative technologies such as self-driving vehicles, we are working with ideas whose originators believe them to be meeting a market desire: in the language of the trialectic, the self-driving vehicle is an interface developed in response to HKJ influences, which take the form of a deviant practice-as-perfomance that exceeds (or at least attempts to exceed) the established performance parameters. Without knowing which deviant performances in particular the self-driving vehicle is intended to respond to, the speculative analyst must instead begin by looking at the design protocols of the proposed technology, as they offer the best available guide to the problems (or "use cases") that their originators see them as solving.

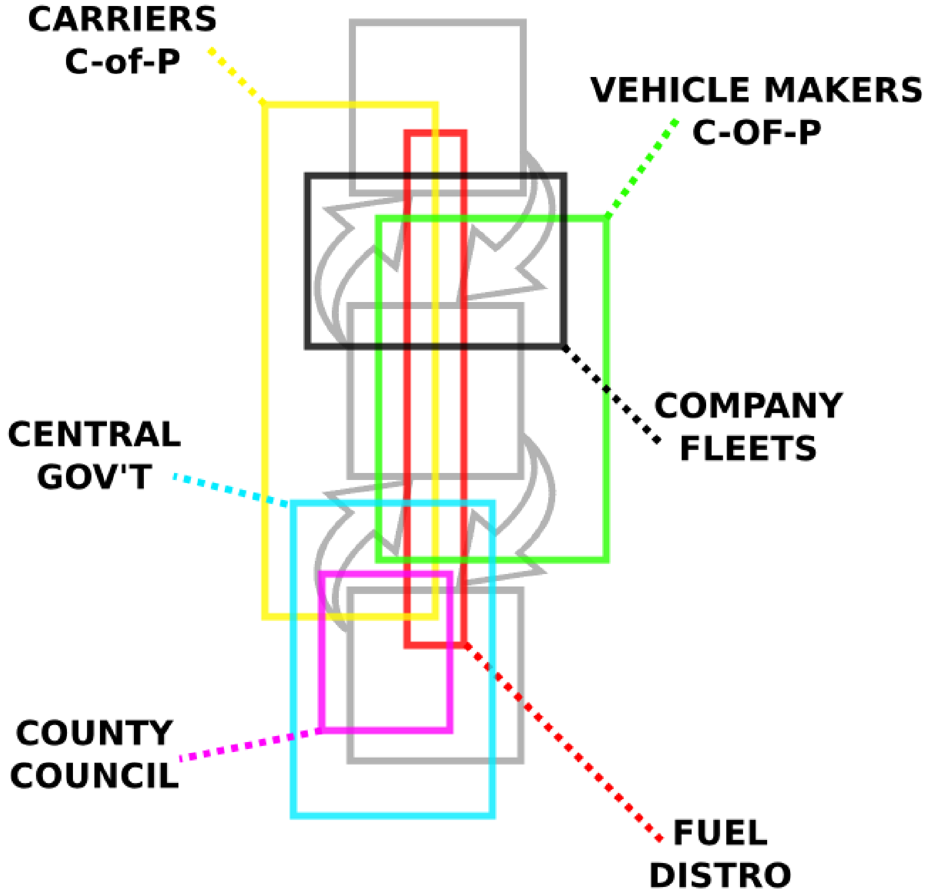

Figure 8.1: Articulated trialectic model: Roads, late 20th and early 21st century

Or, to put it another way: the prototyping process relies on making at this point an explicit assumption that the originators of the proposed disruptor have done their homework, and are not merely chasing technological rainbows. We assume that the technology is deliverable as described under ideal laboratory conditions; it is only by proceeding under such an assumption that the validity of such an assumption might be effectively critiqued.

Design Protocols

The self-driving freight vehicle is an interesting case for the trialectic, in that it involves designing the protagonist away from the interface, and almost out of the picture entirely: the operator (or driver), who would normally be acting as the protagonist's proxy, is replaced by IT systems. As such, the design of the material interface, which is to say the vehicle itself, is geared almost exclusively toward accommodating the parameter-excession desires of the organisation which owns and operates it, rather than the more immediate and personal desires of the (now obsolete) driver. Furthermore, this means that *any influence upon the trialectic from the instigating protagonist must pass through the owner organisation*: the end-user experiences freight logistics almost entirely as a service, and can thus only interact with the system through the protocols offered by the service provider. This means that there is little or no opportunity for the development of deviant and/or excessive protagonist performances: the protagonist simply can't get close enough to the components of the system to perform a hack or a kludge, and must instead give over the execution of the entire performance to the operator. As such, it is to the operator organisation that we must look for HKJ influences on this particular trialectic.

Hacks, Kludges & *Jugaad*

The desires of operator companies for improved performance parameters are manifest in extant deviant practices such as tachometer fraud, and in the hiring of drivers from low-wage markets such as Eastern Europe; the former is effectively a regulatory circumvention which increases the number of usable vehicle-hours per day, while the latter keeps a downward pressure on staff overheads. Like the overloading practices of the interwar man-with-van (see section 5.4) these are hacks performed preemptively by the carrier company on the protagonist's behalf, with the aim of making their service offer more competitive as a result. These excessions thus evidence a continuing desire on the part of operator companies to make yet faster shipments at yet lower costs; these are the only parameters on which it is realistically possible to compete in general freight.

Invention & Iteration

The self-driving vehicle is thus intended to extract improved parameters from the infrastructure layer: speed and cheapness of journey are those of greatest interest to freight operators, as they offer concrete business advantage when seen from the bottom line. Interestingly, while self-drivingness is a distinctly *technological* disruptor, it pushes primarily against the *regulatory* constitution of the infrastructure: after all, the maximum speed of a self-driving truck will likely be no higher than that of a regular truck, and thus any increase in delivery speed is achieved through reducing the number of hours that the shipment is obliged by regulation to stay motionless.

That said, the self-driving vehicle does place greater demands on the infrastructural layer than the manual vehicle, but those demands are not primarily focussed on the roads themselves: a self-driving truck wouldn't take up more road capacity or cause more wear and tear to tarmac than the manual type. However, it would require much more connectivity and/or bandwidth from the telecoms network as a condition of deployment—and the same goes, albeit to a lesser extent, for secondary infrastructures of fueling and fuel distribution, and for the supporting systems of surveillance and traffic management within which automated vehicles would need to operate. The point being that, while a *single* self-driving vehicle might be easily and safely released onto the road network without the need for upgrades and improvements, opening up the roads to *populations* of self-driving vehicles would necessitate the expansion and integration of multiple infrastructures.

Standards & Regulations

The question of populations brings us to the real difficulty regarding self-driving vehicles using the road system: the hundreds of thousands of human-driven vehicles which already use that road system. It is eminently possible to envisage a road system whereupon each and every vehicle is self-driving; envisaging a system whereupon self-driving vehicles share the same roads as human-driven vehicles is rather more of a challenge.

There is a technical aspect to this problem: shared routes would necessitate the self-driving vehicle being able to predict and respond to the responses of un-networked human drivers as well as to the more predictable and programmatic responses of its fellow robots, and this represents a significant increase in the challenge.

There is also a legal and regulatory aspect to the problem, which is best summed up with the question of liability: if a self-driving vehicle kills or injures someone, who is responsible in the eyes of the law? Is it the passenger (if there is one), or the operator organisation, or the vehicle manufacturer? What if the manufacturer had outsourced the development of the software that made the fatal decision—is the software house then liable? The current lack of legal precedents around these questions will present a considerable barrier to uptake: until these questions are answered, few will be willing to underwrite the insurance policies required to make self-driving vehicles a reality, and until self-driving vehicles are fully insurable, no one will use them for freight (or indeed for anything else).

There will likely also be political resistance to the deployment of self-driving vehicles from multiple fronts: labour unions are likely to perceive them as a direct threat to employment, and they will likely be bundled in with other potentially "job-stealing" technologies, in what seems to be a growing discourse of anti-technological discontent. They will also generate a strong argument in favour of reinvestment in railways, given they're a proven technology with almost all of the advantages (if not more) which accrue to self-driving long-haul road freight, and also represent untapped latent capacity in the region.

But in order to complete the iteration of the trialectic, it is necessary to assume that the exemplar is deployed, however partially; therefore it is necessary to consider the compromises which might make deployment possible despite the challenges outlined above. Considering that the liability challenge is considerably reduced when route-sharing is taken out of the picture, segregation by vehicle type seems the most likely compromise: routes, or some lanes of a route, devoted exclusively to the use of self-driving freight. These dedicated routes might be permanent (e.g. always exclusive to self-driving vehicles) or temporally contingent (e.g. a lane which is reserved for self-driving vehicles between 9pm and 7am).

Such a program of vehicular segregation would not be without its own logistical challenges, and would likely involve some sort of physical intervention in the roads (fences, crash barriers, surveillance, signage, safety features) as well as the parallel bolstering of secondary infrastructures, and a whole raft of rules and regulations around the use of self-driving vehicles. None of this will be cheap, or quick to deliver.

8.2 Four divergent futures: building the scenario matrix

The aim of the scenario suite is to provide a set of imaginary worlds or laboratories in which to "test" the exemplar disruptor technology. The prototyping process starts by taking the disruptive technology at its word (or at the word of its promoters) and assuming that deployment is a given, if only in terms of its technological viability; the challenge is then to outline a deployment which is plausible *when considered in the context of the scenario in hand*. As such, the parameters which define the scenarios must be designed to be pertinent to the disruptor under consideration: in the case of freight infrastructure, this necessitates parameters that capture complexity and challenges at both the national and international scales.

Furthermore, it is necessary that the scenarios be reasonably extreme: plausibility is crucial, but probability, not so much. At this point, it bears reiterating that, as explained in section 4.3, the scenarios that follow are not meant to be predictive. They are not meant to be realistic, either—if by "realistic" one means reflective of the likely turn of events. Likely turns of events are, for the most part, already baked into the majority of predictive models and strategy generation processes; the whole point of the speculative methodology is to simulate the effects of *unlikely* turns of events, as a way of "stress-testing" a strategy already developed with likely outcomes in mind. Unlikely events are by definition impossible to predict, but they can be imagined, and their consequences extrapolated from that imagining. It is the consequences, the *parameters* of the scenarios, that matter for the prototyping process, not the scenarios themselves; the scenarios are simply a way of making the parameters "hang together", a way to make them a little more "alive" and engaging to the imagination than a table of numbers or values could ever be. That they are capable of provoking discussion as to their plausibility is, if anything, to be considered a bonus, as such discussions are indicative of a mindset that has been opened up to the consideration and evaluation of divergent future circumstances.

The point is not to test the proposed assemblage against a particular outcome or outcomes, but rather to use a set of drastic outcomes as a proxy for the possibility of a discontinuity in context which, by definition, cannot be predicted or parametricised.* If we are unwilling to consider the worst, then we are unprepared for the worst—and so the speculative mode is a deliberate provocation, an

*If I might briefly break the "fourth wall" of academic objectivity for a moment, by way of exposing my own positionality on this matter: as I expect is the case for the vast majority of British citizens, I very sincerely hope that the outcomes of the Brexit negotiations (still ongoing at time of writing) look nothing like any of the four scenarios that follow—but the enduring and widespread resistance to considering that said scenarios might be even remotely possible is, perhaps, the best possible argument for considering them.

invitation to think the unthinkable: the cost of doing so is minimal (the great merit of narrative prototyping, from a planner's point of view, being its cheapness by comparison with almost all other methods), but the potential cost of *not* doing so is incalculable.

To predict the future is impossible—but to engage with unpredictability in a productive manner is comparatively simple, and that is what the speculative methodology is designed to do. It is neither a replacement for strategic foresight, nor a repudiation of it; rather, it is a supplement to it, an extension of the process which readmits that which has heretofore, by necessity, been externalised. Regarding the scenarios which follow, then, the question to ask shouldn't be "but what if they're wrong?"; it's "but what if they're *right*?"

8.2.1 Scenario matrix: axes and parameters

The axes of a 2x2 scenario generation matrix should be selected so as to be pertinent to the subject of the enquiry. In the case of this prototyping process the subject is, broadly speaking, freight logistics and infrastructure. As the historical methodology has shown, freight logistics has always been important to (and shaped by) both the regional context and the national; as such, the axes should be selected so as to express and explore this entanglement of two organisational scales. The contextual axis (or the reactive axis) should therefore represent external circumstances affecting the UK as an entity on the world stage, while the systemic axis should therefore represent the domestic sociopolitical dynamic within that entity.

Contextual axis: Brexit outcomes

The divergent possibilities of the Brexit process, yet to be formally begun at time of writing, provide the contextual (vertical) axis. Regardless of one's feelings about the result of the referendum, the expert prognosis on its impacts is generally negative in economic and diplomatic terms, with the current debate using the modifiers "hard" and "soft" to denote maximum and minumum predicted impacts respectively. In other words, the open question is not whether Brexit will damage the nation, but *to what extent* it will damage it. In order to capture the flavour of this particular contextual uncertainty, the following infrastructurally pertinent parameters were assigned to the two ends of the axis:

/	Hard Brexit	Soft Brexit
Regulatory regime	looser	tighter
Relations with EU	more isolated	more involved
Domestic political tone	more radical/extreme	more centrist
Economic damage	more damage	less damage

Table 8.1: Contextual axis parameters

Systemic axis: domestic policy

The general ideological slant of domestic policy provides the systemic (horizontal) axis. In contrast to the contextual challenge represented by the outcomes of the Brexit process (which is effectively an externality for anyone outside Whitehall) the ideological orientation of policy in post-Brexit Britain—infrastructure policy, but also policy more broadly—is something closer to a choice, albeit a choice which manifests as a sociopolitical gestalt. Rather than use the time-worn labels of Left and Right, whose significance and meaning have become something of a moveable feast, the modifiers "private" and "public" are used to stand for styles of state intervention in infrastructure, and styles of social policy more broadly:

/	Public	Private
Infra. Investment	More state-led	More private finance
Inequality	Reduce	Increase
Cultural tone	Collectivist	Individualist
Devolution	Faster	Slower

Table 8.2: Systemic axis parameters

8.2.2 The populated matrix

These two axes combine into a 2x2 matrix, as shown below; each quadrant is labelled with a title chosen to illustrate the scenario it defines. Scenario parameters accrue to each quadrant in accordance with the ends of the axes it falls upon. By way of example, the top left quadrant represents a combination of the Hard Brexit pole of the Contextual axis and the Public-oriented Policy pole of the Systemic axis; as such, it inherits all of the parameters from the Hard Brexit column in table 8.1, and all of the parameters from the Public column in table 8.2.

8.2.3 Four scenarios

The following sections are brief sketches of the economic and political timelines for each scenario, based on an extrapolation of the assigned scenario parameters,

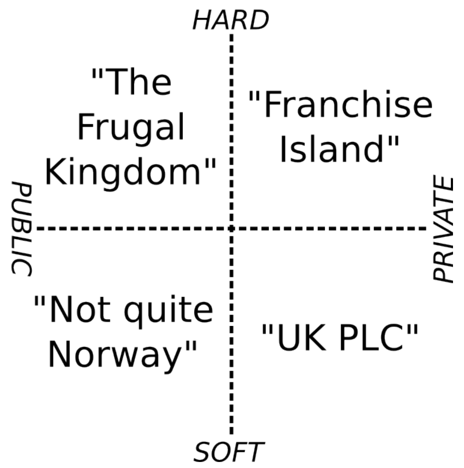

Figure 8.2: 2x2 matrix with scenario titles

which set out the contextual challenges to infrastructure projects implicit in the circumstances.

"Franchise Island" [hard/private]

Parameter	Trend
Investment	private sector
Inequality	increasing
Sociality	individualist
Devolution	slower
Regulation	looser
EU relations	distant
Politics	radical/extreme
Economic damage	more

Table 8.3: "Franchise Island" scenario parameters

The libertarian right retains power throughout and beyond an unruly and defiant Brexit, leaving Britain economically weakened, diplomatically isolated from the continent, and desperate for inward investment on almost any terms. Further reductions in public spending accompanied by tax cuts and a regulatory bonfire compound the inequalities of the pre-Brexit austerity program, making for a cut-throat culture and a growing resentful underclass whose promised utopia has not been delivered. Infrastructural investment remains focussed on London and the south-east, and on prestigious big-ticket projects such as HS2; these are increasingly funded by Hinkley-esque arrangements with foreign and private investors, when they are funded at all.

"UK PLC" [soft/private]

Parameter	Trend
Investment	private sector
Inequality	increasing
Sociality	individualist
Devolution	slower
Regulation	tighter
EU relations	closer
Politics	centrist
Economic damage	less

Table 8.4: "UK PLC" scenario parameters

This is the "liberal continuity future", wherein the infrastructural status quo is altered the least. A fairly soft Brexit conclusion limits the economic self-harm of the process, and a resurgent centrism pushes back against a diminished (yet still very energised) hard right; the social-democratic left splits from the Corbynist rump of "Old Labour" in order to prop up the consensus, but the coalition is fractious, and hence pragmatically technocratic: it's all about keeping the lights on and the trains running while the recovery takes hold, and that means neoliberal business-as-usual when it comes to infrastructure: PFI financing, EU standards and regulations, and the slow expensive grind of consultancy. But while the lights may have been kept on, not everyone can afford to use them... and the radical left is rediscovering protest and street politics, particularly in larger cities.

"The Frugal Kingdom" [hard/public]

Parameter	Trend
Investment	state-led
Inequality	decreasing
Sociality	collectivist
Devolution	faster
Regulation	looser
EU relations	distant
Politics	radical/extreme
Economic damage	more

Table 8.5: "The Frugal Kingdom" scenario parameters

A spectacular and hubristic botching of the Brexit negotiations splits the Tory party and turns public opinion against them, as well as against what is seen as a cruel and vengeful Europe. Seizing its moment, the Corbynist left finally embraces patriotism and the monarchy as King William V takes the throne, ushering in a period of belt-tightening and national introspection. This programme is deliberately and repeatedly framed as being comparable to post-WW2 austerity and rationing: high taxes, careful public spending, the renationalisation of industries abandoned as no longer profitable. But the actuality is mostly a whole lot of make-do-and-mend, particularly when it comes to infrastructure: the opportunities for action implied by devolution and the removal of state-aid restraints are severely hampered by a lack of funds. Cheap, functional solutions are the order of the day—particularly ones that might produce economic opportunities at the grassroots level.

"Not quite Norway" [soft/public]

Parameter	Trend
Investment	state-led
Inequality	decreasing
Sociality	collectivist
Devolution	faster
Regulation	tighter
EU relations	closer
Politics	centrist
Economic damage	less

Table 8.6: "Not quite Norway" scenario parameters

Named for an ECB executive's unguarded assessment of Britain's post-Brexit paradigm, "Not quite Norway" sees the centre-left successfully reconsolidating around their efforts to secure a softer Brexit settlement, whittling away at Tory credibility by successfully portraying them as having stolen UKIP's clothes. With a notionally progressive coalition in power from 2020, EU relations are patched up as well as possible, and gently Keynesian policies begin pushing pack against the privatisation paradigm, starting with the railways. Affordable solutions are very welcome, but the focus of governance is on addressing inequality in the social fabric, in the hope of keeping the lid on simmering nativist resentments; as such, new infrastructure comes a very distant second to maintaining or upgrading existing assets.

8.3 Prototyping: articulation in context

Having iterated the trialectic model (section 1 above) and defined a suite of four scenarios (section 2 above), the next phase is the prototyping process. In essence, this involves placing the trialectic "into" each scenario in turn, and attempting to come up with a plausible compromise between the promise of the proposed system and the obstructions of its circumstances: in other words, having committed to the assumption that the disruptor is *technologically* feasible, the prototyping process is designed to test the sociopolitical, economic and geographical feasibility of its being built successfully under unexpected but not unimaginable circumstances.

For each scenario, the quadrant parameters (picked out in **bold**, for ease of identification) are used to interrogate the trialectic: how might they aid or obstruct the deployment of the technology in question? This process results in a sketch narrative of the imaginary deployment which, when combined with each scenario's sketched "future history" (from the preceding section), serves as a description of the performance options for freight logistics practices particular to that scenario—it explains, in other words, what did and didn't get built, which in turn affects the options and parameters available to would-be performers of freight logistics.

8.3.1 "Franchise Island"

Prototype parameters

The margins on providing freight services are already incredibly thin, as indicated by the long suppression of fuel duty increases; this means that **private-sector investment** in freight infrastructure is only likely to come from the very biggest players, who can either leverage the sheer volume of traffic to a profitable advantage or absorb the running losses into profits made elsewhere in the value chain. **Increasing inequality**, in combination with what looks to be a global trend toward trade protectionism, suggests that growth in long-distance (i.e. international overland) goods traffic will slow or reverse, while domestic traffic might increase. An **individualist political culture** suggests that there will be little enthusiasm for protecting the interests of employees or smaller organisations against agressive business practices. **Slower devolution** ensures that decisions about major infrastructure projects remain under the centralised remit of Westminster: a continuation of the *status quo*, wherein the lion's share of funding goes to London and the south-east.

Hard Brexit offers the opportunity for a **regulatory bonfire**... but only around those matters where no concessions need be made to Europe, which is likely to develop its own regulatory framework for self-driving vehicles. A hard Brexit further suggests that the margins on continental overland trade will be further eaten into, which will have the knock-on effect of **reducing overland trade flows**: fewer goods will arrive in or leave the UK on trucks, while more goods will arrive or leave on container ships. A **radical tone to domestic politics** suggests a theatrical approach to policy, wherein the grand gesture delivered swiftly is assumed to trump the more cautious technocratic attitudes of the past. Meanwhile, **serious damage to the UK economy** ensures a steady stream of discontent and protest, and the revival of old-school street politics.

Deployment sketch

Online retail giant Amazon, already making inroads into logistics and concrete infrastructure, cuts a deal with the UK government under which one lane of of each of the nation's motorways is permanently segregated (through the use of security fences etc.) for the use of self-driving freight vehicles; they also cut a deal with Tata UK to produce the fleet. Quickly eating up the traffic of smaller hauliers as well as growing their own, Amazon effectively treats this logisitics business as a loss-leader on its retail business, taking a hit on profitability so as to get closer to a monopoly position not just in retail but also in long-haul domestic delivery; international long-haul road freight, long in decline, is now death-spiralling due to post-Brexit tariffs, while the container ports are getting busier with imports from other, more distant markets.

In the case of Sheffield, this deployment means that the closest node of the self-driving freight network would be the M1 at Tinsley/Meadowhall; all last-mile connections into or out of the city that make use of the self-driving modality will have to make their way to or from the distribution centres by some other manually-operated mode of transport. In effect, this deployment changes very little: self-driving freight might not even be offered with its self-drivingness as its selling point, and is more likely to just invisibly hoover up a portion of traffic which would previously have taken much the same route, only with a human driver behind the wheel. But it's also likely to only be offered on a containerised or whole-truck basis, as the overheads on coordinating multiple smaller loads are prohibitive to businesses where profits are a function of volume (compare with the reorganisation of rail freight in the 1980s; see section 7.5). This leaves the opportunity for local independent operators to get in on the last-mile game, with a loose regulatory regime and lax law enforcement permitting a profusion of "local carriers" (as found in the pre-turnpike era; see section 5.1), and middlemen distribution "businesses" who are actually just running arbitrage on the spare container capacity of other operators, rather than running their own fleets. However, these businesses are just as likely to link up with the rail freight network or with manually-driven road freight systems, because the motorway network represents only the trunk routes of the road network as a whole, and in many cases it would be cheaper to ship directly between origin and destination in a manual vehicle than it would to book some or all of the space in a self-driving container, and then arrange last-mile connections at both ends separately: modal shifts have always been the slowest and most expensive elements of freight logistics. With respect to the experience of protagonists, most users are unlikely to notice any difference. This is due to the continuation of the freight-as-service paradigm: because the interface device (in this case the truck or HGV) is privately owned and operated, and thus isolated from the influence of the protagonist, the assemblage of freight dispatch is obscured behind standardised online interfaces, particularly for bulk users thereof.

Articulations

Figure 8.3 on page 231 shows a speculative articulation for the trialectic under the Franchise Island scenario. Almost all of the major articulatory actors from the preceding road freight analysis (see above) are still in play, though there have been some significant rearrangements of responsibilities and relationships.

Incumbents:

Carriers C-of-P The carriers community-of-practice has seen its area of influence shrink away from the protagonist; this reflects the increasingly local (and likely ad hoc) nature of "traditional" (which is to say last-mile) freight carrying practices under this new regime, in which local carrying work on the last mile would increasingly be sent out to tender by Amazon, presumably under some sort of Uber/Deliveroo-esque gig-economy model; a continuation of the deregulatory paradigm would enable, if not encourage, this trend. It should be noted that the carrier's influence over the assemblage has been reduced in spite of what might seem to be a fairly immediate connection to the recipient of the delivery; in a deregulated deliveries market, the recipient has fairly limited powers of influence by comparison to the sender, who after all pays for the service, and therefore gets to call the shots and influence the service to their preference and convenience (as anyone who has spent all day sat at home waiting for a parcel to arrive is presumably well aware).

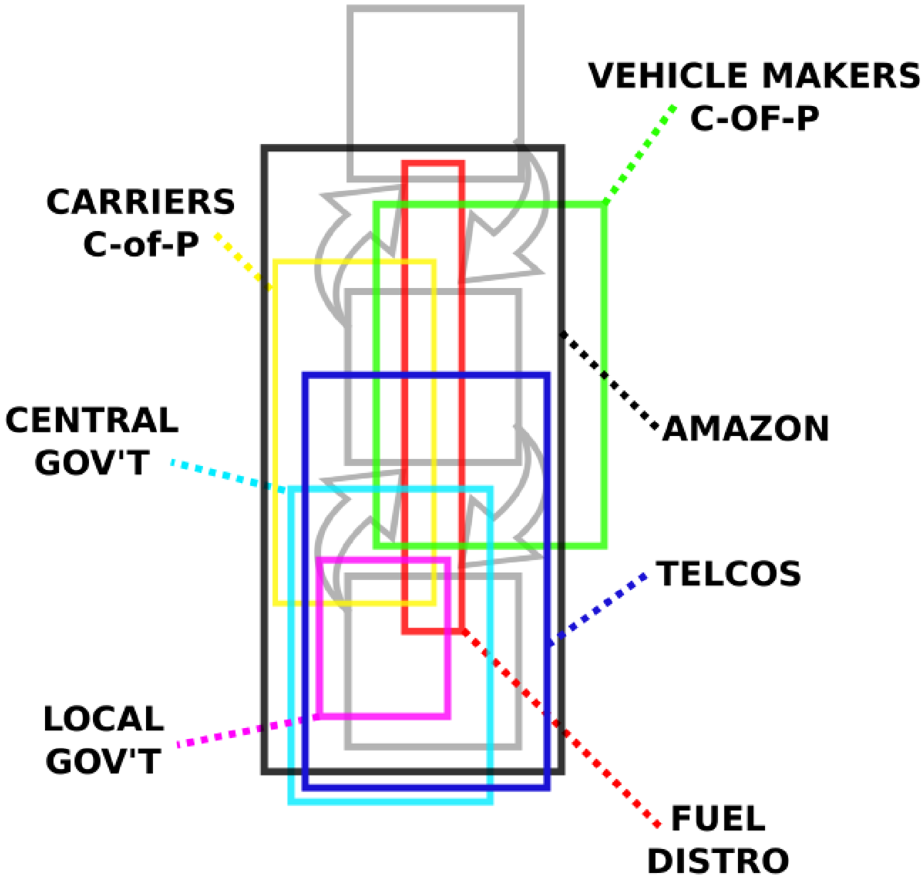

Figure 8.3: Articulatory mapping for Franchise Island scenario

Fuel distribution Fuel distribution infrastructures retain their position, as without them, logistics vehicles are unable to move; however, they too retreat from the influence over the protagonist as price and availability fluctuations are increasingly absorbed into the service as provided. The assemblage couldn't function without it, but its relationships are increasingly oriented toward larger articulatory actors.

Central government, local government, vehicle makers The positions of the two gubernatorial actors remain essentially unchanged: central government still makes the final decisions over infrastructural standards and regulations, and local government is still in charge of maintenance and upkeep. (It is assumed that local government, and hence local and regional taxation bases, will remain on the hook for the majority of maintenance costs associated with non-trunk roads—another reason that self-drivingness is likely to stay restricted to major routes.)

Likewise the role of vehicle makers as a community-of-practice is (perhaps a little conservatively) presumed to stay stable, on the assumption that self-drivingness will be "delivered" through engineering partnerships with IT companies that are for the most part fig-leafed behind the familiar brand identities of the vehicle manufacturing sector.

Incoming:

Amazon In a low-investment scenario such as this, the only way the infrastructural investment necessary to support self-drivingness is likely to happen is if private money is brought in—and in a situation of desperation, that private money will be able to set the terms of the deal. Amazon always seeks to control the entire "stack" (or assemblage) of any sector in which it operates, and would thus insist on significant influence over the infrastructural layer in exchange for the investment necessary to upgrade it for driverless services, as well as lobbying hard for standards and regulations that accommodated its ways of working; however, as can be seen, this influence would be far from exclusive, and involve a significant degree of overlap with government responsibilities (both central and local), as well as with the legacy fuel distribution infrastructures, and the other new entrant to the freight assemblage, namely the telecoms companies.

Telcos Amazon could get fairly easy access for interventions into the roads, because they're the last concrete infrastructure that is still under governmental control; telecommunications, however, have been controlled by private corporations for decades, and would therefore have a significant span of independent influence over the assemblage given the necessity of telecoms bandwidth for any successful deployment of self-drivingness at scale. The telcos (which, in this particular diagram, are effectively a black-boxed proxy for another entire infrastructural assemblage in its own right) would gain a significant influence over the S&R and I&I vectors, and over the infrastructure layer; this influence extends into the interface layer due to the inescapable involvement of telcos in negotiations over standards for communication systems which use their networks (and hence also over aspects of vehicle design), but does not extend to the protagonist, from whose perspective these elements of the assemblage are concealed behind the design of the service, which is entirely dominated by Amazon.

Outgoing:

Company fleets Amazon's behaviour has consistently shown that it only ever enters a market with the intention of eliminating all middle-men and competitors; if we assume a scenario in which Amazon is permitted to intervene in the freight assemblage by a beleaguered government desperate for infrastructural investment at any cost, we can also assume that Amazon will treat the freight side of its operations as a loss-leader with the aim of capturing as many trade flows as possible by leveraging the economies of scale that the corporations vast cash reserves make possible. There are further incentives, too, in that the more "old school" manually-driven freight vehicles Amazon successfully removes from the trunk routes, the more congenial the trunk routes become for their own driverless alternative; thus ruthless price-cutting would make the abandonment of remaining in-house company fleets (already significantly diminished by the rise of "just in time" logistics) inevitable.

8.3.2 "UK PLC"

Prototype parameters

The margins on providing freight services are already incredibly thin, as indicated by the long suppression of fuel duty increases; this means that **private-sector investment** in freight infrastructure is only likely to come from the very biggest players, who can either leverage the sheer volume of traffic to a profitable advantage or absorb the running losses into profits made elsewhere in the value chain. **Increasing inequality**, in combination with what looks to be a global trend toward trade protectionism, suggests that growth in long-distance (i.e. international overland) goods traffic will slow or reverse, while domestic traffic might increase. An **individualist political culture** suggests that there will be little enthusiasm for protecting the interests of employees or smaller organisations against agressive business practices. **Slower devolution** ensures that decisions about major infrastructure projects remain under the centralised remit of Westminster: a continuation of the *status quo*, wherein the lion's share of funding goes to London and the south-east.

A relatively light and orderly Brexit means that **regulations will largely be harmonised** with those pertaining on the continent—and it is international road freight which will be most amenable to driverless technology, as it is only over long routes that the greatest economies can be achieved. As such, **continued engagement with EU goals and priorities**, particularly with regard to environmental matters, would see the UK keen to be involved in any emerging continental system for self-driving freight; however, the same declining demand and systemic challenges will serve to block anything but a limited, segregated deployment. Furthermore, a return to more **centrist political dynamics** means classic technocratic policy-making, particularly with regard to infrastructure: sensible, expensive, and interminably slow. Lucky, then, that Brexit resulted in **minimal economic damage**; given a sense of having dodged the bullet, the bulk of the population is grateful that things haven't gotten too much worse.

Deployment sketch

As part of an effort to reconsolidate the EU, create jobs and reduce carbon emissions, a pan-European project for self-driving long-haul freight is instigated, in partnership with Maersk, Volkswagen and other big private-sector players in logistics and automotive technology. Segregated lanes for self-driving freight vehicles are permanently established on transcontinental routes where freight traffic is most intense. The UK, still fairly close to Europe politically and economically (and hence still dependent on international overland freight for imports) is at one end of this network, but it is also a long way down the list of priority: by 2032, the M1 has finally been retrofitted for segregation as far North as York.

The end result is not unlike that proposed in "Franchise Island", then: self-driving freight is deployed, but only as an enhancement of the trunk routes of a pre-existing network. This means that, much as was the case with turnpiking in the 18th and 19th centuries (see section 5.2), use of the more advanced interface (in this case the self-driving freight vehicle) is restricted to bulk operators on major network edges, and those connecting to said network from nodes further out into the "last mile" will this be obliged to make more modal shifts in order to do so. Where this circumstance differs from turnpiking is in the extent of the advantage conferred by the new assemblage: turnpiking was flawed and often poorly executed, but it still made a huge difference to the availability and capacity of the routes to which it was applied (not least because it was applied to the entire route, rather than a single lane thereof). However, the scalar advantages and economies of self-driving vehicles can only be properly realised when they completely replace the old system of manual vehicles; in any more partial deployment, the improvements will be marginal, and will accrue only to those covering the longest routes with the greatest volume of traffic. (It also seems highly likely that some sort of subsidy will have to be in place to get the project off the ground; perhaps something tied to carbon credits.) By contrast to "Franchise Island", however, stronger regulatory regimes will likely prevent the emergence of local ad hoc last-mile services and arbitrage: Tinsley/Meadowhall is already a staging-point for bulk road freight, so little changes in terms of logistical practicalities on the last mile, and there will be less spare capacity to arbitrage when the bulk of traffic in the system is international long-haul rather than domestic.

Articulations

Figure 8.4 on page 236 shows a speculative articulation for the trialectic under the UK PLC scenario. It bears considerable structural similarity to that of the (preceding) Franchise Island scenario, though there are some crucial differences.

Incumbents:

Carriers C-of-P As in Franchise Island, the carriers community-of-practice has shrunk away from the protagonist, having largely been displaced as the "face" of the service by a consortium of transnational haulage firms. The difference is in the character of the carrier operations represented, which would be less deregulated and ad hoc than under the Franchise Island scenario (though perhaps not a great deal less). Given the limiting of infrastructure upgrades to trunk routes for international freight, the carriers will still have a role to play in inter-regional and last-mile logistics; however, much of this work will be in subservience to the big hauliers.

Fuel distribution Fuel distribution infrastructures retain their position, much as described in section 8.3.1 above..

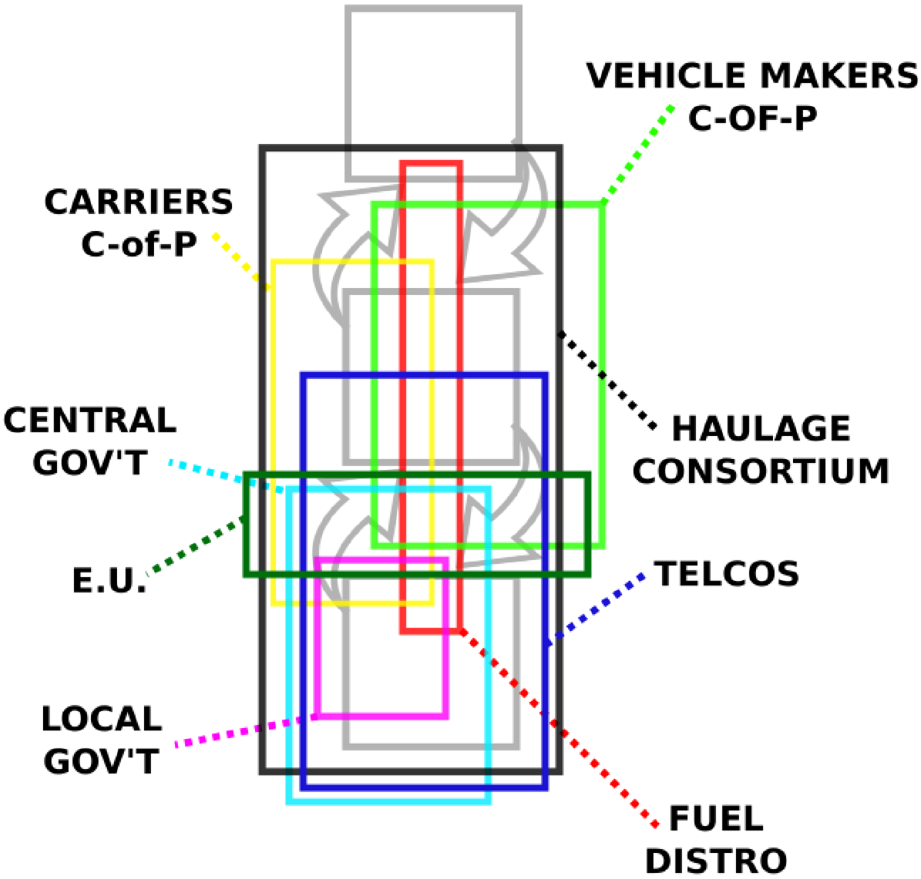

Figure 8.4: Articulatory mapping for UK PLC scenario

Central government, local government, vehicle makers The positions of the two gubernatorial actors and of vehicle makers remain essentially unchanged, much as described in section 8.3.1 above.

Incoming:

Haulage consortium Under the UK PLC scenario, a consortium of international haulage firms takes a similar position to that taken by Amazon in the Franchise Island scenario (see section 8.3.1 above). The extent of its influence is essentially the same, given its assumed role as prime investor in the infrastructural upgrades necessary to make self-drivingness viable on UK motorways. However, the character of its influence is more beneficent (or perhaps just less rapaciously monomaniacal) than that of Amazon, due to both its multiplicity and its subjection to continental laws and regulations (and scrutiny). That said, it is likely to take exactly the same approach to incumbent competitors as would Amazon, even though the circumstances are less favourable to complete market dominance than under the Franchise Island scenario.

Telcos The strong influence of private telcos over the lower half of the assemblage emerges for much the same reasons as are described in section 8.3.1. above: put simply, self-drivingness is a non-starter without considerable involvement from private telcos, not just in terms of infrastructural investment, but also in the development and regulation of an emerging set of system standards for self-drivingness.

E.U. The European Union influence here is, of course, a massive simplification; it black-boxes a number of institutions, agreements, arrangements and precedents for the sake of making explicit an influence which was always implicit in UK affairs through its having been "written into" UK law and trade agreements; post-Brexit, this influence becomes explicit and (ironically enough) less mediated by more local actors and institutions, but is nonetheless largely limited to the S&R and I&I vectors, due to the necessity for the haulage consortium to ensure that their systems work (pretty much) the same on both sides of the Channel.

Outgoing:

Company fleets Company fleets disappear from the scene for much the same reasons as outlined in section 8.3.1 for the Franchise Island scenario.

8.3.3 "The Frugal Kingdom"

Prototype parameters

With a **state-led approach to infrastructural investment**, direct intervention in overland freight systems is at least feasible—although the roads are not necessarily the most obvious candidate infrastructure for intervention. Efforts toward **reducing inequality** are likely to include tax increases and job-creation measures as a hedge against automation, which will make driverless vehicles a hard sell politically as well as technically; however, a **more collectivist political culture** means that benefits other than profitability may play a more important role in decision-making with regard to infrastructure, and an **accelerated devolution process** means that local authorities and communities may be able to propose and enact projects without seeking approval (or funding) from Westminster.

Hard Brexit offers the opportunity for a **regulatory bonfire**... but only around those matters where no concessions need be made to Europe, which is likely to develop its own regulatory framework for self-driving vehicles. A hard Brexit further suggests that the margins on continental overland trade will be further eaten into, which will have the knock-on effect of **reducing overland trade flows**: fewer goods will arrive in or leave the UK on trucks, while more goods will arrive or leave on container ships. A **radical tone to domestic politics** suggests a theatrical approach to policy, wherein the grand gesture delivered swiftly is assumed to trump the more cautious technocratic attitudes of the past. Meanwhile, **serious damage to the UK economy** ensures a steady stream of discontent and protest, and the revival of old-school street politics.

Deployment sketch

Under these circumstances, even a partial deployment of self-driving freight looks pretty implausible. State-led investment is all well and good, but only when there's money to spare, and an isolated UK shouldering a self-imposed austerity is unlikely to look at self-driving freight as the wheel most in need of grease: it would be simpler (and probably cheaper) to instead re-invest in the newly renationalised railways to improve long-haul domestic capacity, and infrastructural projects which promise to remove jobs rather than create them are going to be a hard sell to a bitter, impoverished country.

But the aim of the scenarios is to assume that the disruptor is delivered, so the parameters can be pushed a little further. Assuming that the austerity project is comparable to that of the world wars, and that road freight has been renationalised as well as rail, the opportunity to *impose* a change of assemblage is theoretically available... and rapid devolution (combined with economic desperation) might well allow locations distant from Westminster to make their own infrastructural moves.

However, none of this changes the fact that, under these circumstances, all of the seeming advantages of self-driving freight become disadvantages: it's an assemblage expressly developed to exploit the middleman position (arguably a form of tech-leveraged rent extraction, particularly given the road network is state-funded), which makes it anathema to a nationalised set-up, and in any case its marginal gains on profitability only accrue on long routes (particularly international) with heavy traffic. Nonetheless, the romance of the boondoggle will likely prevail—and loose regulations combined with devolved powers means it might be just about plausible for a syndicate of city and regional councils in the North to be trying to kludge together a very crude and low-budget version of a segregated self-driving freight lane running through the East-West corridor across the Pennines between Liverpool and Humberside; note, however, that such a project would be in competition with the long-mooted restoration and/or expansion of the cross-Pennine rail links.

Articulations

Figure 8.5 on page 240 shows a speculative articulation for the trialectic under the Frugal Kingdom scenario. It represents perhaps the most radical restructuring of the articulatory actors of the four scenarios

Incumbents:

Carriers C-of-P As in both of the preceding scenarios, the carriers community-of-practice has shrunk away from the protagonist, though not quite to the same extent. This shrinkage in general is reflective of the increasing opacity and/or invisibility of material logistics to both senders and receivers of goods; this is the continuation of a trend toward logistics-as-a-service that has marked infrastructural change from its very beginnings, as has been shown throughout sections 5, 6 and 7 of this thesis. However, the shrinkage is less marked in Frugal Kingdom than in either Franchise Island or UK PLC; this is due to a turn toward more socialistic or social-democratic policy under conditions of fiscal austerity, which will serve to slow the rate of change more generally, and in particular impede the gobbling-up and/or subjugation of smaller hauliers, and carriers focussed on last-mile work.

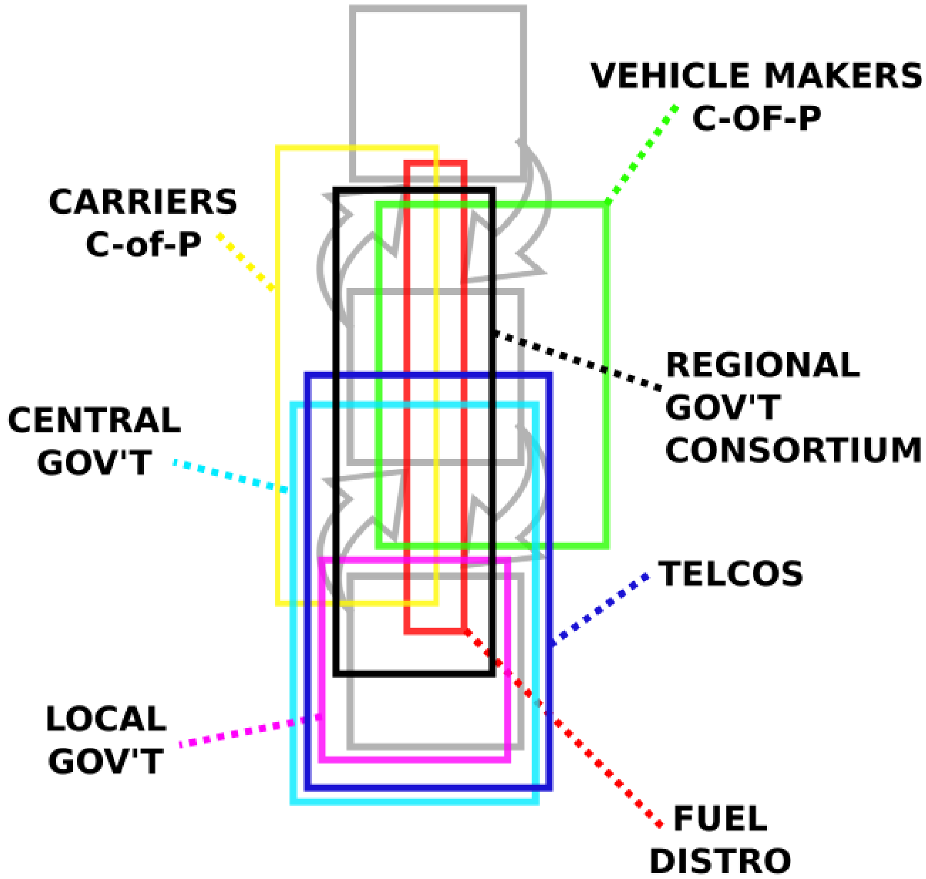

Figure 8.5: Articulatory mapping for Frugal Kingdom scenario

Fuel distribution, vehicle makers Fuel distribution infrastructures and vehicle makers retain their entrenched positions, much as described in section 8.3.1 above.

Central government, local government This scenario sees a significant expansion of the remit of responsibility for gubernatorial actors in the freight assemblage—though this should not be taken to suggest that their control and influence is particularly effective. (Parallels might be drawn with the Nationalisation phase of the railways, discussed in section 7.4, wherein control was similarly reasserted from the centre under conditions of austerity.) Central government gets much more broadly involved with the interface layer and the I&I and S&R vectors, which will bring it into an unavoidable agonism with the telcos. But note that the self-driving freight system realised in this scenario is not a central government project; this sort of capital expenditure on new or upgraded infrastructure is contraindicated under the contextual conditions.

Incoming:

Regional government consortium As discussed in the deployment sketch (see above), the crude deployment of self-drivingness in this scenario is imagined as being a regional effort cobbled together by devolved local government actors in the north attempting to upgrade infrastructure on the cheap under conditions of austerity and economic decline; this consortium might be an evolution of (or even an antagonist to) the Transport for the North (TfN) body, recently (at time of writing) granted some (largely toothless and symbolic) statutory powers, if not much in the way of funds. This consortium has a fairly broad area of responsibility over the assemblage, but rather than indicating its power or authority, this should be seen as illustrating the difficulties it will have in trying to achieve its aims: as can be seen, it has substantial overlaps of responsibility with every other major actor in the articulation, which implies multiple fronts of negotiation and agonism, sometimes with other state actors at different scales and in different locations (central government in London, assorted local governments implicated in the proposed route), and sometimes with privatised industries (telcos, and to a lesser extent vehicle makers). For a small and under-resourced actor operating under austerity, this will be a highly challenging environment in which to achieve even a crude proof-of-concept deployment of self-drivingness.

Telcos The strong influence of private telcos over the lower half of the assemblage emerges for much the same reasons as are described in section 8.3.1. above:

put simply, no concession to telco influence means no viable self-drivingness. If anything, this problem is intensified under the Frugal Kingdom scenario: without any likelihood of capital investment in the legacy road infrastructure, any deployment of self-drivingness will be utterly dependent on telcos upgrading their systems, creating a position of influence that is unlikely to go unexploited.

Outgoing:

Company fleets Company fleets disappear from the scene for much the same reasons as outlined in section 8.3.1: the continuation of a medium-term trend for logistics outsourcing, albeit a trend slowed by the circumstances (as discussed above).

8.3.4 "Not quite Norway"

Prototype parameters

With a **state-led approach to infrastructural investment**, direct intervention in overland freight systems is at least feasible—although the roads are not necessarily the most obvious candidate infrastructure for intervention. Efforts toward **reducing inequality** are likely to include tax increases and job-creation measures as a hedge against automation, which will make driverless vehicles a hard sell politically as well as technically; however, a **more collectivist political culture** means that benefits other than profitability may play a more important role in decision-making with regard to infrastructure, and an **accelerated devolution process** means that local authorities and communities may be able to propose and enact projects without seeking approval (or funding) from Westminster.

A relatively light and orderly Brexit means that **regulations will largely be harmonised** with those pertaining on the continent—and it is international road freight which will be most amenable to driverless technology, as it is only over long routes that the greatest economies can be achieved. As such, **continued engagement with EU goals and priorities**, particularly with regard to environmental matters, would see the UK keen to be involved in any emerging continental system for self-driving freight; however, the same declining demand and systemic challenges will serve to block anything but a limited, segregated deployment. Furthermore, a return to more **centrist political dynamics** means classic technocratic policy-making, particularly with regard to infrastructure: sensible, expensive, and interminably slow. Lucky, then, that Brexit resulted in **minimal economic damage**;

given a sense of having dodged the bullet, the bulk of the population is grateful that things haven't gotten too much worse.

Deployment sketch

Broadly speaking, the deployment in this scenario would likely be similar to that in "UK PLC" above: a limited, segregated deployment on the major trunk routes for European overland freight flows, motivated more by systemic efficiency and reduced emissions than profitability or faster delivery. Better relations with the continent and better financial circumstances might well mean that the project is a little more advanced in the UK by 2032, with a number of major motorways featuring a self-driving lane. In terms of Sheffield specifically, however, the end result is the same: the nearest node of the enhanced trunk route network is at Tinsley/Meadowhall, and the last mile is just as much of a challenge as it is today.

The difference is that in this scenario, opportunities exist for the state to intervene in the last mile so as to enhance the viability (and reduce the carbon footprint) of not only the self-driving system, but the freight network more generally, in which development has tended to focus on lucrative trunk routes while the last mile has been left to rot. As such, we can imagine the devolved authorities of Yorkshire and the East Midlands investing in urban freight distribution systems, keeping costs low by reviving moribund infrastructures such as the Sheffield District rail loop or the canals, and supporting the development of zero-emission last-mile carrier services, such as rickshaws and cycle couriers, through an on-line system (something like Deliveroo) that lets individual operators bid for carrier jobs in their area.

Articulations

Figure 8.6 on page 244 shows a speculative articulation for the trialectic under the Not Quite Norway scenario. It bears substantial structural similarities with the articulation under UK PLC (see above), but there are some important differences.

Incumbents:

Carriers C-of-P The carriers community-of-practice has shrunk away from the protagonist to a similar extent to that observed under Franchise island and UK PLC (see above); as discussed, this is the continuation of a paradigmatic move toward logistical opacity and freight-as-a-service, whereby neither sender nor recipient has much contact with (or interest in, or influence over) the functioning of

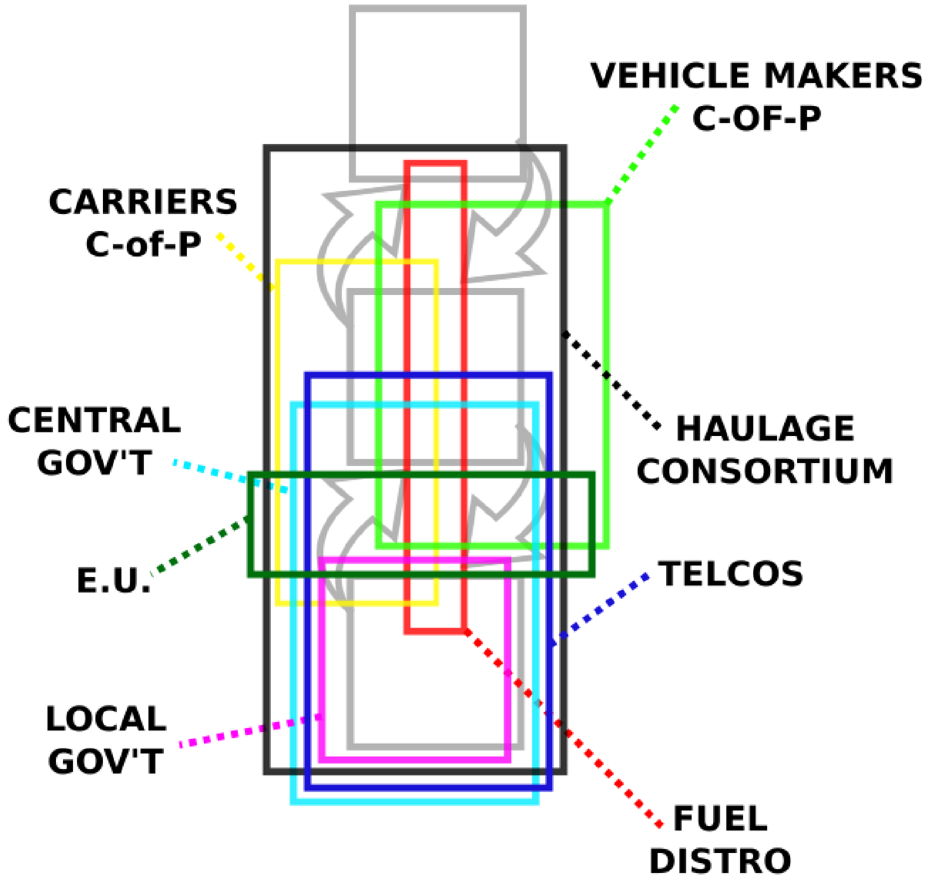

Figure 8.6: Articulatory mapping for Not Quite Norway scenario

the assemblage; by comparison with Frugal Kingdom, the continuation of technocratic infrastructure policy is likely to sustain this paradigmatic change.

Fuel distribution, vehicle makers Fuel distribution infrastructures and vehicle makers retain their entrenched positions, much as described in section 8.3.1 above.

Central government, local government This scenario sees some expansion with regard to the influence of central government over the assemblage, though for very different reasons to that seen under Frugal Kingdom: here, the influence extension is largely facilitative, with the state acting as a broker for the relationships (between the haulage consortium, the telcos, vehicle makes and local government) necessary to bring a complex "multi-stakeholder" infrastructure project together. Accelerated devolution accompanied by relatively reasonable economic circumstances also suggests the expansion of local government influence and responsibility; whether this turned out to be supportive of or resistant to the deployment of self-drivingness would likely vary by location, but it seems reasonable to assume that, once the self-drivingness project was seen to be off the ground, the majority of local government actors would opt for support in hope of gleaning some of the economic benefits.

Incoming:

Haulage consortium The role and influence of the haulage consortium actor under Nor Quite Norway is broadly as that outlined under UK PLC in section 8.3.2 above.

Telcos The strong influence of private telcos over the lower half of the assemblage emerges for much the same reasons as are described in section 8.3.1. above: put simply, no concession to telco influence means no viable self-drivingness.

E.U. The (highly simplified) influence of European Union institutions under the Not Quite Norway scenario is broadly the same as that described under UK PLC in section 8.3.2 above.

Outgoing:

Company fleets Company fleets disappear from the scene for much the same reasons as outlined in section 8.3.1: the continuation of a medium-term trend for logistics outsourcing, albeit a trend slowed by the circumstances (as discussed above).

8.4 Summary

This chapter has demonstrated the use of the trialectic model as a tool through which to draw upon and extrapolate from the precedents of historical infrastructuration, so as to engage in informed and grounded speculation about potential future infrastructuration. In this case, self-driving vehicles were used as an exemplar "disruptor" technology, whose potential impacts upon freight logistics practices in the Sheffield region were explored against the context of four divergent future scenarios, each of which represents a particular blend of contextual opportunities and obstacles for infrastructural development. The trialectic model was reiterated for each scenario, so as to play out a suite of plausible deployments for the exemplar technology; these speculations then informed the development of four story synopses, one for each scenario, which—once developed into full-blown narrative stories—portray the performance of freight logistics practices under the new sociotechnical regime, from the perspective of a fictionalised protagonist.

The resulting narratives or prototypes illustrate a series of challenges to the deployment of self-driving freight vehicles in the Sheffield region, and by implication many other regions of Britain. For instance, it is apparent that the economies of scale which would make self-driving fleets appealing can only be achieved when the network has achieved significant density, meaning there is no advantage for "early adopters", only expense. Furthermore, it is apparent that most of the tangible benefits of self-driving freight accrue to the vehicle's operator, meaning that there is little or no reason for anyone else to be particularly supportive of them: no one else in the assemblage would experience the operation any differently to the way they do at present (particularly in the Sheffield region, where almost all local freight already comes in or out of the city via the logistics hubs at Tinsley/Meadowhall, which is where any self-driving lorry would end its journey). And of course, these problems all presuppose a well-executed and politically acceptable answer to the challenge of integrating (or segregating) self-driving vehicles within a road network already overburdened with human-driven vehicles—easy enough on paper, but hard to actualise (especially if self-driving vehicles become a focus for protests against job losses to technological automation, as seems likely).

It bears noting that these challenges are entangled with one another: for example, the challenges of integrating self-driving vehicles with human-driven vehicles emerges from the necessity of self-driving capacity being delivered as an upgrade to a limited network of already-established trunk routes, while the challenges of finding funding and investment are closely related to to the already narrow profit margins in the freight sector.

The advantage of the narrative prototyping approach is that it can portray these unquantifiable difficulties from a human and non-specialist perspective. Other genres of foresight narrative, such as the feasibility study or the cost-benefit analysis, are constrained by disciplinary "knowledge siloing", able to narrate futures only in the technocratic and quantitative terms of their own enquiry. Narrative prototyping, by contrast, while incapable of the quantitative rigour of other forms of foresight, has the capacity to identify and illustrate systemic and inter-systemic challenges in a rich but accessible qualitative form—and it is that inter-systemic perspective which is most missing from paradigmatic approaches to infrastructural foresight. Narrative prototyping is not a tool of prediction or prophecy, but a sandbox—a low-risk, low-cost space for testing high-risk, high-cost ideas that cross disciplinary and technological boundaries.

Chapter 9

Discussion

Introduction

This chapter begins by discussing the project's achievements and outputs in the light of the three research questions defined in chapter 3. There then follows a series of reflections on the overall methodology of the project, followed by a look back at its overall aim. Finally, the author's personal reflections precede some possibilities for further research which build outward from the work herein.

9.1 Model behaviour: the trialectic perspective on sociotechnical change

The first research question of this project was stated as follows:

> *Starting from a materialist and practice-oriented perspective, how might one model and analyse the mutually influential and longitudinal relationships between everyday consumptive practices and the infrastructures which enable them?*

The model and methodology developed in fulfillment of RQ1 are described in chapter 4. The model, known as the infrastructural trialectic, features three main elements:

- the Protagonist, representing the instigating performer of the practice under analysis;
- the Interface, representing the technological devices and/or commercial services through which the Protagonist accesses infrastructural capacities; and

- the Infrastructure, representing the networks and systems whose functionality is mediated through the use of the Interface.

The three elements are linked by four "vectors of influence", which represent the flow of pressures and desires between the elements, which are often (though not always) agonistic in character: they visualise a contestation for advantage between the model's main elements. By populating the model with the interfaces and infrastructures prevalent during the moment under analsysis, these flows of influence can be traced and explored more fully, thus revealing the contestation between layers as an ongoing process through which the sociotechnical assemblage(s) underpinning the practice in question is stabilised or destabilised, and through which its reconfigurations are shaped.

The trialectic model is accompanied by a methodology that allows the researcher to "build outward" from the core elements of the model, and to produce a map of the other actors and entities involved in the articulation of the assemblage at any given historical moment. This process of articulatory mapping produces a unique visualisation of the actor-networks involved in the (re)shaping of practices, and of the systems which are enrolled in their performance. When applied to a sequence of historical moments in the evolution of a particular assemblage, the result is a series of diagrams and analytical accounts that capture the development and reconfiguration of infrastructural assemblages over the longue duree of history. (This process historical analysis also provides the structured knowledge necessary for the subsequent application of the methodology's second, speculative mode.)

The trialectic model and methodology provide a new way of exploring sociotechnical change at the infrastructural scale, and improves upon prevailing models and theories through three significant achievements. The trialectic approach provides:

- a manageable materialist model of agency in sociotechnical transition, accompanied by
- a situated and systemic methodology, which together produce
- novel and non-heroic narratives of sociotechnical change.

The deeper implications of these achievements in the context of theories of sociotechnical change will discussed in greater detail in section 9.3 of this chapter. A detailed discussion of the methodological challenges encountered in the application of the trialectic (in both the historical and speculative modes) can be found in section 9.4.

9.1.1 Going with the flow: workshopping the trialectic model

An opportunity arose through which the trialectic model might be "road-tested" via exposure to a wide array of practitioners concerned with matters of infrastructure and/or sociotechnical change. As such, a workshop-format session was arranged for the final day (18th May 2018) of the Twenty65 Conference (held in Deansgate, Manchester, UK), an event aimed at bringing together academics, industry practitioners and other actors in the water infrastructure sector.

This particular setting offered the opportunity of access to a wide range of appropriate yet cross-sectoral and multidisciplinary respondents. Furthermore—given the conference's focus on water treatment and distribution infrastructures—it necessitated not only the simplification of the model to fit the workshop format, but the selection of new discursive examples more appropriate to the sectoral interests represented at the event. (Or, more simply: it was not possible to simply reuse examples from the analysis presented within this thesis, so the model had to be reapplied in a fresh problem-space.)

In order to structure and collect feedback on the trialectic model and its usefulness, an anonymised questionnaire was designed (and successfully submitted for research ethics clearance) ahead of the conference, and copies were distributed to delegates who attended the workshop. The questionnaire was designed to gather both quantitative and qualitative responses as to the novelty and effectiveness of the trialectic model within the broader field of models of socio-technical change, and the extent to which it functioned as a facilitator for cross-disciplinary (and cross-sectoral) discussions of the dynamics of sociotechnical change.

The specific questions asked were as follows, with questions 1, 2 and 3 accompanied by a row of boxes numbered 1 through 10 for respondents to mark accordingly, and questions 4, 5 and 6 accompanied by areas in which unconstrained comments might be provided:

- Q1: By placing a tick in one of the boxes below, how different did you find the trialectic model to be in comparison to other models or theories of sociotechnical change with which you are familiar? (1 = "not at all different", 10 = "totally unique")

- Q2: To what extent did the trialectic model make you think about systemic change from a new perspective? (1 = "not new at all", 10 = "totally new perspective")

- Q3: How effective was the trialectic model at facilitating a discussion of the challenges and dynamics of sociotechnical change between participants from different areas of expertise? (1 = "totally ineffective", 10 = "totally effective")

- Q4: What aspect or aspects of the model did you think were particularly good, useful or novel?
- Q5: What aspect or aspects of the model did you think were particularly bad, difficult or overlooked?
- Q6: Any other comments?

Workshop feedback analysis

Taken in aggregate, the feedback from the workshop was generally positive, though far from lacking in substantive and valuable criticisms.

The average of all scores provided in answer to Q1 was 5.9 (n=10); given that a number of respondents identified themselves as being already familiar with (if not significantly experienced in the deployment of) social practice theory, this would seem to be a fairly respectable assessment of the trialectic model's theoretical novelty.

The average of all scores provided in answer to Q2 was 6.6 (n=11); only one score was lower than 5, and this was from a respondent with considerable experience in working with models derived from social practice theory, who as such would presumably be accustomed to thinking in terms and concepts similar to those that the trialectic deploys, and thus unlikely to find its perspective particularly challenging or provocative.

The average of all scores provided in answer to Q3 was 6.7 (n=11); a wider spread of scores in response to this question suggests that, perhaps unsurprisingly, the trialectic model works better for some than for others. Rather more surprisingly, however, the four highest scores all came from respondents who identified as engineering or science academics, while the two lowest scores came from respondents who identified as academic social scientists! (The qualitative feedback from these latter respondents also expressed the most dissatisfaction with the lack of clarity in the workshop's delivery, and with its terminological density.)

The qualitative feedback puts these scores into context, with comments in response to Q4 describing the trialectic as "potentially really useful" and praising it for successfully "expanding out the problem space", "show[ing] complex systems in a very simple model" and "driv[ing] complex thinking". In addition, Q5 generated important criticisms, including the aforementioned complaints regarding terminological density, as well as a series of variations on the theme of the model's complexity, e.g.: "unclear as to how responsibility for decision-making is distributed", "hard to understand initially (particularly category distinctions)", "difficult to distinguish where things belonged", "sometimes not a precise distinction in the fields of the model".

These critiques, I would argue, speak at least as much to limitations inherent in the workshop format as to the model itself. As indicated in the Methodology section, the trialectic is a relational model, with the result that the "belongingness" of any particular element or influence is a function of the context in which it is being applied; however, it is evidently easy to parse this feature as a bug in circumstances where there is little prior familiarity with the trialectic or similar models, and limited opportunity with which to explain it thoroughly. A more hubristic researcher than myself might even go so far as to claim the comment regarding "responsibility for decision-making" as an endorsement of the trialectic's success—after all, as this study has shown (and as shall be discussed below), the precise allocation of such responsibility is all but impossible, as that responsibility is distributed throughout an assemblage of actors in various relationships of alliance and/or contestation. However, it seems reasonable to suggest that this should have been presented as part of the initial framing of the model, rather than emerging as a conclusion to be drawn from it.

The workshop format was challenging, however, for a number of reasons. As already mentioned, the water-sector orientation of the host conference necessitated the provision of alternative examples and case studies to those presented in this thesis. Furthermore, in the terms of the trialectic itself the contemporary assemblages associated with domestic water-consumption practices have been largely stable for the last five or six decades for the majority of UK citizens, and those assemblages have furthermore provided a service that has been effectively unlimited in principle and largely uninterrupted in practice: despite privatisation, in other words, very little has changed from a demand-side perspective, and there has been little or no incentive for it to do so, resulting in a stable assemblage with little action in the DP and I&I vectors other than predominantly aesthetic iterations of interface technologies, or products aiming for efficiencies relating to infrastructures other than water. Or, more simply still: it turns out to be hard to discuss the dynamics of innovation in the context of an assemblage where very little innovation has taken place for half a century or so.

Better results might have been achieved had there been more time with which to delve into historical examples of water consumption assemblages, thereby establishing precedents for restructuration and highlighting the dynamics of change in a manner more akin to that demonstrated in the analysis chapters of this thesis. However, the ninety-minute opportunity in question left no space for such introductory explorations. Nonetheless, the average scores in response to Q1, Q2 and Q3 are significantly generous, and seen in the light of the qualitative responses (as well as the circumstantial challenges attendant on the workshop format) I feel that the trialectic might fairly be said to have made a better showing than might be expected of an otherwise untested theoretical model—and I further feel that, with a more temporally generous format (and greater experience in workshop design and facilitation on the part of its creator), it might do better still in times to come. However, the ubiquity of comments regarding its theoretical weightiness and relational ambiguities suggest that it will always do its best work when applied in the context for which it was developed—which is to say a deep and patient anthropological engagement with the material manifestations of sociotechnical change in a particular time and place.

9.2 A sociotechnical sandbox: narrative prototyping for infrastructure futures

The second research question was stated as follows:

> *Drawing on the model and analysis developed in fulfillment of Objective 1, how might such findings be used as the basis of a speculative exploration of the advantages and obstacles associated with the deployment of proposed future infrastructures?*

It was answered by the development and application of a second, speculative mode to the trialectic model and methodology, in which the findings generated by the application of the first, historical mode (in answer to RQ1) become the basis data for an imaginative extrapolative process of narrative prototyping. This novel process involves selecting a proposed disruptive technology with functional pertinence to the practice under study and assessing its potential for deployment under challenging contextual circumstances through the use of narrative prototyping, an approach that combines features from strategic foresight and critical/speculative design in order to produce critical evaluations of future infrastructures in an accessible form

Having identified self-driving vehicle systems as a disruptor technology relevant to freight logistics, the "black box" of self-drivingness was deconstructed, in order that its applicability to all transport-relevant assemblages might be assessed. Having determined that the technology was most likely to impact upon the road network, it was then introduced into the trialectic model, through which the vectors of influence and dynamics of assemblage formation were traced (with reference to the precedents captured by the historical mode), and the dominant relationships and tensions identified.

Next, a variation on the ubiquitous 2x2 scenario matrix methodology was used to generate a suite of four divergent and deliberately challenging future contexts against which self-driving technology might be assessed. These scenarios were then combined with the iterated trialectic in a speculative yet rigorous process of extrapolation in order to produce deployment sketches—brief narrative summaries of attempts, successful or otherwise, to roll out self-driving freight systems in the Sheffield area under the conditions stipulated by the scenarios.

9.2.1 On the role for criticism in infrastructural foresight

The deep objective of RQ2 was to develop a deliberately and explicitly critical futures methodology for working at the infrastructural scale. Scenario matrices and paper prototypes of all sorts are increasingly commonplace practices, both within the academy and without, but much infrastructural foresight tends toward the technical and/or quantitative: feasibility assessments probe technical viability, while cost-benefit analyses assess the economic case. This is not to dismiss such work as irrelevant, but to highlight its limitations, which are the limitations of a positivist-reductionist epistemology: put simply, such an approach assesses an unbuilt hyperobject as if it were deployed without flaw or error under controlled conditions (or under an assumed continuation of the status quo, which amounts to the same thing).

This more critical take on infrastructural foresight should therefore be seen as a corrective or counterbalance to the inherent techno-optimism of more prevalent approaches. The world abounds with slick slide-decks and glossy visual renderings that extol the glamorous yet sustainable virtues of this technology or that system; this methodology essentially opts to take the technologists at their word and assume that their claims of technical and economic viability are valid under the implicit laboratory conditions of their own assessments, and then subject those claims to the sort of contextual difficulties that such assessments tend to avoid talking about. This methodology hence moves the debate about future technologies from possibility under laboratory conditions to plausibility under the divergent chaos of the actual—a distinction of great relevance to the development of systems that take decades to fund and build, in a world where change itself seems to be the only constant.

It might be argued that a prototyping process in which none of the four imagined deployments is significantly successful would itself be an unsuccessful process, but this is not the case. Indeed, the counterargument might take the form that a failed deployment has far more to teach us than an easy success, particularly with regard to infrastructure-scale project. This is a prototyping process, certainly, but it is also a test-to-destruction—which is a dangerous and/or expensive game to play with actual infrastructures. This project thereby demonstrates the utility of narrative prototyping to act as a sort of sandbox or test rig for systems which are otherwise too large, complex, critical and expensive to experiment with.

9.2.2 On the merits of materialist fictions

It was originally intended that each deployment sketch—which might be considered as analogous to the part of the writing process that science fiction authors and critics refer to as "worldbuilding"—be further developed into full-blown short stories, in which the characters would be depicted interacting with the imagined systems as part of their everyday lives.

This final stage was left out due to time constraints, and not without some regret. The author has made the case elsewhere (Raven, 2017b) that prose science fiction allows for the portrayal of sociotechnical futures in a manner which, done carefully and thoughtfully, can "despecialise" these complex debates. This in turn could open up infrastructural futures to non-expert assessment and debate in a manner almost totally orthogonal to the technocratic "experts only" style of the feasibility study or cost-benefit analysis, which are highly coded generic documents that, intentionally or otherwise, exclude the majority of people. Story, by contrast, can be understood by almost anyone with a reasonable level of literacy, and thus might form part of a consultative outreach strategy which took "stakeholder engagement" on new infrastructural configurations as a vital part of the design process.

However, even the deployment sketches can be shown to fulfil the overall aim of the project, namely to make infrastructure legible, and to narrate it from a more human perspective. To some extent, this is a pay-off from the early insistence on a strictly materialist model, in that a materialist approach results in narratives populated predominantly by actual actors (whether human, non-human or hybrid), as opposed to abstract concepts and categories.

For example, consider this (incomplete) list of actors identified in the first of four deployment sketches (see section 8.3.1): *Amazon; the government of the United Kingdom; haulage firms; vehicle manufacturers; the M1 motorway*. Now, it must be conceded that these are "black boxes" in the strictest interpretation of that term (as it is used in A-NT and related social theories), but nonetheless, they are empirically observable entities: if one chose to do so, one could study their actions.

Now compare with this list (also incomplete, but illustrative) of actors identified in a more traditional transportation futures scenario sketch (Elzen, Geels, Hofman, & Green, 2004): *traffic; transportation; infrastructure(s); pricing mechanisms; congestion*. There are some concrete actors in there, but abstractions abound, as does the passive narrative voice (which results in a somewhat surreal genre of story, wherein broad concepts, insubstantial notions and second-order systemic phenomena react to one another's spontaneous and despatialised provocations, as observed by an omniscient deity with a very weird relationship to time).

The deployment sketches produced in this project, by contrast, tell a story which could feasibly be passed to a novelist or screenwriter in order to form the basis of narratives with which an ordinary person might identify and empathise. While it would be unfair to claim that such is impossible to achieve through the use of traditional scenario methodologies, it nonetheless seems plain that to do so would be much harder work: the narrative prototyping process, meanwhile, gets any would-be producer straight into the action, with a ready-made cast of actors waiting to be given their lines and stage direction.

But in effect, this is to restate the distinction between a scenario and a prototype. Scenarios, as the word implies, outline a scene, a situation; in this case, the scenarios are just a set of contextual parameters, like the backdrop, set and props for a drama. Having dressed the stage, many foresight processes then go on to re-stage the same old stories over and over again, with little or no interaction between the actors and the set: the scenario becomes little more than wallpaper for the laboratory of the assessment, a gesture toward verisimilitude.

By contrast, this form of narrative prototyping goes the full distance, drawing on historical precedents so as to extrapolate actions that are believable in context: both figuratively and literally, it brings socio-technical transition to life. So while this is clearly a form of strategic foresight practice, it stands far closer to design-led methodologies—such as speculative design (Dunne & Raby, 2013) and design fiction (Lindley & Coulton, 2015)—than to the more quantitative and positivist approaches of the business-school futures tradition.

Perhaps most importantly, narrative prototyping is well suited to working with explicitly situated knowledges, in that both are engaged with the specific as a way of accessing the general: as Haraway (1988) has put it, "The only way to find a larger vision is to be somewhere in particular", and this principle has, as far as has been possible, governed this entire project: situated knowledges provide concrete actors, relationships and locations, while "god trick" methodologies can only provide abstractions and placeless phenomena. This in turn approximates the rigorous testing that only the messiness of the actual can provide, and reemphasises the heterogeneity of infrastructural space.

By way of example, while self-driving freight systems for Sheffield are depicted as effectively still-born or stunted in all four scenarios, the results might have been very different for a different location, with its concomitant differences in circumstance and connectivity. Prototyping the very same technology against the very same scenario parameters in London, for instance, might produce more positive results, precisely because the situation of London is more conducive: it is larger, more densely populated, better off, better connected, and closer to the country's dominant source of overland freight; as such, funding and industrial partners might be easier to find, and populations easier to persuade.

With that said, it should go without saying that it would be absurd to suggest prototyping every proposed assemblage in every possible location; but on the other hand, it seems eminently reasonable to suggest that they at least be prototyped in locations where their deployment is actually being proposed, rather than in the non-space of an unsituated scenario.

9.3 Beyond transitions: theoretical implications of the trialectic model

The third research question is as follows:

> *How might this methodology improve or expand our understanding of the concept of sociotechnical transition?*

RQ3 can be considered as explicitly orienting this project toward theoretical concerns, and particularly toward conceptualisations of socio-technical change. Seen in this light, the trialectic model and its associated methodology represent the development of a novel framework for the study of socio-technical change, and a demonstration of its application in a longitudinal case-study.

This project resulted in the development of

- a manageable materialist model of agency in sociotechnical transition, accompanied by
- a situated and systemic methodology, which together produce
- novel and non-heroic narratives of sociotechnical change.

This section discusses the implications of these achievements for the study of sociotechnical change, and for the concept of "transitions" more broadly.

9.3.1 A manageable materialist model of agency in sociotechnical change

The trialectic model starts with the agency of the protagonist—an individual making a technological choice in fulfillment of of the performance of a particular practice. The great advantage of basing the model on SPT is that its orientation toward a specific practice provides a teleological basis for the analysis: in other words, we know the protagonist's basic motivation from the outset, which—when combined with the parameters of their existing performance—allows us to infer the improvements which might motivate them to take up a new technology. Of course, those motivations may be primarily economical: the reduction of overheads is responsible for much technological take-up, particularly in the business sector. But cost is far from the only factor in play: faster delivery and lower rates of spoilage in transit can both be seen to influence modal choices throughout the analysis, with packhorses (somewhat counterintuitively) trumping carts and waggons for delivery speed in the pre-turnpike era, and with waterway transit trumping road modalities for the safe and convenient transit of certain fragile or bulky goods during the same period.

Furthermore, the trialectic is a relational ontology: its elements all interact on the same conceptual plane, and are not structured hierarchically. At this point, one might realistically quibble that the arrangement of the elements in the trialectic recapitulates a hierarchy of sorts, in that the interaction of the protagonist and the infrastructure is explicitly mediated by the interface, which implies some kind of separation. The vertical linearity of the model is perhaps guilty of compounding this impression, and there is also an argument to be made about the relative velocity of change in the three elements (whereby the performance of a practice can be changed almost instantly, while the development of new interface technologies takes time, and infrastructures necessarily change far more slowly).

But what is most important is that none of the elements are seen as necessarily more important or influential than the others: the trialectic represents a network of relationships between empirically observable actors, and any importance or influence for one element or another is a function of the agonisms and linkages between all of them.

This achievement can be seen as addressing the first critique of the Multi-Level Perspective as defined in the literature review (see section 2.1.1), namely that of Agency & Hierarchy, wherein it was shown that the dominant model and methodology for the study of transitions obscures the agency of change by burying it in an ill-defined organisational hierarchy. The accounts generated by MLP-based studies are populated by inventions and technologies propagating themselves through a loosely-defined landscape, competing to be the most rational and economically viable option available. If there is any agency on display in these accounts, then it is largely ascribed to the inventions and technologies themselves, thus embedding the implicit (and demonstrably false) assumption that technologies succeed primarily on their own intrinsic merits; in other words, the MLP and other such models, while claiming to explore the agency of change, tend to locate the agency of change in "innovation" itself, which in turn tends to be concretised as a particular technology or service.

It is thus perhaps the proudest achievement of the trialectic model that it successfully portrays the agency of change as emergent from a complex yet consistent set of relationships between human, non-human and hybrid actors. Each of the elements has its role to play in the formation of the assemblage, and the vectors of influence characterise the foundational agonisms from which the necessity of and desire for change are derived; meanwhile, the articulatory mapping process extends the web of agency outward, thus not only indicating its absolute reliance upon a supporting cast of other infrastructures, actors and institutions, but also visualising the sociotechnical articulations which link them together.

9.3.2 A situated and systemic analysis of sociotechnical change

Perhaps it is more obvious when approached from a practice-oriented perspective, as in this thesis, but it seems inescapable that geographical variance is in fact the key to understanding the dynamics of sociotechnical change. The question, put simply, is "why *here*, but not yet *there*?"—and this situated, geographical approach is an important part of what the trialectic brings to the study of sociotechnical change that dominant paradigms largely eschew. This strategy is both simple and profound: simple, in that it only differs from paradigmatic approaches in the decision to situate the analysis in a particular location (as opposed to within a broad geographical generalisation, such as the borders of a nation-state), but profound, in that it brings a very abstract notion of change—quite literally—down to earth. As remarked above, a situated study of change as set out in this methodology results in analyses populated by empirically observable entities: the actors in the stories it generates are recognisable and relateable because they are drawn from a world that we recognise, and it is exactly this particularity of the situated which, perhaps counterintuitively, gets us closer to the general truth (to whatever extent there is a general truth to be approached)

This achievement shows that the trialectic approach addresses the critique of placelessness leveled at the MLP (see again section 2.1.1), which by contrast is blinded to the actual landscape thanks to its reliance on the abstract notion of "the (sociotechnical) landscape". As a result, the MLP cannot help but obscure the vital and subtle spatial dynamics of sociotechnical transition behind its own theoretical architecture; to borrow from Gertrude Stein, the problem with the MLP is that “there is no ‘there’ there”.

That said, the trialectic approach is far from rigorously spatial in the sense that GIS-based studies are rigorously spatial (though it could be developed somewhat in that direction). In its earlier phases of development, the trialectic model was intended to be married to another form of visualisation which would situate the protagonist in a dimensionally-crushed map designed to indicate their proximity to different degrees of infrastructural affordance; this plan was stymied in part by the selection of freight logisitics as the practice under study (because general-purpose transportation networks are nodally rich, fully duplex and comparatively decentralised by comparison with, say, a water distribution system), but also by the inevitable victory of temporal constraint over intellectual ambition. (It was, in other words, just too much.)

However, with greater resources, and perhaps with a smaller sample (in temporal terms), the trialectic approach could be more closely and explicitly linked to geography than it is herein; given the rich seam of findings from network theory which the situated approach has already revealed, a more rigorously spatialised iteration of this methodology might open up the possibility of an explictly and empirically spatial understanding of sociotechnical change. The trialectic approach doesn’t go anywhere near so far as it stands, but in its insistence on situated knowledges, it nonetheless goes some way to addressing the geographical blindness which is a feature of so much transitions research. Furthermore, the trialectic approach takes pains to not mistake holistic thinking for systemic thinking, as the MLP has been accused of doing (see again section 2.1.1).

Thus the trialectic model and methodology, as outlined and demonstrated in this project, offers an improved perspective on the problem: where the MLP bounds transitions by geopolitical borders, the trialectic approach insists upon a situated study that takes explicit account of spatiotemporal variance and the geographical diffusion of practices; where the MLP incorporates a holistic assumption in its structure, the trialectic approach eschews causality in favour of a systemic perpective, in which the agency behind sociotechnical change is assumed to be emergent from manifold relationships and interactions between all actors, rather than being imposed, incentivised or managed by a privileged few.

In the process, the very concept of transition starts to look like something of a tautology, an artefact of its own analytical assumptions: loosely bounded in both time and space, largely unquantified, loaded with spatial terminology but otherwise unengaged with the spatiality which is intrinsic to sociotechnical change, it acts mostly as a frame within which to assemble historical data into a particular pre-determined sort of story—which brings us neatly to the third bundle of critique.

9.3.3 Novel and non-heroic narratives of sociotechnical change

The trialectic approach has demonstrated its ability to narrate sociotechnical change which falls outside of the established pattern commonly known as "transition". While the relationships at the heart of the trialectic are constant across all of the narratives which it generates, it is notable that this study contains accounts not only of "successful" transitions (which is to say narratives of change in which the focal technology "wins"), but of failed or stymied transitions (e.g. the non-event of steam-waggon freight on roads; see section 5.3), and of declines into redundancy or forced obsolescence (e.g. the buying-up and sidelining of the Sheffield waterways by local railway interests)—all of which, notably, have very little to do with the intrinsic merits of the assemblages in question, and a great deal more to do with the manner in which they fit into the web of situated interests and relationships. This is in stark contrast with the MLP, which (as discussed in section 2.1.1) is quite clearly described as plot-level heuristic for sociotechnical transitions, and as such (unsurprisingly) tends to reproduce the same basic narrative over and over again.

The trialectic model is also a heuristic, but where the MLP might be said to be applying its rules-of-thumb at the level of structure—which is to say, presupposing a plot—the trialectic's rules-of-thumb are applied at the level of agency—which is to say, the trialectic makes some basic assumptions regarding the sorts of relationships involved in the formation and sustenance of a practice, and then allows a plot to emerge from agency, by following the developing relationships and agonisms within which sociotechnical change actually takes place. Or, more simply: the trialectic heuristic *locates and traces a narrative* in patterns of historical data, while the MLP *imposes a narrative* upon historical data.

Of course, both methodologies are fundamentally interpretive, and share some shortcomings with regard to their necessary reliance on secondary sources. But by comparison, the MLP's heuristic is far more deterministic than that of the trialectic, meaning that the trialectic is therefore more broadly applicable to the study of sociotechnical change: it is capable of narrating stasis and failure as well as success. And while success is surely preferable to stasis and failure, the path to the former might be far better illuminated by a more thorough understanding of the latter.

Summary: "transition" as tautology

RQ3 asked how the model and methodology developed in this project might improve or expand our understanding of the concept of sociotechnical transition. In the preceding sections, it has been shown that the trialectic approach highlights and addresses a number of long-standing critiques of the MLP. Given the MLP's paradigmatic status in much future-oriented research on sociotechnical change, particularly the project of decarbonisation, this thesis may be taken as an indication that transitions research anchored in the MLP are unavoidably reproducing a generic narrative of innovation and, in doing so, are overlooking the inescapably spatial nature of sociotechnical change. Furthermore, through focussing its narratives on heroic technologies or innovations, the MLP can only gesture vaguely at the metasystemic interdependencies which underpin the usage (or non-usage) of particular technologies. Ultimately, the very nature of transition as a bounded entity has very little theoretical grounding, which may go some way to explaining its seeming success: when a stereotype is sufficiently broad, you can drape it over pretty much anything.

This project has shown that if we are to think of transition at all, it is perhaps better to think of it not as a bounded entity, not as something that somehow happens to entire populations all at once, but rather as a basic condition of existence in human society. Transition is not "*there*, and *then*", but ubiquitous and perpetual, always-already ongoing everywhere, albeit at different rates and in different directions. The transitions of the MLP are stories that only make sense in hindsight, tautological artefacts of their own analysis; in effect, "transition" is a fairytale that we repeat in the hope that repetition will make it come true.

If we wish to truly understand the dynamics of sociotechnical change, rather then merely describe a dynamic which we imagine might be amenable to certain forms of control or management, then we must abandon the hackneyed plot of transition and return our attention to the actual actors on the stage. The trialectic approach certainly cannot claim a more simple account of sociotechnical change than can the MLP, but the results of this project strongly suggest that the relentless search for simple accounts serves only to obscure the ineluctable complexity of sociotechnical change as it actually occurs. The trialectic approach shows that "innovation" is not inherent in infrastructures, interfaces, institutions or individuals, nor in influencers, product managers, or "change agents". Innovation is in fact a network phenomenon arising from the mediation and (re)negotiation of a pattern of relationships between human and non-human actors. But at the same time, it shows that innovation is spatial, in that infrastructural networks propagate the potential for alternative performances. Armed with these understandings, we might begin to approach the questions of historical sociotechnical change without having predetermined our findings—which in turn might allow us to approach future sociotechnical change in a similarly open-minded manner.

9.4 Reflections on overall methodology

This section gathers a series of reflections on the application of the project's model and methodology.

9.4.1 Breadth: on the matter of metasystemicity

The horizontality of this study—its cross-systemic breadth, if you like—was necessitated by the choice of freight distribution as the practice under study. To reiterate quickly: freight distribution is a practice-as-entity, which is to say a category comprising assorted forms of action which share a common *telos* or purpose, in this case the shipping of goods from one place to another; those assorted actions which comprise the practice-as-entity are practices-as-performance, which is to say that they each represent one particular way in which the shipping of goods might realistically be made to happen. So, the shipping of goods by whatever means is the practice(-as-entity), while the shipping of goods by cart or by barge or by train—or even by some combination thereof—are performances of that practice.

It is painfully obvious with hindsight that one would have been hard pressed to pick a practice-as-entity more broad and basic than freight distribution—broad in that in covers everything from small parcels to industrial-scale commodity shipping, and basic in that such logistical distributive practices are a foundational function of almost every aspect of human civilisation as we currently know it. Or, more simply: there's very few things that we humans do that don't require the moving around of stuff.

Therefore the upside of studying freight distribution was being obliged to look closely at the developmental dynamics of what are arguably the most fundamental infrastructures of all—and in returning to their unglamorous and largely overlooked beginnings, this project has revealed that contemporary calls for cooperative multimodal linkages between distribution systems should be seen less as calls for innovation, and more as calls for a return to an operational paradigm which in fact pertained, in various forms, for almost as long as there have been multiple modes of transport capable of such cooperation. Even containerisation, sometimes described as the *sine qua non* of modern multimodal logistical thinking, is shown to have precedents that predate powered railways.

The selection of freight logisitics also presented "the proxy problem", in that the *instigating* protagonist of a freight practice performance (that is, the person who wishes Article X to be shipped from Location A to Location B) is highly unlikely to be the *performing* protagonist of said performance (that is, the person who loads the goods, drives the vehicle, fills in the paperwork etc.); in essence, the performing protagonist(s) are agents in proxy for the instigator, tasked with fulfillment of the performance on their behalf. This presents few problems for the underlying theory, if any: the diffusion of agency is an explicit assumption all through the methodology, after all, and given the trialectic is a relational ontology—which is to say that its elements are defined by the relationships they are in, rather than any intrinsic properties they possess—multiple substitute or proxy performers are perfectly reasonable; they literally just take one another's place in the assemblage. Indeed, the trialectic actually benefits from this in some regards, as it forces our attention toward the question of ownership and control over the interface layer, which in the context of freight is often only accessible to the public as a service.

Furthermore, studying freight logistics draws attention to the role of private ownership in the systematic undermining of intersystemic cooperation. For instance, the manner in which the Sheffield-area railway interests effectively sidelined the Sheffield canal system (by buying it up, rigging its tariffs, and steadfastly refusing to redevelop the infrastructure in response to changes in interface technologies) is a form of failed or foreclosed-upon transition which is largely absent from the literature—perhaps because said literature is predisposed to the imposition of a standardised heroic narrative of innovation (as discussed above).

However, the depth and breadth of the study was also a limitation, in that it prevented a more detailed or granular look at specific moments, technologies and systems. In one sense, that was the entire point of the methodology, which responded to a desire to get away from modes of analysis which fetishise and conflate "innovation" and "technology"—but three centuries deep by three systems wide was nonetheless an overambitious sample, the richness of which has perhaps resulted in a de-emphasis of the detailed understanding which this study hoped to advance; larger nets can let slip the smaller fish. On the bright side, however, and unintentionally, the sheer breadth of freight distribution ended up providing the greatest potential insights into metasystemicity and the network phenomenology of sociotechnical change (for which see below).

9.4.2 Depth: on the subject of scale

As mentioned above, the trialectic approach is rooted in SPT and A-NT, both of which—but in particular the latter—have a strong epistemological commitment to avoiding "black-boxing". Effort has been made to seek fidelity to these principles wherever possible, but of course, the refusal of "black-boxing" can only be taken so far, particularly in the context of a one-person project with a very broad scope and limited resources.

While there is a strong tradition of system mapping in technical and quantitative disciplines, A-NT is notable for the relative absence of visualisation practices in its application. It is in some respects surprising that a theory whose central metaphor is the network so rarely seeks to trace that network with anything other than words.

Or perhaps not so surprising, given how messy even a fairly simple system can look on paper—particularly when that system is a flat (i.e. non-hierarchical) ontology. It is for this reason that system mapping softwares come with tools for imposing some sort of spatial order on what would otherwise be a tangled cat's-cradle of nodes and edges. By centering the articulatory mapping process on the trialectic model, this methodology accidentally achieves a similar effect, in that it visually organises a complex network of relationships in a way that allows them to be traced, and to be compared ot one another. While no element of the trialectic is ontologically privileged (i.e. none is inherently superior to another), the elements present at the locus or site of the performance are *visually* privileged, as they thereby provide an analytical anchor-point which is consistent across multiple performances and assemblages in the same study, and a pragmatic way in which to deploy black-boxing as a tactic in a research strategy which, in theory, eschews it completely.

The articulatory mapping stage of the process could thus be seen as the point at which black-boxing becomes necessary, if only because representing the relationships hidden within those boxes is incompatible with the metasystemic scale of the enquiry: put more simply, opening up the black boxes on the articulatory maps would make them unreadable and useless. They are, it must be said, pretty complex diagrams already—but they represent an attempt to visualise a very complex set of relationships, so complexity is to be expected, if not actually welcomed. A complex visualisation is surely preferable to no visualisation at all.

9.4.3 Length: on the topic of temporality

The longitudinality of this study plainly contributed to its challenges, but it is hard to see how it could have been avoided in this particular deployment. To be clear, the trialectic and the articulatory mapping process can stand alone: there is no reason it could not be applied to a single practice at a single historical moment in a specific place, and indeed it was designed with this sort of portability very much in mind. For example, the trialectic could be used to study transitions in urban commuting practices during the second world war, or domestic culinary practices of the 1980s: these are both consumptive practices underpinned by one or more infrastructures, and the trialectic was developed with questions of resource consumption (and its reduction) very much in mind.

But the relationality of the trialectic means that, in theory at least, it could be applied at different scales, so as to answer different questions. For example, by treating personal computing hardware as the infrastructural layer and operating system software as the interface layer, the trialectic should be capable of narrating transitions in personal computing operating systems from the perspective of the end user; or, to return to transportation at a different point in the technological stack, by treating the running gear and drive train of a car as the infrastructural layer and the controls, dashboard and interior as the interface, a new perspective on vehicular development and design is opened up—one with people and practices at its heart.

To repeat: there is nothing inherent to the trialectic model and historical-mode methodology that necessitates its longitudinal application, in the manner performed in this project. However, longitudinality *is* necessary in such circumstances as one wishes to deploy the second, speculative mode of the methodology: put simply, there must be a solid base of historical analysis upon which one's extrapolations into futurity are to be constructed.

9.4.4 Complexity: a retrospective role for network theory

As discussed in passing above, the situatedness of the trialectic approach had an extra unexpected advantage, in that by drawing greater attention to spatial relationships, it allowed for the use of a number of concepts and ideas from network theory to assist in explaining the dynamics of sociotechnical change. As discussed in the literature review, the MLP and other theories of change (such as the literature on innovation diffusion) make some light and gestural use of concepts from network theory, but rarely get further than a genuflection to "network effects", which serve as an easy (if flimsy) way to explain sudden punctuations of what had previously been an equilibrium.

At this point it bears reiterating the distinctions between differing disciplinary perspectives upon networks. As discussed at greater length in the literature review of this thesis (see section 2.1.1), there is a strong tradition of quantitative and mathematical analysis of networks, which is underpinned by the discipline known as graph theory. In these traditions, the structure or spatial topology of a network is treated as being related to but nonetheless analytically distinct from its dynamics—that is to say, the edges and nodes of a network (which, in the case of transport networks such as roads, waterways and railways, refer to the physical infrastructures themselves) are considered as a substrate or platform upon which the dynamics of agent behaviours (i.e. the movements of vehicles, goods and passengers around said networks) are acted out; for a more detailed discussion of graph theory, see e.g. Chartrand (2006). This approach is particularly prevalent in network modelling, which seeks to predict—or at least to estimate—the dynamic phenomena attendant on any given network, such as journey times, traffic density etc.; it is understood that the structure and dynamics of a network are necessarily closely related, but from an ontological perspective, network science nonetheless treats them as being analytically distinct from one another. Or, to rephrase, network science sees a difference between "the network" and the agents which communicate, trade or travel using said network as their medium; by way of illustration, network science would see the roads themselves as "structure", and scheduled movements of vehicles around the road system as "dynamics".

By contrast, sociological approaches to networks such as Actor-Network Theory and (albeit less explicitly) Social Practice Theory are rooted in the assumption of a flat ontology—which is to say that such theories would consider the structural and dynamic elements of any given network to be of equal ontological status, and thus analytically inseparable. This thesis takes an approach to network analysis which is far closer to that of A-NT than to network science: which is to say it considers the topology of the network and the behaviour of the agents which use the network as being not just related but mutually constitutive, and thus considers them side by side. It could be argued that the trialectic model at the heart of this thesis (see Chapter 4) in fact reiterates the ontological hierarchy of network science, by way of its distinction between the Infrastructure, the Interface and the Protagonist—and it might further be argued that such a heuristic distinction makes the anarchic tangle of a truly flat ontology far more amenable to analysis. But nonetheless the trialectic does not confer lesser or greater status on any of its elements, with the arguable exception of its privileging of the perspective of the protagonist: from the perspective of the trialectic model, the distinction between structure and dynamics is not just arbitrary, but actively obstructive to the understanding which is being sought.

Nonetheless, this is not to deny the truths of network science—merely to argue that they can be used in a more qualitative and descriptive sense than is traditional to classical network scientific applications. Indeed, the MLP makes use of network-theoretical concepts but, as shall be argued in this section, does so in a gestural manner common to theories of change originating in the Innovation Diffusion literature, which we might describe as being strongly biased toward the dynamic side of the network-scientific ontological dichotomy. The trialectic approach, by contrast, attempts to make qualitative use of both the dynamic and the structural understandings of networks, so as to avoid the MLP's tendency to make a hero of a supposedly innovative interface technology.

Network phenomena are often topological in origin, and the topology of infrastructural networks is an unavoidably spatial matter: it's quite literally all about where things are in relation to one another. But for the MLP, supporting infrastructures are largely treated as contextual externalities to the development of the technologies which depend upon them; relegated to the unmapped wastes of the sociotechnical landscape (until such moment as, seemingly apropos of nothing, someone decides to build or upgrade them), there is little sense of their importance to the success (or otherwise) of the technology under study. So-called network effects emerge from the interconnectedness of actors in a system—and that interconnectedness is made possible by infrastructural networks, which make possible the exchange of resources, goods, money and information. Information science has studied network effects very closely, but while its lessons have been taken up enthusiastically and used to inform the models of planners working to optimise transportation networks, they have made few inroads into the study of the evolution of infrastructural systems, in which transitions and the MLP are arguably the dominant epistemological paradigm.

To reiterate, the MLP *does* acknowledge network effects, albeit in the most simple manifestation thereof, namely that of the "tipping point" at which a given system has added sufficient nodes and connectivity that joining it becomes an ever-more-beneficial option. The canonical example is a telephone network: for "early adopters", there's little to gain in terms of functionality, because there are still very few other users with which to interact. But eventually a sufficient body of subscribers exists that the advantages of joining are clear and relevant to a significant number of the wider population, who then join up as well. This leads to the classic "S-curve" of network growth (as shown in Figure 9.1 on page 269—note that the same shape is echoed in the torrent of undefined arrows illustrating

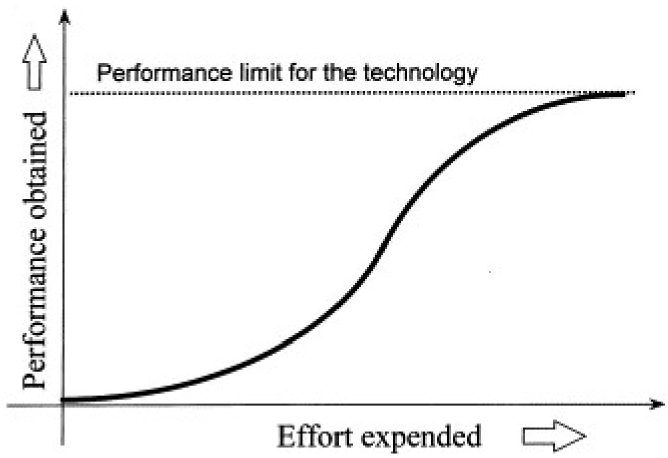

Figure 9.1: Exemplary "S-curve" of network growth / innovation uptake (Nieto et al., 1998)

the MLP's dynamics in Figure 2.1 on page 13), with the near-vertical mid-section of the plot representing the period during which rapid subscriber growth underwrites network expansion and/or densification. A second tipping point, less often discussed, comes at the other end of the curve: at this point, the cost of adding further nodes and connections—the easiest and cheapest "low-hanging" possibilities for expansion having long since been taken up—is larger than the return to be gained from the new subscribers thus added, with the result that network growth slows off to a crawl without significant external intervention. (This growth-killing tipping point can be observed in long-standing issues, still very much current at time of writing, regarding the roll-out of high-speed broadband to rural areas of the UK: no one denies the need to connect that last 5% of the population, but equally no one is willing to foot the bill for the work required.)

Infrastructural networks such as transportation are a deal more complex than the abstractions customarily dealt with in network theory, but nonetheless, something very much like the S-curve can be seen playing out in a plot of transport network growth in the UK (Albert, 1972, p13). This suggests that network theoretical concepts can speak to the developmental dynamics of infrastructural systems other than just telecommunications.

And indeed, the MLP marshals network effects to explain tipping points in the uptake of a technology, albeit in a gestural way. But there is more to network theory than tipping points, and this project has shown that taking a network perspective can illuminate the dynamics of sociotechnical change in a way that the MLP cannot.

The MLP's problem with networks is exacerbated by its focus on the innovation or technology as the "hero" of its analysis: because the generic transition plot sees the heroic innovation as eventually "winning", it is therefore unavoidably seen as being in competition with other technologies that perform a similar function. This model might be more plausible when applied to innovations lacking an infrastructural underpinning, as in such a case the two technologies would be competing on a level playing field with regards to their basic functional viability.

However, technologies not needful of at least one supporting infrastructure are extremely rare—and an infrastructurally-supported technology cannot compete in a location devoid of the pertinent infrastructure. You cannot send something by train if there are no rails between origin and destination; likewise sending by barge in the absence of waterways, or by van in the absence of well-surfaced roads.

Now, in such circumstances as two different systems both link the same two locations, direct competition can indeed occur, as seen clearly with the turnpike and navigation routes between Sheffield and Tinsley. But by looking at the practice of shipping goods more broadly, rather than focussing on one particular technological mode of goods shipping in the manner of the MLP, the trialectic approach can reveal and explain what looks rather more like a form of cooperation or symbiosis, such as that prior to the arrival of the railways whereby certain goods (particularly those with a low value-to-mass ratio) end up going by water, while others (lighter, higher value) end up going by road: these decisions are influenced by the availability (or otherwise) of the relevant network, but crucially also by the affordances offered by the particular interfaces to that network which are on offer (which may well take the form of services rather than technologies, at least from the perspective of the instigating protagonist). Such symbioses can also be observed within the confines of a single system, such as the extensive coexistence of pack-horse trains and waggons during and long after the turnpike era: it turns out that the excellence of any given "solution" is very much a function of the particularity of the performance, and that the supposedly obvious general superiority of, say, waggons over pack-horses, is revealed to be neither obvious nor general at all.

Furthermore, the situatedness of the trialectic approach allows for further complexity to be revealed in the relationships between seemingly separate, competing modes of transport, as it forces the analyst toward the consideration of more complex performances of freight shipping. Any given routing of a shipment may require (or perhaps simply benefit from) using multiple modes to complete the journey, and the advantages or disadvantages of such multimodality are entirely a function of how the different modal systems are distributed in space. These admittedly mundane bases for the selection of one mode or another cannot be accounted for by the MLP thanks to its implicit assumption of infrastructural homogeneity over large geographical regions; the MLP can explain why someone might ship by rail rather than by road, but struggles to explain why someone might send by road rather than by rail, or by some mixture of road, rail and waterway. Without taking the time to consider the spatiality of networks, these systemic interconnections are routinely overlooked or downplayed; through its focus on "winners", the MLP ignores the more quiet successes of intersystemic stability and cooperation—which, as shown in the course of the historical analysis documented in chapters 5, 6 and 7, have been a vital feature of sociotechnical change in the UK since the beginnings of its infrastructural history.

In revealing non-competetive modes of interaction, the trialectic approach leads inevitably outward to an appreciation of the systemic whole as advocated by Latour (see Literature Review), and in doing so manifests another network phenomenon, namely the manner in which seemingly disparate networks or systems actually function as a system-of-systems, or a metasystem. This project has shown clearly that, at almost all points in history, the major transport networks of the UK have evolved alongside each other much like organisms in a large, spatially heterogeneous ecosystem—and indeed, they are vital members of that ecosystem, neither its subjects nor its object. Ontologically and functionally speaking, the three major systems—roads, waterways and rail—are one big system for the distribution of goods; the elements of that metasystem which are enrolled into a particular performance are as much a function of the geography of that performance as they are a rational choice or preference, if not perhaps more so.

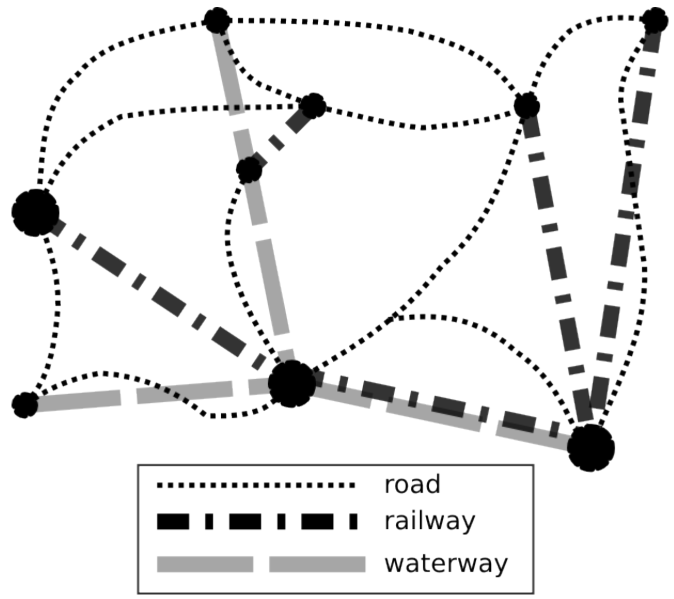

Figure 9.2: Mocked-up regional transport network

By way of illustration, consider the mocked-up regional transport network shown in Figure 9.2 on page 271. There are three different systems or modes represented here, but all of them fulfil the basic function of being able to carry goods between nodes; as such, from the network perspective, this counts as a single packet-switching network comprised of three sorts of edge-connector, the properties of which differ with regard to which sorts of goods they handle best, how much they cost, and how fast they move; therefore selection of the final route (and as such, selection of the mode or modes employed) is governed by the spatial availability of infrastructure in relation to origin and destination (because one can't make use of an infrastructure which isn't there), but also by a swathe of other parameters influenced by the particularities of the performance, dominated in this case by matters such as the mass, quantity and fragility of the goods to be shipped.

To appreciate the full variability of performances, then—to consider all the possibilities of fulfilment, rather than just the most obvious or most popular—it is clearly necessary to look *across* the systemic divisions, because the interconnectedness of infrastructures results in their influencing one another's development, and because the constitution of the metasystem varies geographically. The situatedness of a performance is a vital clue to the composition of that practice, as one's location dictates not only what tools and devices (interfaces) are available to you, but also which infrastructures are accessible through them.

This is brought further into focus through the network-theoretical notion of "the last mile". In communications network theory, the last mile is the final connection between a local exchange and the subscriber's home; because the last mile is only of use for routings in which the client is either origin or destination, it is the part of the network where economies of scale are hardest to achieve (by comparison with busy trunk routes, where bulk traffic can be handled with bulk efficiencies). If we consider freight shipping as a metasystemic or multimodal network, as above, the last mile is (and indeed was) almost invariably a road, and most likely a minor one (which is to say a low-bandwidth connection); anything shipped to that address by rail or waterway would therefore have to travel to or from the nearest railhead or waterway basin using a road-based mode.

The notion of the last mile helps resolve what seem initially to be paradoxes regarding technological transition. For example, it is widely understood that by the start of the 20th century, the steam engine (in the particular modal form of the train) was a vastly superior option for the shipping of freight by comparison with all the others—but yet during this period there were more horse-drawn vehicles in use than in any period prior. The last mile makes it obvious: the train has the advantage right up until the rails run out, at which point goods must proceed to their final destination by the older, cruder and (crucially) more flexible mode of cart or waggon. Again, the two modes, far from being in competition, are in fact interdependent upon one another; indeed, each acts as a source and a sink of traffic for the other.

But metasystemicity is not limited to the symbiosis of transportation networks alone, as the analysis of this project illustrates. All but the most simple routine shipments of goods require exchanges of information to make them happen: they must be organised, in other words. Hence there is another network of communications which must run in parallel with the network of freight—and it must carry information more swiftly than the freight can move, if it is to provide any organisational advantage.

Prior to the advent of rail, information moved by road: sometimes as freight (such as the turnpike-era gazettes of local prices and factors, delivered between towns by carriers), but urgent managerial messages regarding the mobilisation of stock went by the far faster means of a horse- or foot-post. As such, any understanding of the freight metasystem must also include an understanding of the communications network by which it is organised.

That's fairly simple when the communication system uses the same infrastructures as the distribution system, as was the case in the time of the carriers. But the advent of the telegraph—initially a subsystem of the railways, which eventually metastasised in the most spectacular fashion—effectively dematerialised communications traffic over all but the the last miles of the network (where a message would rematerialise so as to be carried to the recipient)... then later, the telephone took over the last mile, and now the bundle of protocols known as "the internet" has upped the bandwidth of the last mile beyond imagining. The point being: the practice of shipping freight inevitably involves the use of systems which seem at first glance to have nothing to do with the shipping of freight. The MLP can only acknowledge this truth as a contextual condition of the sociotechnical landscape, focussed as it is on its heroic innovation, the systems whose existence makes the innovation viable are left outside the analytical frame, meaning that its account of change is partial and incomplete. By contrast, the trialectic approach—with its A-NT-informed commitment to following actors and relationships rather than recapitulating predetermined plots—reveals these metasystemic connections, and thus provides a more complete (if, admittedly, more complex) account of the dynamics of sociotechnical change.

Obviously, there are limits to this metasystemic approach: for starters, utterly unbounded research can only exist in the context of utterly unbounded budgets!

But there is the more obvious and self-enforcing limiting factor of complexity itself—meaning that, while proudly rooted in Latourian opposition to "black-boxing" in sociological research, this methodology necessarily indulges in black-boxing (in the form of the articulatory mapping process), because when working outward from the practice perspective to the systemic perspective—an analytical move analogous to zooming out slowly from the centre of an image—an excess of detail around the edges serves only to muddy the clarity of the relationships at the centre of the analysis. Pragmatic compromise is perfectly acceptable, and indeed inevitable; the strength of the trialectic lies in its anchoring the study at the point of performance, meaning that no matter how far one follows the web of relationships, one can always find one's way back to the performance—to someone doing something.

To give an example of how this might play out for a different consumptive practice, consider the possible performances related to the use of potable water for cooking or drinking in a large city with a significant favela/slum sector. The obvious infrastructure to study here would be whatever passes for a local water-delivery network: wells, pumps, standpipes, mains distribution. But for many people in such a city, those systems may be non-functional or unavailable; for them, water might come on a tanker truck (perhaps state-provided, perhaps private and for profit), or it might come in branded bottles in the back of a rickshaw or the bed of a handcart, or simply carried on foot. And so, all the roads and road vehicles of the city are also potentially part of its water delivery network... and those roads, as we have seen, are dependent on railways and waterways, on electricity and communications, and so on.

Flat ontologies and their implications tend to bring a certain sort of positivist out in hives: if everything is potentially relevant, they will say, then we could be "following the actors" until the heat death of the universe! The words of Haraway are rarely a comfort to such commentators, but she speaks the truth nonetheless: "nothing is connected to everything, but everything is connected to something" (Haraway, 2016b). The point is not that *every* performance of a practice *must* be considered in the context of *every* single element comprising the *entire* global metasystem; it would be improvement enough were they to be considered in any systemic context at all.

9.4.5 Thickness: on the subject of secondary sources

The methodology for this project stipulated a historical method based upon the use of secondary sources, and it should be acknowledged that this is not entirely unproblematic; indeed, reliance upon secondary sources is another critique levelled at applications of the MLP (see again Geels, 2011). However, that critique is specifically concerned with the uncritical reappropriation of top-level narratives of change and their application to inappropriate analytical scales; it's not that they use secondary sources, in other words, but that they use poor secondary sources in the wrong way.

The trialectic methodology, by contrast, clearly specifies the need to seek out sources as specific to the site of study as possible, so as to avoid the implicit homogenisation produced by the MLP. Critics of anthropologies of technology—and of interpretive methods more generally—might argue that what results is description rather than explanation, and there is an extent to which that is true. However, the trialectic model itself serves simultaneously as theoretical lens and sampling strategy, and therefore drives the researcher toward relevant data; the result may be more descriptive and less explanatory than the output of an MLP study, but it has nonetheless produced a variety of detailed and situated narratives of sociotechnical change, which not only highlight the MLP's reproduction of generic narratives but also undermine the very concept of "transition" itself.

Nonetheless, the paucity of sources for the earlier analytical moments bears noting, particularly with regard to the roads, with almost every author of a secondary source bemoaning the lack of primary materials from which to work: the records and accounts of the majority of navigation companies and turnpike trusts were lost long ago, for example, meaning that much has to be inferred from what little data remains.

Furthermore, sources with a suitable focus—-which is to say studies with an interest in the specifics of design and usage, rather than the generalities of statistics—are rarer still, and those covering Sheffield and/or the surrounding regions are of a certain vintage. Fortunately there is sufficient generalisable detail available regarding the early roads that the necessary conjecture can be performed with confidence.

The opposite problem pertains to sources covering more recent periods and systems—sources on the railways, for instance, are plentiful. The story of rail in Britain is often well treated (and indeed well referenced) at the national scale for a popular audience (see e.g. S. Bradley, 2015), but regional and local studies remain the province of the enthusiast presses rather than the academic presses. As such, one is obliged (and not without good reason) to consider the curation of such sources as, say, Chapman (2013) to be well below scholarly standards, poorly referenced and frequently anecdotal.

With that said, the issue is somewhat ameliorated by the nature of the data required for the trialectic approach, because the telling details of functional design and service set-up are fairly objective: while an author may have an opinion on the scheduling of services or the standards for braking, the facts of those phenomena are not changed by their opinion, and hence retain their value for this sort of research. (It is also fortunate that these tend to be exactly the sort of details which enthusiast authors delight in sharing.)

In summary, while the necessity of relying on secondary sources is less than ideal, it is also all but unavoidable—which is why it is such a commonplace in anthropologies of technology. However, the situated and design-focussed approach at the heart of the trialectic methodology makes the best of this necessity, and through insisting on the seeking out of the most locally specific sources available, addresses this potential shortcoming directly—and in doing so demonstrates a rigour regarding that the MLP is unable to match.

9.5 Aim

The aim of this project was to *make infrastructure legible*. This phrasing was chosen for its particular sociological meaning, whereby "legibility"—to oversimplify hugely—implies a new, comprehensive and systemic understanding of a heretofore occluded ontological entity, but also for the more prosaic meaning, wherein that which is hard to parse is made less so.

Quite how comprehensive an understanding of infrastructure the trialectic approach has achieved is impossible to determine, but the understanding developed herein is: a novel contribution to scholarship in the relevant fields; inherently systemic by design; and demonstrably more comprehensive than that of the MLP, which—as has been shown—can only narrate one particular genre of innovation story.

With regard to making infrastructure easier to parse, the speculative mode of the methodology demonstrates a clear and rigorous route through which the complexities of sociotechnical change might be represented not just at the human level, but from a human perspective: this is achieved through the use of fiction, which is less a new technique for thinking about the future than a rehabilitation of the oldest technique known to humankind. By applying the trialectic model to historical data, and through deploying narrative and speculative strategies, this project has advanced our understanding of how infrastructures evolve and entangle over time—and, crucially, provided a tool-set with which to test tomorrow's proposed infrastructures against that new understanding of the obstacles to sociotechnical change and the propagation of new practices.

9.6 Personal reflection

To describe the process of taking a PhD as a journey of (self-)discovery is almost beyond cliche—but cliches are born of deeper truths.

I was greatly privileged to be able to design my own project from scratch, and the central aim thus reflects a genuine curiosity which the past four years have served only to sharpen. Before joining the academy, I had spent about as much time thinking about infrastructure as the average person, which is to say hardly any. But working as an RA on two EPSRC "sandpit" projects from the infrastructure theme, while also writing a Master's dissertation which used science fiction storytelling as a way to explore the relationship between the fabric of a city and its citizens, brought me to a point of wanting to understand how it was that I could have spent so little thought on infrastructure. What did it mean? How did something so essential, so ubiquitous, somehow nonetheless slip from public view, hiding in plain sight? How did it—did *we*—end up this way? And how might it end up in another twenty, fifty, hundred years?

With the benefit of hindsight, experience and the extensive comparison of notes with other postgrads, I'm not surprised that many of those early questions remain unanswered—they appear to me now as high-level markers of a rich, fascinating and complex problem domain that it is far beyond my abilities or capacities to ever exhaust. Indeed, those questions still exercise me now, despite four years spent trying to answer just one aspect of them. This sense of having barely scratched the surface of a subject is commonplace among newly minted PhDs, I'm told; I consider myself fortunate that this feeling is not accompanied in my case by frustration and/or ennui (though I would quite like to not have to think about networked freight logistics for the next six months or so, if at all possible).

As a mature student from an arts background, I had a great deal to learn about academic work in general, and about sociological work in particular. Creative writing is most definitely a discipline, in the sense that it can be taught and it must be practiced, but it is a solitary discipline with considerable teleological headroom—which is to say that while you have to discipline your writerly backside into the chair (and the words onto the page), there's little in the way of obstacles to doing whatever seems needful at whatever pace feels appropriate, with the obvious exception of one's final deadline; in terms of project management, the variables are almost all under your own control. By contrast, an interdisciplinary PhD positioned somewhere between civil engineering and urban studies turns out to be a deal more complicated, not least because one is denied the fiction writer's greatest prerogative, namely that of simply *imagining* one's way out of a tricky corner. Reality, by contrast, while far from being as objectively real as the label implies, sorely lacks the fertile tractability of the blank page, and has a knack for disrupting the most careful and lapidary plotting (as "change agents" and "transition managers" everywhere are doubtless aware). And while only a madman or a braggart would claim writing fiction is easy—because it's never easy if you want it to turn out any good—I will claim with some confidence that writing a thesis is harder, because it has to do so many different things at once. (And, if truth be told, fiction always wins on the fun factor... after all, it's the closest you can get to playing god without getting involved in politics or investment banking.)

That said, I have observed many similarities between the phenomenology of large research projects and the phenomenology of large fiction projects—most notably the manner in which, toward the end, they end up keeping you occupied in a very literal sense. There have been weeks of working on this thesis when I have been all but unable to see the world without seeing it as a theatre or laboratory in which theories and models of change spool themselves out before me; weeks when I've been unable to tell whether the project is inhabiting my mind, or my mind is somehow inhabiting the project. I used to never see infrastructure for looking; now it feels rather more like I can't see anything other than infrastructure.

I was also pleased to find that science fiction scholarship had done more to prepare me for becoming a social scientist than I had expected it to. In part, this is because science fiction criticism has always been strongly engaged with theory, and in particular with theories of technology and sociotechnical change; I was thereby exposed to some basic ideas and applications, which I hope have been shown to serve me well. But there is also a sense—utterly unquantifiable and self-reported, to be sure—that thinking with social theory and doing the work that we writers of genre fiction sometimes refer to as "worldbuilding" are strangely similar; they seem to exercise the same sets of imagination-muscles, so to speak. And so perhaps the greatest self-discovery of all is that there was a frustrated social theorist trapped inside of me, seeking release through science fiction... and while I look forward to (re)establishing a regular fiction writing practice in the wake of my PhD, I also hope to also develop this new, related skill, and put it to good use. (The irony here, of course, is that social theorists are only marginally more employable than are science fiction writers.)

On a more personal level, I've learned a great deal about how the academy functions (not all of which I'm happier for knowing, in truth); I've learned a great deal about mental illness, and how it interacts with stressors over which you have some control (e.g. one's thesis project) as well as those over which you effectively have no control at all (e.g. national and global socioeconomics in the dog days of neoliberal capitalism); I learned that the right sort of exercise regime actually makes you less tired, not more; I learned that the world of academic research is full of opportunities to do interesting things and write interesting work, and I learned that if you try to do all of them at the same time as trying to finish your PhD, you'll be insanely busy and quite possibly make yourself ill more than once (but will have nonetheless managed to do a bunch of interesting things that you might never have had the chance to do otherwise).

But perhaps most importantly, I saw a fundamental finding of my research being mirrored back at me from the process of the research itself. This project has shown that "innovation"—which is, after all, just a fancy B-school word meant to frame change and difference as a marketable product—is not inherent in individual actors or objects, but is instead a function of the networks of relationships between actors. And while the ideas and theories herein are very much my own work, I could not have developed them into this project without being embedded in a network made up of the support, knowledge and criticism of my fellow academics.

I thereby tentatively conclude that people, perhaps, are the ultimate infrastructure.

9.7 Where next?

Having developed and demonstrated a methodology for making infrastructure legible, it would be good to see how well it works at different scales, and in different contexts.

For example, this project's chosen practice-as-entity, freight logistics, was deliberately picked for its breadth and fundamentality; it is also, as discussed in section 4.2.3, a proxy practice, meaning that the practice is performed on the behalf of the instigating protagonist by one or more proxy actors. In order to assess how effectively the trialectic methodology can work at different scales, then, it would interesting to deploy it into a project with a tighter focus; this could be achieved by selecting a more personal practice with a domestic setting (such as dishwashing, for example), and using the speculative mode to explore the reconfiguration of such practices around new technologies touted as sustainable alternatives. Such a project might also adapt the speculative mode into a more participatory process, whether through enrolling other researchers into the scenario development and prototyping processes, or even engaging directly with citizens through workshops and other forms of action research.

It would also be interesting to see how well the trialectic model holds up in other contexts, and whether it might serve as a truly generalisable model of sociotechnical change. The trialectic has been developed within and applied to the British context of infrastructural development, but how would it fare in a location where infrastructural history is not 300 years deep but only 100 years deep, or shallower still? Will it be capable of narrating the rise and fall of assemblages in countries that have experienced infrastructural "leapfrogging", such as the African nations that skipped over landline telephony and went straight to cellular? In light of the funding opportunities emerging from the Global Challenges Research Fund, there might also be justifications for not simply applying the trialectic approach in developing countries, but also retooling it for specific contexts in collaboration with local researchers. So, rather than use the trialectic to describe how innovation happens in other countries, one might instead teach researchers in other countries how to (re)use the trialectic to work it out for themselves—which would be in keeping with the spirit of *jugaad*, if nothing else!

Chapter 10

Conclusions

Introduction

In this chapter, conclusions are drawn regarding the fulfilment of the aim and objectives of the project. As captured in its title, the underlying aim of the project was to *make infrastructure legible*; this goal was given more concrete expression in three defined objectives, which took the form of research questions. Those research questions are restated in the sections below, accompanied by conclusions drawn from the preceding chapters, which represent answers to the questions. In the the final section, conclusions are drawn regarding the fulfillment of the overall aim of the project, and its unique contributions to knowledge are identified.

10.1 Conclusions in fulfillment of RQ1

The first research question of this project was stated as follows:

> *Starting from a materialist and practice-oriented perspective, how might one model and analyse the mutually influential and longitudinal relationships between everyday consumptive practices and the infrastructures which enable them?*

This objective is fulfilled through the description of the trialectic model and the accompanying methodology for its application to longitudinal case studies, a process referred to as "articulatory mapping" (see chapter 4).

The Trialectic Model

The trialectic model is in itself a unique contribution to infrastructure scholarship, and arguably also to the literature on innovation. Its novelty consists primarily in its being a fully materialist model of socio-technical change which traces the mutual influences of practices and infrastructures upon one another, as mediated by an evolving array of intermediary technologies. The main advantages of the trialectic model are as follows:

- it is a relational materialist ontology—which is to say that, while it necessarily relies on conceptual categories (protagonist, interface, infrastructure), those categories emerge from clear relationships (hence 'relational') between empirically observable entities (hence 'materialist'), as opposed to emerging from arbitrary hierarchies of scale or abstract theoretical constructs; or, more simply, it is a theoretical model that deals only with things that actually exist(ed);
- it represents sociotechnical change as an emergent function of multiple complex relationships, as opposed to the result of linear and/or hierarchical causalities—which is to say that, in stark contrast to prevailing models such as the Multi-Level Perspective, it explicitly embeds aspects of network theory in its account of how networks develop, thus enhancing its explanatory power by reference to a highly relevant but oddly overlooked field of study;
- it substitutes the prevalent economic models of human behaviour with the more generous and humanist model of social practice theory, which better reflects cutting-edge qualitative understandings about how consumptive practices are shaped, and reframes consumption reduction challenges (e.g. grid decarbonisation) as being distributed across a complex network of actors, rather than resting solely on the shoulders of "the consumer".

In summary, the trialectic model builds upon social practice theory so as to represent sociotechnical change in a manner that explicitly rejects abstract sociological concepts and hierarchies, favouring instead a longitudinal close focus on the things people do, and on the technologies and systems which they use in the course of doing them.

Articulatory Mapping

The articulatory mapping methodology is a novel application of network-centric social theory (such as Actor-Network Theory) to a materialist model of sociotechnical change rooted in social practice throry. Taking the trialectic model (see above) as its foundation, articulatory mapping serves to further explore and visualise the tangle of organisational and institutional actors which mediate the agonistic relationships of the trialectic, which in doing so serve to articulate and stabilise the sociotechnical assemblages which underpin consumptive practices. Or, in other words: articulatory mapping explicitly situates the action and agency of people doing things with technology within the web of objects and organisations which make doing those things possible. The main advantages of the articulatory mapping methodology are as follows:

- it produces a relational visualisation or "map" of a given sociotechnical assemblage at a given historical moment and location; useful in its own right, such a map might also serve as the outline for a project of more detailed research into a given technology at a particular historical moment;
- it thus allows for the comparison and contrast of the developmental histories of seemingly different infrastructural systems across different historical epochs and locations; this in turn opens up the possibility of drawing conclusions regarding sociotechnical change which are system-agnostic, if not necessarily universal;
- it reveals (and also, in truth, is somewhat hampered by) the inescapable interdependency of infrastructural systems, as it traces the ways in which such systems have competed, cooperated, compromised and collapsed with the passing of time.

In summary, the articulatory mapping methodology allows for the visualisation of the full extent of a given sociotechnical assemblage at a given historical moment, which further allows for the comparison of seemingly disparate assemblages, and for loosely generalizable conclusions regarding the dynamics of sociotechnical change over the long term.

Both the trialectic model and the articulatory mapping methodology have been shown in this project to draw on archival, academic and other sources so as to successfully capture historical moments of sociotechnical change associated with one specific practice-as-entity (namely freight logistics) across three different infrastructures, and to analyse them in terms which are largely context-independent.

While applied here only to a single practice-as-entity, the results imply that that the combined model and methodology should be equally capable of handling other consumptive practices in the same way—indeed, freight logistics may have been among the practices *least* amenable to this approach, given the analytical complications arising from the "[x]-as-a-service" business models which have dominated it historically; it seems likely that practices with a more domestic locus, wherein interface technologies are predominantly under the direct control (if not the ownership) of the protagonist, will present fewer explicatory challenges.

10.2 Conclusions in fulfillment of RQ2

The second research question was stated as follows:

> *Drawing on the model and analysis developed in fulfillment of Objective 1, how might such findings be used as the basis of a speculative exploration of the advantages and obstacles associated with the deployment of proposed future infrastructures?*

This objective is fulfilled through the description of a specifically future-oriented "speculative mode" (see section 4.3) of the model and methodology developed in response to Objective 1, and its use as the front end of a process of scenario creation and narrative prototyping adapted from futures studies and critical/speculative design practices (as documented in chapter 8).

While neither the scenario generation process or the notion of narrative prototyping are novel in and of themselves, it is unusual for such methods in combination to draw upon situated longitudinal qualitative studies as input data; and while scenario-based exercises are not uncommon in research oriented toward infrastructural strategy, both the explicitly narrative form of this project's final outputs and its explicitly critical teleology mark it out as a clear advance from the academic and consultative status quo in this sector. The advantages of the narrative prototyping process are as follows:

- it enables the use of longitudinal studies of sociotechnical change as the basis of informed speculation regarding the challenges attending the deployment of proposed future infrastructures;
- it allows for the "stress testing" of a proposed future infrastructure against a suite of differing and deliberately extreme contextual circumstances, thus highlighting worst-case outcomes which more "reasonable" or "realistic" scenarios would never reveal;
- both the process and its final outputs can inform strategic planning and decision-making regarding future infrastructures at local, regional and national scales;
- it can represent speculative future assemblages in a 'despecialised' form, thus broadening the potential audience for such representations, which in turn might open up discussion and debate around future infrastructures to audiences beyond the academy and the policy circuit: the Cost-Benefit Analysis report is a highly specialised genre, whereas almost anyone can understand a story.

In summary, the narrative prototyping process fulfills Objective 2 by synthesising the findings of a longitudinal study (the definition and application of whose parameters and methods represent the fulfillment of Objective 1) and extrapolating them into four different futures through the medium of narrative prose; this process allows for an informed and, most importantly, *accessible* exploration and critique of proposed future infrastructures, and the difficulties in deploying them under uncertain sociopolitical circumstances.

10.3 Conclusions in fulfillment of RQ3

The third research question was stated as follows:

> *How might this methodology improve or expand our understanding of the concept of sociotechnical transition?*

Current UK and EU research into sociotechnical change at the infrastructural scale is dominated by the literature on transitions, and by the Multi-Level Perspective model at its heart. In the literature review (see section 2.1.1), the following shortcomings were identified in this framework:

1. the MLP relies on theoretical abstractions and arbitrary hierarchical structures which presuppose the nature of the articulatory relationships which stabilise sociotechnical assemblages, making its explanations somewhat tautological;
2. despite its reliance on geographical metaphors (e.g. niche, landscape, regime), the transitions model is frequently applied with little or no consideration to the spatial distribution of the phenomena with which it is concerned—it is a placeless, universalising theory;
3. despite its interest in infrastructural networks and the technologies which depend upon them, the MLP (and the transitions literature more broadly) has little or no regard for network theory.

It is concluded that this project addresses these issues, albeit incompletely, as follows:

1. the trialectic model and its associated articulatory mapping methodology has no hierarchies, only relationships—it is a "flat ontology", and entirely materialist in its formulation (which is to say that it deals only with empirically observable entities);

2. the explicitly situated application the trialectic and the articulatory mapping process replaces the idealised conceptual landscape of the MLP with the more contingent and problematic landscapes of history and geography, in which practices (much like infrastructures and technologies) are unevenly distributed: in doing so, it reveals the concept of transition as an over-reductive population-scale description of a complex, highly granular phenomenon which actually emerges from countless individual relationships and transactions;

3. the trialectic and its associated methodology are intimately informed by network theoretical concepts (e.g. bandwidth, availability, "the last mile"), which serve to reveal and explain some of the obduracies, failed innovations and systemic declines that the transitions literature has struggled with, ignored or glossed over.

In summary, the trialectic model and its associated articulatory mapping methodology are shown to address three significant shortfalls in the dominant approach to sociotechnical change at the infrastructural scale: theoretical idealism (and the false objectivity which is its product), placelessness, and network illiteracy.

10.4 Fulfillment of aim and contributions to knowledge

The core aim of this project was defined as follows:

> It is the aim of this thesis to *make infrastructure legible*: to narrate it from a more human-centric perspective than that which prevails in the majority of contemporary research in the field. In less lyrical terms, the project aims to understand how infrastructures develop, how they evolve and entangle over time.

It is concluded that the aim is fulfilled: as indicated above, the trialectic model and its associated methodology are rooted in social practice theory and informed by the flat ontologies of Actor-Network Theory, which provide a more human-centric perspective on innovation and sociotechnical change than the managerial "god's-eye view" of prevailing approaches to such questions; the outputs of the case studies to which the trialectic model were applied, and the outputs of the narrative prototyping process concretise that perspective, and in doing so provide a vivid, grass-roots account not only of the infrastructural reconfigurations of the past, but the potential reconfigurations of the future.

As regards contributions to knowledge:

- the trialectic model is an entirely novel and original contribution to the literature on sociotechnical change, and arguably also to the innovation literature;
- the articulatory mapping methodology, while based on established branches of social theory, represents a novel combination of social practice theory with Actor-Network Theory, and is capable of producing a novel visualisation of the relational structure of sociotechnical assemblages;
- the narrative prototyping process is largely comprised of established techniques from futures studies and speculative/critical design (albeit deployed in somewhat off-label ways), but the application of such techniques to data produced by situated longitudinal qualitative case studies is distinctive, as is the insistence on narrative prose stories as the final form of the outputs.

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