IMPERIAL COLLEGE LONDON

Stability and change in large technical systems:

The privatisation of Great Britain's railways

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April 2015

Submitted to Imperial College in fulfilment of the requirements for the degree of Doctor of Philosophy.

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I confirm that the work contained in this thesis is my own. The work of others has been appropriately cited and referenced.

ABSTRACT

Established infrastructure systems, such as telecommunications, energy and transportation, play an important economic and social role in the societies they support. Recent infrastructure privatisations and restructurings provide opportunities for improving our understanding of how change occurs in well-established mature systems. Some outcomes, including accidents and failures, have taken system-builders and policy-makers alike by surprise. This research seeks to improve understanding of infrastructure system change by studying a momentum changing event: the privatisation and restructuring of Great Britain's railway system.

The Multi-Level Perspective (MLP) and Large Technical Systems (LTS) theory are used together to examine system development before, during and after restructuring. A novel method is developed using LTS theory to structure data generation from contemporarily written archive sources. Two empirical studies are conducted. The first study analyses the gradual development of this mature system; it highlights the importance of the installed system in development and identifies several system-builders. The second study considers changes in system development that occurred across system privatisation and restructuring; it finds that changes emerged in actors and in activity within the socio-technical regime and it highlights some critical changes linked to later system failure.

This work provides three contributions to existing research. (1)The method developed provides a systematic approach to studying established LTS across the broad scope and long periods necessary to capture change; it has the potential to be applied in other studies and could facilitate cross-sector and cross-study comparisons. (2)An extension of LTS theory is proposed that improves its application to the cases of established infrastructure systems and can enhance understanding of the way they change. (3)In considering potential system transformation of the system privatisation, the use of LTS and MLP framework is advocated. LTS theory is used to operationalise the socio-technical regime concept to address some of the limitations of the MLP framework.

ACKNOWLEDGEMENTS

The completion of this work in this form would not have been possible without the care, support and inspiration I received from colleagues, friends and family.

Imperial College Business School and the EPSRC provided the resources and teaching to complete the research. Fellow students and staff in the Innovation and Entrepreneurship Group at Imperial College and in the wider innovation studies community have offered insights, feedback and lively debate. Particular thanks go to Lars Frederiksen, Ammon Salter and Markus Perkmann for their guidance and to my fellow PhD students for their inspiration and company.

This work owes a great debt to the many members of the UK railway industry and the railway research community who have engaged with and supported the research. I wish to acknowledge, particularly, the writers and editors of Modern Railways magazine that is an important data source for this work; colleagues in the Rail Research UK Association that introduced me to this complex and fascinating industry and Francis How for his support and for illuminating discussions on innovation in rail. Special thanks go to the railway engineers and managers who were interviewed as part of this work and who welcomed and supported this inquiry.

I have been fortunate to benefit from the able and generous supervision of James Barlow and Andrew Davies. I am extremely grateful to James for his time, guidance and insight in shepherding the research through the final 18 months of work and the form of this document is, in no small part, due to his dedication. Andy has guided this work from beginning to end and has been an architect of the experience as well as the research; he saw potential in the case study and has offered ideas, insight and wisdom throughout its development and mine. No matter what stage the research or the depth of a state of crisis, I never left a supervision meeting feeling worse than I started it and I almost always felt immeasurably better! Thank you.

From tea to time-keeping and chatter to childcare, I have been supported and cared for by my friends and family throughout this endeavour. More tea, cake, West Wing, laughter, prayer and friendship have been offered over the last few years than I thought possible. The support of the Lovell, Jackson, Dixon del Tufo Ward, Austin and Women's Group families has been so important; I have been blessed with the company and kindness of some wonderful people.

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

INTRODUCTION

This dissertation investigates the development of established infrastructure systems. These large technical systems provide services such as water, energy and transportation; they underpin economic and social activity in the society they serve. These systems offer potential for societal shift or a basis for stability; they have the ability to change the way we live: to improve it or to undermine it. This research seeks a clearer understanding of how mature infrastructure systems change, shift and transform.

The theoretical foundation of this research comes from the work of Thomas Hughes. He recognised the distinctive characteristics of Large Technical Systems (LTS) and asked how they came to be developed, grown and established. In studying the development of electricity systems he observed and abstracted a mechanism of system change which is applicable across time, space and system; this theory of system change through reverse salient correction is at the core of this thesis and it is the means by which a novel method is developed to allow the study of large, established systems over time; this is described in chapter 4.

The Multi–Level Perspective (MLP) view is underpinned by similar principles to LTS research: both consider different types of activity (technological, economic, political etc.) and the connections between them, both model development in terms of a trajectory and each is consistent with a view of the world as a *seamless web* (Hughes, 1983) of connections and interactions. The MLP was developed to consider how technological transitions take place (Geels, 2002) and it provides a framework for analysing interactions between a system and its environment. However, the MLP is difficult to operationalise and research in this area been criticised for methodological weaknesses (e.g. Genus & Coles, 2008; Smith et al., 2010). This research considers these two frameworks, LTS and MLP, together to examine the privatisation and restructuring of established infrastructure systems; it also explores opportunities for overcoming methodological barriers by using the LTS, reverse salient correction, model of change to operationalise the MLP concept of sociotechnical regime.

The relatively recent phenomenon of privatisation of mature infrastructure systems in Europe highlights the incomplete understanding held on the development of mature infrastructure systems. Many nationalised infrastructure systems were reorganised and privatised in the 1980s and 1990s. These reconfigurations of infrastructure systems (Summerton, 1994) provide a series of natural experiments for the study of change in LTS.

The empirical case of Great Britain's railway industry across its privatisation in the mid-1990s is used to consider how mature infrastructure systems develop and change. The industry, background to privatisation and the form of the reorganised system are introduced, incorporating infrastructure systems concepts, in Chapter 2. It was one of the later infrastructure system privatisations in the UK

and, unlike some earlier examples, it was initiated with little encouragement from the existing system members. Initiated from outside the system, an established and high-momentum national infrastructure system is reorganised changing organisational structures for operation and for development, initiating a new mode of governance and requiring a new structure for regulation but many of the individuals working within the system remain and the established, installed system being developed and operated was not reconfigured.

Using the method developed in chapter 4 three phases of development in the railway system are studied; a sample of development activity, in the railway's infrastructure, is taken from each. The study presented in chapter 5 uses these data to investigate how established infrastructure systems change. This study of within-system change in an established system highlights the importance of the installed system for directing and enabling system development; it also finds that, even under the nationalised, vertically integrated, British Rail, there was more than one focus for system development. In chapter 6, the data samples of activity for system development, combined with interviews with system actors, are used to examine the sociotechnical regime in action and their comparison shows changes in the way the system is being developed before and after railway privatisation. Support is found for the suggestion that system reconfiguration can lead to discontinuities in the sociotechnical regime directing system development (Markard & Truffer, 2006). The system takes time to re-establish development practices and some dangers of this time-lag are highlighted.

This research develops a novel method, based on LTS theory, for studying the development of mature infrastructure systems using archive industry publications. An extension to the LTS model of system change is proposed to assist its application to change in established infrastructure systems. These tools are applied within the MLP framework to consider how mature infrastructure systems change and the place of momentum-changing events.

What is infrastructure and why study it?

National infrastructure is a set of underlying structures and services offered to individuals and organisations operating within a nation state and its provision is overseen by governments; it includes utilities and transport systems. More generally, infrastructure refers to something provided outside the frame of reference of an activity being discussed and which is taken as given. For example, the IT infrastructure within a firm provides a service or platform for the activities going on within that organisation. Infrastructure can be built to enable activity or pre-existing infrastructure can provide the basis and inspiration for activity.

Some national infrastructure, what Helm (2010) refers to as 'the core network utilities', has a significant portion of its utility embedded in a substantial physical network. These systems are the focus of this research. However national infrastructures can also deliver functions such as healthcare and education

(Helm, 2010). Infrastructure, whether it is at firm or national level, provides the foundations for activity. It offers a consistent and reliable interface with which to interact for industries, firms or individuals. Part of its purpose is to generate stability, to bring the complex and chaotic environment under control and to provide a known interface to users.

Despite part of the purpose of national infrastructure systems being to provide stability, they also develop and change (Summerton, 1994). Long installed systems are extended, they contract, they are updated to make use of new technologies and to meet (or even generate) new needs developing in society. In some respects, however, they are a special case for the field of innovation studies. These infrastructure systems are connected to their past more strongly than products which have developed into their current form and identity through many cycles of design, manufacture, use and disposal. Hughes (1983), in his study of how electricity systems have emerged and developed, refers to the idea of society, technology and geography being formed around an established infrastructure system as the *soft-determinism* of a high-momentum system.

To survive, an infrastructure system does not need to be the best possible solution but more valuable than the combined cost and benefit of a new installation. However, unlike more disposable products, this presents infrastructure systems with the challenge of remaining relevant both to users and, more broadly, its setting over long periods; the available technologies and the expectations of users will be formed by more than the existing and competing systems but also by broader societal and technological developments. The twin challenge for an infrastructure system then is that it must continue to provide stability in the important dimensions of interaction for the organisations, physical systems and individuals that use it whilst keeping pace with a changing environment: its possibilities and its expectations.

Overview

A background to systems thinking and its use within this research is presented in chapter 1 and both LTS theory and the MLP are introduced. The application of these theories to understanding change in established infrastructure systems is discussed further in chapter 3 and they are used to introduce a novel method in chapter 4. Chapter 2 provides a background to the railway system in Great Britain. The empirical studies are presented in chapters 5 and 6. Chapter 7 concludes.

1 THEORY PERSPECTIVES

How do infrastructure systems change: this chapter introduces systems and complexity concepts and considers their place within innovation studies theory. It sets in context and introduces the two core frameworks used in this work: Large Technical Systems theory (LTS) and the Multi-Level Perspective (MLP).

The transport and utilities networks on which many societies rely are composed of many components, procedures and agents. Change in one of these systems has to reflect the connections between the many and diverse elements of which it is constructed. Component changes need to acknowledge and incorporate connections to other system components. However, system change is about the system's performance not that of each component and so change in components needs to be guided by system needs and the contributions being made to system performance by other components. This interconnectedness is a central part of examining innovation in national infrastructure systems. Literature illuminating innovation of and within an interconnected whole is discussed below.

1.1 Systems and complexity theories

Since the early twentieth century there have been several waves of scientific activity which have characterised the progress of science as being focused on the understanding of increasingly small components and which have reacted against this approach; these movements have sought to investigate the behaviour of *wholes* or *systems.* General Systems Theory began to emerge between the First and Second World Wars; it responded both to the emergence of technological systems accompanied by new challenges and to the earlier investigations of this type occurring independently in different academic fields (von Bertalanffy, 1968). General Systems Theory was intended to provide concepts, language and logic for systems ideas to be applied coherently across diverse fields (von Bertalanffy, 1968). These ideas have entered the study of innovation, most notably through the work of Simon (1962), Rosenberg (1969) and Hughes (1983)[1].

A more recent wave of these ideas is found in complexity theory, which is also concerned with the behaviour of complex systems and focuses on the phenomena of complexity and emergence (Maguire et al., 2006). This view was brought into economics through the works of Arthur (1989) and David (1985) amongst others. Unlike neo-classical economics, these ideas emphasised the importance of history; as a result economic historians, like Paul David, whose work on path dependence is featured below, were amongst the first to work with and develop these ideas in economics (Waldrop, 1992).

Although both systems and complexity ideas have entered into the management and innovation literatures, Richardson & Midgley (2004) point out that they entered the field separately and that despite

[1]According to Dosi (1982) Hughes's work was one inspiration behind the work of Nelson and Winter (1977; 1982) which, in turn, was an important foundation element for what became innovation studies.

many similarities the two traditions rarely interact. Both sets of ideas entered into the social sciences from initiation elsewhere, both have important foundations in biology as well as significant contributions from physicists (von Bertalanffy, 1968; Waldrop, 1992) and, most importantly, they are both concerned with interconnectedness driving behaviour: the messy reality! Richardson (2004) finds that, although two separate literatures remain, the early distinctions have started to break down, leaving a substantial conceptual overlap between these two seemingly independent streams of research.

The systems and complexity literatures do not appear to be inconsistent but they do present different approaches (Richardson, 2004). Organisation research which features complexity ideas tends to take a positivist approach (Anderson et al., 1999; Richardson, 2004). Much of the research touching on complexity theory in innovation is model- or simulation-based, so much so that Frenken's (2006) review of complexity science and technological innovation only considers the use of modelling techniques in the field. By contrast, innovation research, supported by a systems perspective, has tended to focus on the construction of systems, as an abstraction or way of manipulating a complex reality, and on the role of designer or system-builder in creating man-made systems (e.g. Simon, 1962; Rosenberg, 1982; Hughes, 1983).

Infrastructure systems encompass physical, procedural and human elements; they are initiated and developed into systems through deliberate action, and the work of system-builders is an important factor determining system form. The national infrastructure networks of transportation and utilities can be seen as attempts to tame a complex and chaotic world and to push it into predictability through the creation of controllable interfaces and bounded activity. Ideas on emergence and complexity are incorporated into this work as they provide a direct connection to the chaotic world from which systems-builders attempt to generate predictability; however, to consider change in existing infrastructure, a systems view is taken.

This research studies the railway system of Great Britain and the empirical work focuses on the railway infrastructure within this system. The railway system incorporates the physical, organisational and procedural elements that lead to the operation of railway services in Great Britain. Drawing the boundary around the elements that contribute directly to this outcome is not simple. Particularly for the analysis of the development of a system, what is perceived as 'the system' by system actors is relevant because if a designer has influence over two components they can be developed with reference to each other whereas something that is not considered within his remit will be taken as given or necessary parameter will be specified. As a result the starting point for identifying the system boundary is everything that was under the control of the British Rail Board in 1992[2]; however, as discussed below,

[2]This is referred to as the 'core system' in Table 2-1.

it is possible for what is considered to be within the system to change over time and this work does not define the system boundary *a priori*.[3]

1.2 Applying a systems perspective

It is not the intention of this work to argue that a systems view is always the best way of viewing the world. A systems view allows connections or interdependencies between elements to be acknowledged and included as an important part of the story to be told. Although the presence of interdependencies can occur by accident due to the laws of physics and human interaction, the recognition and acceptance of their presence is part of their continued influence on system development. An important characteristic of many settings where interdependencies are important is that those who develop them recognise interdependencies and incorporate them into development decisions. This can be through designing elements and their interactions by accepting the wholeness of a system (Rosenberg, 1982) or by attempting to adjust them so that they can, to a point, be allowed to develop separately, as is the case in modular design (Langlois & Robertson, 1992). This acknowledgement of system-developer(s) and their decisions discriminates between the complexity and systems streams of research; this factor drives the selection of the systems tradition here. Infrastructure systems tend to be technological structures which have been conceived and developed as a system. For example, see Edison's construction of a system for the delivery of electric light (Rosenberg, 1982; Hughes, 1983): the *light bulb* was only the beginning.

The concept of 'a system' does not lead to a clearly defined set of objects but to a way of viewing the world to help understand its behaviour. In analysis, the application of a systems view and the identification of 'the system' under consideration depend on the study to be carried out; for example, a railway vehicle can be treated as a system, perhaps by the manufacturer, or as a subsystem within the railway system, perhaps by an operator or system-developer. Setting and analysis need to be considered together.

The established infrastructure systems considered in this research incorporate an installed physical network and have high inertia (Hughes, 1987). A useful distinction for these systems, not dwelt upon at other stages of development, is the distinction between the operation of a system and its development. The distinction is brought into focus by considering systems literature which deals with complex products; for example, Complex Product Systems (CoPS) (Hobday, 1998) research that analyses how the designing organisations of items like high-speed trains deal with developing their complexity and producing innovations within their products. These products are rarely *thrown over the wall*[4] between designers and operators but these are two distinctive functions; the interaction between them is itself an

[3]For example, there are instances of the heavy rail system ceding lines to various local, light rail initiatives over time.
[4]Completed items are moved from one stage of their design or manufacture to the next without further communication between the parties conducting each stage.

interesting site for investigation (e.g. Davies 2004). In the early phases of the development of infrastructure systems a similar interaction of emerging design and proposed operation might be expected to that within the CoPS literature; however, in extending systems research to deal with the updating and further development of now established and operational systems, considering the way operations and development interact for them is important.

1.2.1 What makes a system more of a system or more in need of a system view?

A systems view acknowledges not only the role of parts but also that of their interactions in generating the behaviour of a system. This is captured in the common characterisation of systems, with a phrase dating back to Aristotle (Richardson, 2004), as *being more than the sum of their parts*. For example, in a highly influential paper in the management field, Herbert Simon loosely describes a complex system as *'... one made up of a large number of parts that interact in a nonsimple way.'*; by way of clarification he adds *'...given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole.*' (Simon, 1962, p.468).

There need to be many, and usually a diversity of, components involved in a system; not, perhaps, to make it a system but to make it necessary to treat it as one or to have need of systems ideas.[5] However, it is in the connections between the components that the 'wholeness' or 'systemness' is held. These connections prevent the analysis of the whole as *a collection of parts.* Hughes identifies interdependencies as a key characteristic of infrastructure systems; alteration or removal of one component requires appropriate adjustments in other components (Hughes, 1987).

There are two concepts at work here. One deals with the nature of each connection and considers the responsiveness of a link between two elements; this can be referred to as interdependence (e.g. Baldwin & Clark, 2000) or coupling (Perrow, 1984; Weick, 1976). The other is about the density and pattern of connections throughout a system; this has been captured with the terms complexity (e.g. Simon, 1962; Perrow, 1984), unpredictable interdependencies (e.g. Brusoni et al., 2001) and intensity (Beckman, 1994).

Connections between elements

Considering system development, when designing a physical artefact, the connection between two elements has been described as an interdependence existing between the design parameters of two components (e.g. a mug and its cap: Baldwin & Clark, 2000, p36). When generating a design for an artefact or organisation to meet a particular function there are many of these interdependencies to be navigated and an appropriate set of parameters, encompassing all of the relevant variables, needs to be

[5]In some work 'scope' has been used to characterise the number of connections/elements present within the system (Shenhar & Dvir, 1996; Hobday et al., 2005).

assembled; where interdependence exists, linked variables will need to have their parameters allocated with consideration of each other. A design can be considered a point within a performance landscape which is generated by the relevant variables and potential parameters to be selected; highly interdependent variables (in responsiveness and number) lead to rugged landscapes, and this affects the process of search/design decision-making (Levinthal, 1997; Baldwin & Clark, 2000; Flemming & Sorensen, 2004).

Another discussion of such connections uses the term *coupling*. The extent of a connection is encapsulated in the idea of tight or loose coupling (Weick, 1976; Perrow, 1984). The extent of coupling between two elements is a function of the responsiveness of the connection and the distinctiveness between the two elements (Weick, 1976). This becomes clearer when the language of the modularity literature is used: the coupling of two elements is described in the interface between them and the more clearly that interface is defined, creating a more precise distinction between the elements and a clearer description of the ways in which they are linked (i.e. the parameters which cross it, for example, the temperature output of component A could be processed into an on/off switch in component B), the more visible the connection becomes.

The connections between elements exist within physical products, organisations and combinations of physical and human elements within a system. Through the terms coupling, interdependence and interface these connections can be abstracted so that the type of element (though not the interface definition) is not important.

Pattern of connections

The pattern of interdependencies between components is sometimes referred to as complexity. This is expressed in the idea that a system can be large and complicated but also linear (Perrow, 1984; Maguire et al., 2006) and that it is the interdependencies venturing off a linear path which generate complexity or the unpredictabilities or emergence in system behaviour. Such interdependencies often arise through the search for efficiency in design or material; for example, waste heat emitted from an engine is often used elsewhere in a system.

Modularity when used as a design strategy, which is one approach to managing the development of systems, uses redundancy in design to manage complexity. One approach is to rearrange the allocation of activities between components to reduce these non-linear interactions (Baldwin & Clark, 2000). Another application of redundancy is in interface design. This makes inter-component interactions explicit through interface specification and uses design rules to constrain module development in order to manage interdependencies (Baldwin & Clark, 2000). This approach to system development freezes interface specifications to allow modules to develop independently for a period of time. Where

interfaces can be controlled by neutral entities, modularity can be used for long-term segmentation of systems so that developments can be managed locally (e.g. Langlois & Robertson, 1992).

The distinction between development and operation is not always explicitly made within systems conversations in the management literature. In the fields which consider products as systems (CoPS and modularity) system design, and the way it is managed by firms, is often the focus; in Perrow's (1984) work on *normal accidents* there is an emphasis on operation, though the relevance of the development decisions to that operation is implied. In Weick's (1976) important paper on loose coupling applied to organisations, each focus – operation and development – is taken in different places.

When dealing with systems with a significant role for physical (and therefore deliberately designed) elements, the need for the distinction between the two different viewpoints, of design and of operation, on a system becomes clear, as does the root of the distinction, time. When dealing with two linked elements, to an operator they may be independent (except under rare circumstances), whereas a designer needs to consider all states of a system within its intended operation and therefore can see a channel for connection which might only be used in the case of an accident (e.g. Perrow, 1984). Orton & Weick (1990) review the idea of loose coupling and find that the dialectical approach, incorporating both responsiveness and distinctiveness, is not always retained; a clearer use of the distinction between development and operation may assist that. Perrow's (1984) work focuses on the operation of physical systems and does not incorporate distinctiveness as part of ideas on loose/tight coupling, but distinctiveness in this context is likely to be constant most of the time. By contrast, it is clear, from both Perrow's (1984) and Orton & Weick's (1990) work that responsiveness varies with operation; for example, component A reaches temperature x, which switches an input to component B; these elements are not responsive most of the time but interact at crucial moments.[6] Weick's (1976) original article clearly identifies his interest to be in persistently coupled elements, so although not claiming to have design control over these connections his viewpoint appears to fit with that of a designer.

In the development of a system a designer or system-builder can make choices that affect the form both of each individual inter-component relationship and of the pattern of interdependencies that exists throughout the system[7]. They have a range of interdependence options available and their decisions affect the forms of interdependencies felt in operation. Where an operating system continues to develop, operators' needs and practices formed on the current system are likely to influence decisions to change the interdependence structure. In developing these, systems operation is expected to be more important in the system-builders' processes than would be captured in research on the design of product systems and, similarly, operators may take a role in initiating or guiding system development in mature

[6]Were this connection being dealt with by a designer, the interaction channel for these components and the communication between them would need to be designed for all states of operation.
[7]The system's architecture.

operational systems. This distinction between development and operations perspectives is referred to throughout this dissertation. Refocusing on system development and considering how systems change, the next section discusses how innovation theory applies to systems and considers the needs or peculiarities involved in changing collections of interdependent elements.

1.3 Innovation in systems

The idea of innovation advancing knowledge via a trajectory is well-established within innovation studies research and these ideas are also present in frameworks for the way systems change. That technological advance takes the form of a trajectory is linked to *path dependence*; as David (1985) so ably illustrates with his discussion of the history of the QWERTY keyboard, today's decisions are influenced by decisions and events of the past.

Dosi (1982) extended Kuhn's (1962) ideas on the progression of scientific knowledge to the area of technology. Dosi (1982) defines technology as knowledge and argues that it advances through the establishment of technological paradigms, which define the 'relevant' problems and direct the development of knowledge for their solution. The *'pattern of "normal" problem solving activity'* (Dosi, 1982, p152) within a technological paradigm forms a trajectory of development. Nelson and Winter (1977; 1982) present the idea of *natural trajectories of progress* and institutionally formed *technological regimes* which guide technological change.

When investigating the development of technological systems there is an additional consideration in the connections between different system components as they develop. A system can be conceived as having a technology trajectory, or a set of bound trajectories, of its own (Dosi, 1982; Hughes, 1983; Geels, 2002).

In a section of the innovation literature treating products as systems, modularity and systems integration, different approaches to managing system complexity in its development are considered. A modular approach uses redundancy (Simon, 1962) and design rules (Baldwin & Clark, 2000) to loosen the coupling at certain interfaces within a system; connections between components[8] are made explicit so that their development trajectories can advance without continuous reference to one another. In the case of systems which display tight coupling between components or which cannot make the connections between modules explicit, an approach is needed within design and manufacture which acknowledges the need to manage interdependencies between components (Brusoni et al., 2001), for example the design of an aeroplane which anticipates fuselage lengthening once testing and further development have taken place (Rosenberg, 1982).

[8]The use of the term 'components' here incorporates assemblies and subsystems, it does not only refer to the lowest level of the hierarchy.

Two frameworks which consider how large interconnected systems develop and change, and which target systems considered as more than physical components, are discussed below. These frameworks, Large Technological Systems theory and the Multi-Level Perspective, are particularly appropriate for considering the extreme cases of *systemness*: infrastructure systems. These are the perspectives upon which this dissertation builds.

1.3.1 Large Technical Systems Theory

Hughes's (1983; 1987) work on Large Technological Systems (LTS) considers how infrastructure systems came into existence and how they develop over time. Hughes (1983) bases much of his work on a detailed study of the emergence and growth of electricity networks and the work led by Edison; however, he is able to generalise by considering work of other inventor-entrepreneurs (e.g. Elmer Sperry) and by following the transfer of the idea of the system to other geographical settings. Hughes (1983; 1987) creates a framework for the way in which systems expand, develop and mature.

Technological systems *'are both socially constructed and society shaping'* (Hughes, 1987, p51). Hughes (1987) is very clear that these systems are created by individuals working within the constraints of an existing environment. For example, the technology being developed needs to compete with certain specific systems and be developed to attract various stages of funding. There is not one technological solution which drives all else. In considering the transfer of technological systems to new settings, Hughes (1983) shows that even systems based on the same technological core can take very different forms in different local environments, so a system is constructed to be appropriate to its environment. Hughes (1983; 1987) uses the concept of style to describe such variations in technological systems across settings.

Hughes considers that system components are present for and interact towards the achievement of the '*common system goal*' (Hughes, 1987, p51). He employs the concepts of *reverse salients* and critical problems[9] to explain how a system develops and expands to aid or improve its ability to meet its goal (Hughes, 1983; 1987; 1992). Reverse salient refers to a point in a front (military or weather, for example) which is held back (Hughes, 1992). This image of an advancing line emphasises the interconnectedness of system components and how it is their combined performance that matters to system controllers and users.

Once a reverse salient has been identified as holding up system performance (relative to the system goal) a critical problem is defined, by those seeking system development, in response to the reverse salient which will be eliminated with its solution (Hughes, 1983). There is an important distinction between the identification of a reverse salient and the definition of the critical problem to be solved to

[9]These are similar to the ideas of bottleneck and focusing device, respectively, introduced by Rosenberg (1969), also when discussing the development of systems.

eliminate it. A reverse salient is obvious to those within the system (Hughes, 1983, p22) and is, therefore, not open to manipulation (except through alteration of the common understanding held of the system's goal). However, the critical problem to eliminate it is constructed by system actors and is open to resulting direction (Hughes, 1987).

So the pattern of reverse salient identification and correction underlies all system change regardless of the individual system-builders and the system's technology, size and maturity. However, the way the system picks up and responds to reverse salients is open to influence and agency by system developers; the same reverse salient could be moved forward the same amount using different areas of expertise. For example, the reliability of a physical component could be addressed through redesigning the component (likely to be overseen by design engineers) or through redesigning maintenance processes (likely to be overseen by operations specialists or maintenance engineers). Decisions like this (and those at the lower level, part of the redesign) are where agency is acknowledged in this framework for system change and the principal problem-solvers developing the system are referred to as *system-builders* (Hughes, 1979; 1987). Although Hughes does not address it directly, this framework also leaves open the possibility that the definition of the system goal being referred to may be able to change over time.

Hughes (1983; 1987; 1992) presents a framework for how systems develop and change; he finds that over their establishment and life, systems acquire style and momentum. This makes them more difficult to change. In different phases of system development different actors take on the identification of reverse salients and the definition of critical problems, providing change in the way the system changes. Although acknowledging its possibility, Hughes (1983) does not dwell upon the breaking of momentum or the reconfiguration of mature systems. This is considered in this dissertation. The redirection of system trajectories or the replacement of one system with another is considered in research into technological transitions which is discussed below.

1.3.2 Technological transitions and the Multi-Level Perspective

The Multi-Level Perspective (MLP), a framework for how systems develop and change, has emerged from research on the establishment of technological transitions, the development of a new trajectory to replace a mature system, and system transformation, the substantial redirection of existing trajectories.

The replacement of one technology trajectory with another can also be viewed as the replacement of one system by another (Geels, 2002). The focus of the MLP, a sociotechnical regime, builds on the concept of technological regimes (Nelson & Winter, 1982). This is extended beyond a cognitive focus on problem-solving to incorporate existing knowledge bases, physical system, engineering practices, operation, technologies and institutions (Kemp et al., 1998). Like the technological regime, the concept of the sociotechnical regime considers the way in which decisions are made about changes to the system. Sociotechnical regime incorporates the idea of focus by engineers and decision-makers, the heuristics

through which decisions are made (e.g. reducing mass per passenger in aeroplane design is identified as a good thing). It also encompasses the structures around engineers' focus which will influence it, such as the existing physical system and knowledge bases available to draw upon.

The central idea of the MLP is that this sociotechnical regime generates a particular technology trajectory; it will select ideas and move the system along that trajectory. For a system to follow a new trajectory a new sociotechnical regime needs to be established and significant changes in the existing trajectory would be accompanied by modifications in the sociotechnical regime (Geels, 2007). So the focus of this view is not so much on the redevelopment of a system but on the redevelopment of the way that that system is developed.

Within the MLP framework the sociotechnical regime represents the system level and the treatment of a set of interrelated elements as a system will be embodied in that regime. However, the MLP incorporates three levels of analysis and considers how an industry or system connects with the broader social landscape and with idea or technology development. The concepts of landscape, sociotechnical regime and niches make up the three levels of the MLP which are represented graphically in Figure 1-1. The argument made in research focusing on technological transitions is that developments on all three levels need to link up and reinforce one another for a transition (a switch to a new trajectory) to take place (e.g. Geels, 2002). This is to say that support and reinforcement from the landscape and niche levels are needed for a new sociotechnical regime to be established.

A system is set within a broader social landscape and it will both work within the landscape's constraints and contribute to it. For example, the landscape will provide the education of individuals, the rules of doing business, the way individuals might wish to use a system and the technological principles available to draw on. An example combining landscape and a change in sociotechnical regime, in the setting of water provision for a city, is the increased social importance of cleanliness connecting with technology selection and development norms in the water industry's sociotechnical regime which will then adjust the technologies incorporated in the water provision system (Geels, 2005a).

A system is also affected by niches for technology development. These are sheltered environments incubating new technologies and, with them, new (local) sociotechnical regimes; they define the setting of a technology and direct the development of what could become a new system or a major element adjusting the existing system. Geels (2002; 2007) argues that a change in system technology trajectory will come as a result of a technology being developed within such a niche, possibly set in part of the existing system (e.g. an R&D lab or one part of the shipping market (Geels, 2002)). Many niches will be in existence and few will connect with the system level and become the basis for a transition or transformation of a system (see Figure 1-1); for such a change to take place the niche will need to align itself with needs present in the landscape perhaps not met by the existing system. Later work on the MLP framework has found that different patterns for transition are possible. Changes do not have to be

initiated by an expanding technological niche but, for example, a disruption to the sociotechnical regime might encourage the advance of a niche technology into the main system (Geels & Schot, 2007).

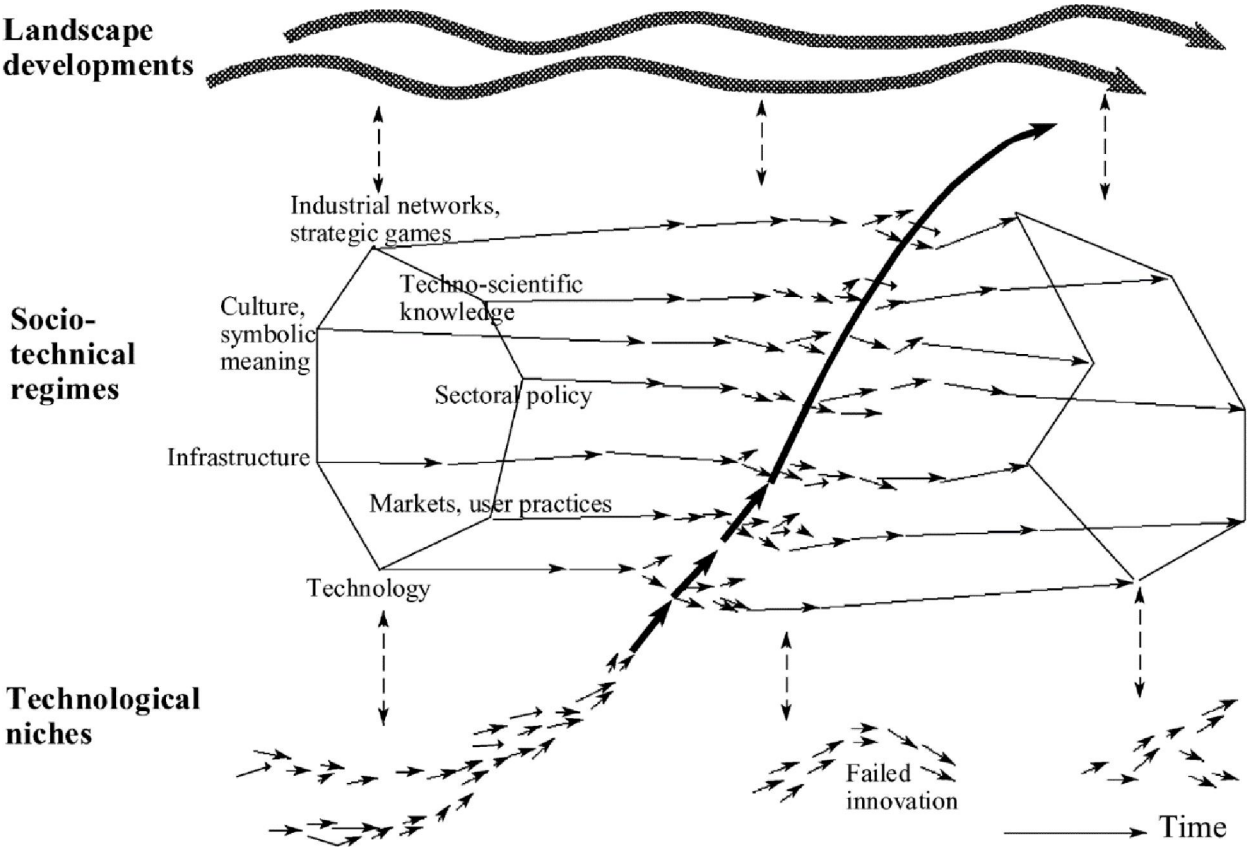

Figure 1-1 A dynamic view of the MLP for technology transition (Geels, 2002, p1263)

The MLP focuses on transition and transformation of existing regimes and contains several mechanisms of this kind of disruptive change in a world of acknowledged interconnectedness. However, it can be characterised as an 'outside-in' theory which leaves the within-system mechanisms and determinants of change direction undefined (Geels, 2005b; Shove & Walker, 2007; Geels, 2010). This leads to difficulties in operationalising and testing this framework. In this dissertation I apply the MLP to frame the privatisation event, building upon its strengths as a framework for study of system-environment interactions, whilst acknowledging and seeking to address some of its weaknesses with respect to mechanisms of change.

1.4 Summary

In considering infrastructure systems, human and physical elements are involved and the development and the operation of a system are not as easily separated as in cases where an artefact is considered as the system (e.g. modularity and CoPS literature). An important factor in many of the mature infrastructure systems on which western societies now rely is that they were conceived as systems by

their original inventors and later developers. Infrastructure systems such as railways and electricity networks have retained the characteristic of relatively *tight coupling* (Orton & Weick, 1990; Perrow, 1984) between system components and hold a relatively high level of complexity (Perrow, 1984). These systems have continued to be treated as systems by operators, developers and policymakers over much of their existence. Although these industries contain many of the elements studied elsewhere in the management literature, an overwhelming characteristic of their operation and their development is their 'systemness'. Whether one sees them as inherently *'best considered as systems'* (Helm, 2010, p20) or simply acknowledges that they have been developed and treated as systems for significant portions of their existence, it is important to take a systems view when explaining their development rather than treating the organisations and subsystems of which they are comprised as autonomous units.

To consider how mature infrastructure systems develop and change, Large Technical Systems (LTS) theory and the Multi-Level Perspective (MLP) will be used. The LTS mechanism of system change through reverse salient identification and correction can be applied across systems and across phases of development. It therefore provides the basis for comparisons of development both between different infrastructure systems and between different phases of development within the same system. This mechanism underpins the novel method developed in this research for the study of mature infrastructure systems that is described in Chapter 4 and applied in the empirical work. Part of mature system change can be momentum-breaking events. Drawing on its focus on alteration in the way systems change and their interaction with their environment, the MLP is used to frame an analysis of system development through trajectory disruption. Having introduced these theoretical perspectives here, their application to mature infrastructure systems is developed in Chapter 3. The next chapter introduces the setting for the empirical work in this research: Great Britatin's railway system and its privatisation.

2 THE RAILWAY SYSTEM

This chapter introduces the Railway system of Great Britain by highlighting key features of its creation and early growth, by introducing the organisations that came to run it and by describing privatisation and some important structural changes that have come in its aftermath. Firstly the basic structure of the technological system is described.

2.1 Railways Systems

Railway systems are taken here to refer to vehicles operating on dedicated tracks, formed of rails[10], using a mass transit model[11]. The term 'permanent way' is used to refer to the provided dedicated routes for railway vehicles including the permanent equipment involved. This includes the geotechnical development, civil engineering structures, the track bed, the track itself and other elements (such as signalling or electricity supply) that can be provided as part of the railway infrastructure[12]. This research focuses upon the infrastructure development of the railway system of Great Britain. The definition of infrastructure used in the empirical work is based upon this concept of permanent way.[13]

The standardisation of the permanent way is part of what characterises each railway system; these choices are one reflection of Hughes's (1983) concept of 'style'. As discussed below, the operation of railway services and the development and standardisation of a national rail network in Great Britain were both controlled by the British Rail board for a long period until privatisation distributed system development and operation. The track gauge – the distance between the rails – used in the railways of Great Britain is the 'Stephenson' track gauge of 4ft 8½in; the British Government selected this standard over Brunel's 7ft track gauge in 1846, though it took until 1892 for the conversion of all Great Western tracks to the national gauge to be complete[14] (Johnson & Long, 1981, p550). In addition to track gauge, railway infrastructure has a loading gauge, which refers to the dimensions of a vehicle that the permanent way can accommodate and which is not consistent throughout the network.

As noted above interfaces between vehicle and infrastructure are not always standardised throughout the railway network. Electrification in Great Britain has taken more than one form. Developments to use electricity to power trains started early, before the supply of electricity had been standardised, and a variety of local systems were created; the first public electric railway in Great Britain was built in

[10]So excluding guided bus systems which form a hybrid model using mass transit and dedicated routes but not incorporating rails.
[11]Early ideas for railway passenger transport included independently operated railway vehicles on provided infrastructure (Allen, 1982, p12) and a significant innovation in the creation of the first passenger railway, the Stockton and Darlington Railway, opened in 1825, was the use of mass transit.
[12]Power supply and signalling functions are elements of the railway system that can sit in different places between the infrastructure and the vehicle according to different technological decisions. E.g. Diesel vehicles only need refuelling points provided whereas electric vehicles sometime use continuous infrastructure as part of the permanent way.
[13]The operationalisation of this boundary in data generation is discussed further in appendix B (see p143).
[14]The track gauge standard is different from those used in Ireland and in other parts of Europe.

1883 along Brighton sea front (Johnson & Long, 1981, p202). Early projects were almost all based on direct current supply and used a third rail set within the track connecting with a conductor attached to the vehicle (Johnson & Long, 1981, p202)[15]. A third rail electrification network is still used within the national network but overhead lines, mostly using alternating current, are also used. Overhead lines are suspended above the railway track and a conductor is attached to the vehicle on a pantograph. By 2009 approximately one third of the British network was electrified, approximately two thirds of this used an overhead approach and most of the rest used a third rail (Department for Transport, 2009).

Train control and signalling systems are also linked to the permanent way. These too do not have a uniform design throughout the system. In a 1993 article Roger Ford highlights the differences in specification required between high-volume, high-speed main lines and rural services and he discusses the microprocessor-based safety signalling system, Solid State Interlocking (SSI) replacing relay based signalling from 1985 onwards (Ford, 1993). Lineside signals communicate instructions to the train driver. The control of the signals and the movement of points (elements in the track that adjust the train path) now tend to be centralised into signalling control centres and operated remotely[16].

There have also been developments in train control that move from lineside to in-cab signals; European Rail Traffic Management System (ERTMS) was in the plans for the West Coast main line modernisation but it was dropped in favour of a simpler technology[17]; there are now several proposed implementation projects for the British network[18]. There are other on-train control systems for safety that have been used on the network including the Advanced Warning System (AWS), Train Protection and Warning System (TPWS) and Advanced Train Protection (ATP) that are intended to mitigate against human error by reducing the danger of or preventing signals passed at danger events (SPADs), respectively. These systems were both out of use on the train involved in the Southall accident and discussion, in the national press, of their effective application followed soon after that accident (Gourvish, 2008, p14).

Although modern railway systems hold much of the same basic architecture, in terms of the wheel-rail interface and the mass transit approach, that was present in early systems, the technology has been far from static. These are systems that develop to incorporate technologies generated elsewhere (Russell, 1998) as well as using internally generated design changes. However, asset lives are high and conditions vary throughout the network; this leads to variety in the technologies and designs used within the network.

[15]These direct current systems also used locally owned or railway owned power stations (Johnson & Long, 1981, p208)
[16]Decisions over the form of control centres used on the West Coast main line and elsewhere on the network feature in the 1998 sample, e.g. 1998, #85 on a more centralised Network Management Centre (NMC) proposal.
[17]Interview V, see appendix A.
[18]http://www.networkrail.co.uk/aspx/12275.aspx (accessed 26/03/2015)

2.2 System Origins

Although the use of dedicated tracks for wheeled vehicles has occurred in various places for hundreds of years, the birth of the railway industry can be placed at the first running of a mechanically propelled vehicle on rails; this occurred in 1804 in Merthyr Tydfil in Wales and the engineer credited is Richard Trevithick. Even in these early days the interdependence of the vehicle and its track was evident as Trevithick's heavy engine, required to achieve the adhesion needed to haul loads uphill, caused failures in the track (Allen, 1982, p10). The problem of successful adhesion at the wheel-rail interface generated a wide variety of designs appearing across the British Isles (Allen, 1982, p10) These included Mathew Murray's locomotives with a cog wheel operating on a toothed rack rail (1811) and William Hedley's Puffin Billy which had more than one pair of driven wheels (1813) (Allen, 1982, p.11).

The engineer more broadly credited with the creation of the railway, George Stephenson, was a refiner of the concept; he was the engineer behind the world's first passenger train that opened the Stockton and Darlington Railway on 27th September 1825 (Allen, 1982, p12). Further improvements to reliability were required; however, a series of engines produced by Timothy Hackworth, the engineer employed by Stephenson for the Stockton and Darlington Railway, in 1827 enabled the demonstration of the viability and profitability of the passenger railway concept (Allen, 1982, p12).

The railway grew through the developments of competing companies; a well-documented feature of expansion was the investment bubble of the 1840s called the 'railway mania'. There was some standardisation, for example in track gauge (through not universally) and in the form of locomotives (Allen, 1982, p40), but the railway grew through the development of a series of individual systems. The industry presided over a stable network by the 1870s (Allen, 1982, p69). The railways were nationalised for both the 1914-1918 and the 1939-1945 wars. In January 1923, 123 private railways were amalgamated into the 'Big Four' railway organisations, (the London Midland and Scottish Railway, the London and North Eastern Railway, the Great Western Railway and the Southern Railway) under the terms of the Railways Act of 1921 (Haresnape, 1979, p18).

2.3 British Rail

After the Second World War the new Transport Act 1947 created a British Transport Commission which brought the 'Big Four' railway companies, and some other railway organisations, into public ownership on New Year's Day 1948 (Allen, 1982, p183). The British Railways Board[19] came into existence in 1962 (Gourvish, 2002, p2). At this time it was intended that the railways would be self-sufficient but in the Transport Act 1968 the principle of subsidy for the provision of unprofitable but socially beneficial services was recognised (Allen, 1982, p198).

[19]The BR Board later instituted the name 'British Rail' (Bonavia, 1979, p13)

Following the 1963 Reshaping Plan, more commonly known as the Beeching Plan, the railway network was reduced in size; activities were reduced to focus on the ability of the railway to move materials and people well in bulk in order to reduce financial losses (Allen, 1982, p198-199). Until 1982 British Rail was organised in a four tiered structure; below British Railways Board it was a regional structure with five multifunctional regions made of divisions which were in turn divided into areas (Gourvish, 1990). Between 1982 and 1986 changes were made to the organisational structure of British Rail leading to a functional architecture; this involved the introduction of five sectors between the British Railways Board and the Regional Directors: Freight, Parcels, InterCity, Provincial, and London & South East (Gourvish, 1990). In the early 1990s another reorganisation was initiated, which came to be known as 'Organising for Quality' (OfQ) (Gourvish, 2002, p374). This involved the final elimination of the regional-level structure, an alteration of the sector/functional structure, and the ownership of operational of assets by the sector-level businesses (Gourvish, 2002, p374-383).[20]

2.3.1 The Organisation of Engineering[21]

After the 1948 nationalisation, engineering design was moved from the four separate organisations to come under the control of the centralised Railway Executive; one element of this nationalisation process was work to unify design and technical standards across the system described by Johnson & Long (1981, p34). Then, following the Transport Act 1953 and the abolition of the Railway Executive, there was some decentralisation of engineering activity into the regional structure of the railway, though several engineering functions remained centrally run under British Railways Division of the British Transport Commission (Johnson & Long, 1981, p57-65). In the same month as this new organisational form came into effect the Modernisation Plan, representing large scale reinvestment for the British railway, was announced: January 1955 (Johnson & Long, 1981, p67). With the formation of the British Railways Board in 1962, to be chaired by Dr Richard Beeching, there was a recentralisation of engineering control including the removal of the railway's main workshops from regional control (Johnson & Long, 1981, p73-74).

From the late 1950s into the 1960s the British Rail Research department gained greater autonomy from the various engineering functions (Johnson & Long, 1981, p448). In 1964 the new Engineering Research Laboratories were opened in Derby (Johnson & Long, 1981, p451). Key projects to be undertaken by British Rail Research at these facilities included a fundamental investigation into wheel/rail interaction, the Advanced Passenger Train (APT) and the train control programme (Johnson & Long, 1981, p454-457). British Rail Engineering Limited (BREL) was a subsidiary of British Rail

[20]Gourvish (2002, p390) also highlights that this move reinforced the vertical integration between infrastructure and operations which was about to be altered.

[21]'Engineering' here is a term that incorporates technology development work from R&D work to local design and adjustment. The distribution of this work and the degree of centralisation has changed over time, even within the tenure of British Rail. This will have influenced the degree of standardisation within the network and it affects system characteristics and boundaries.

formed, from the workshop division which built and maintained rolling stock, in 1970 (Johnson & Long, 1981, p543).

2.4 Leading up to privatisation

This nationalised, vertically integrated organisation, British Rail, had presided over considerable technological development of the railway network as well as its rationalisation. In 1979 a new government was elected; it wished to reduce the size of the public sector and increase the role for private business across nationalised infrastructure systems.

The first move towards increased private-sector involvement was the decision to sell BR's subsidiary businesses; this included the mechanical engineering works, BREL. BREL was restructured and its sale, completed in 1989, meant construction and heavy maintenance capabilities left BR; other maintenance was retained in subsidiary British Rail Maintenance Limited (BRML)[22] (Gourvish, 2002, p243). The core component of BREL was sold to a management and employee buyout (MEBO) with considerable support from Trafalgar House and Asea Brown Boveri (ABB) (Gourvish, 2002, p246).

Following the sale of the subsidiary businesses BR continued to operate as an integrated company. It now purchased new vehicles and heavy maintenance from the private sector; one player in that sector was now BREL. After its privatisation, BREL had problems with product quality and delivering to schedule to British Rail (Gourvish, 2002, p246). Discussing product approvals problems after privatisation the record from interview F (see Appendix A) highlights that *'...British Rail used to design trains, they were then built by a manufacturer and if there was a design problem BR paid for modifications in service.'*

The OfQ initiative, implemented between 1990 and 1992, saw the division of British Rail into a five businesses, which each contained several profit centres. Business units would own all the assets and manage the production process. The holding company, and with it the BR Board, could then focus on higher-level issues: strategy, investments, safety etc. Although a central engineering group remained at headquarters, the rest of the engineering functions within BR were decentralised into the five businesses as part of the restructuring. Responsibility for safety standards at Headquarters passed to the Group standards; this was a new body of two parts: Group Technical Standards and a Group Operational Standards. (Gourvish, 2002, p374-382).

As demonstrated by the OfQ initiative, control of the operation of the system and its structure was held centrally by the BR Board in this period. The reorganisation, OfQ, was conceived and directed by the BR Board. The issue of privatisation of the core industry came to the fore in the early 1990s. The decision to proceed, and to do so on the basis of a track-owning organisation and separate operating

[22]In 1993, as part of the privatisation process, the government decided to sell BRML (Modern Railways, September 1993, p519; Interview: C (see Appendix A)).

companies, crystallised with the white paper[23] (based on the Conservative Party's election manifesto for the 1992 general election) published in July 1992 and formalised in the Railways Act 1993.

2.5 Privatisation

Between 1993 and 1997 (Gourvish, 2008) BR was restructured and privatised to form a competitive market for the provision of railway services and the development of the railway system. The Government's motivation for the introduction of competition has been linked to anticipated European legislation (Nash, 2008), reducing state subsidy of the industry (Harris & Godward, 1997, p63-64) and a political commitment to the power of the markets and transactions (Glaister 2004; Tyrrall, 2004).

The Railways Act 1993 did not deal with the new institutions in detail. The new structure for the industry was developed by the Department of Transport (DTp) with input from the BR Board, consultants and outside experts. The structure selected was for an independent track authority, Railtrack, and separate operating companies to be created; while the Freight and Parcels businesses were to be sold, a franchise model was to be used for passenger operations with the proposed introduction of open access competition at a later date.

Plans included two regulatory bodies. One was to oversee the franchising process: the Office for Passenger Rail Franchising (OPRAF), lead by the Franchising Director. The other was to be a regulator to protect consumer interests, to enforce existing competition law and to check issues around access to the infrastructure: the Office for Rail Regulation (ORR), led by the Rail Regulator. (Harris & Godward, p104-105). Shadow regulators were appointed just before the launch of the Railways Act 1993, however the regulation set up *'was expected to evolve with the privatisation process…'* (Gourvish, 2002, p423). Initially both regulators were to be subject to guidance from the DTp (Gourvish, 2002, p424). The franchising director was to work to a brief from the Secretary of State regarding passenger rail services while the Rail Regulator, was (until the end of 1996) required to take guidance from the Secretary of State into account (Gourvish, 2002, p424).

2.5.1 Infrastructure

Railtrack was set up to own and manage the railway infrastructure. It was first created in shadow form as a division of BR in March 1993 and continued to be developed until its flotation on the stock market in May 1996. The internal structure of this organisation was different from the structure used by BR following OfQ. Railtrack would buy in all of its engineering requirements, not just renewal and new construction work but also detailed inspection and monitoring functions, and so it was to be *'an access, capacity management and sales organisation'* (Gourvish, 2002, p402).

[23]"New Opportunities for the Railways" (Department for Transport, 1992)

The organisational units that were going to provide Railtrack with the maintenance and renewal of the infrastructure were created from existing post-OfQ profit centres. These became 7 Infrastructure Maintenance Units (IMUs) and 7 Track Renewal Centres (TRCs) which were sold to Management Buy Outs and engineering consultancy and contracting firms (e.g. WS Atkins and Balfour Beatty) Gourvish, 2002, p403-404). Gourvish (2002, p404) also highlights the importance of and difficulties in developing a contracting relationship between these firms and Railtrack; this is a section of the privatised structure that sees further development that is discussed in chapter 6.

2.5.2 Operations

BR's post-OfQ 19 profit centres were developed into 25 franchises (Gourvish, 2002, p411); they were established into Train Operating Units (TOUs) within BR in April 1994 and became Train Operating Companies (TOCs). They were sold to management buy outs (MBOs) and existing private sector organisations in 1996-7. Franchise agreements would be decided and overseen by the Franchising Director who in the first instance would negotiate access and charges with Railtrack and prospective operators would then bid for them (Gourvish, 2002, 408). An access charging regime for franchisees' use of the railway infrastructure was set up with input from Railtrack and ministers and officials in the DTp[24].

To provide vehicles to the TOCs, BR's fleet of vehicles was divided between three Rolling Stock Companies (ROSCOs), initially set up inside BR. These companies were to own the vehicles and be responsible for the heavy maintenance for them, however the organisations were set up without in-house maintenance and they would need to purchase it (Gourvish, 2002, p420).[25] The contractual relationship between TOC and ROSCO varies. A 'dry' lease refers to only finance being provided by the ROSCO and the TOC taking responsibility for all maintenance (this includes examples of contracting that maintenance to a third party), whereas a 'wet' lease refers to maintenance being included in the ROSCO's offering leading to an approach close to a 'power by the hour' model; since privatisation these contracts have moved towards the dry lease end of the spectrum (Interviews A, C, E, appendix A).

The freight businesses within BR were sold. The three trainload businesses and Res parcels were sold to North & South Railways Ltd (belonging to US-based Wisconsin Central railroad) that was later renamed English, Welsh and Scottish Railways Ltd (EWS) and went on to purchase Railfreight Distribution as well; Freightliner was bought through a management buyout (MBO). After an initial

[24]See Gourvish, 2002, p404-410 for an account this process.

[25]At privatisation *'..it was intended that there would be strong relationships between particular manufacturers and ROSCOs because there are benefits to a ROSCO having many trains on the same design platform…'* (Interview record C, appendix A); however, there is not evidence of this type of relationship in the privatised industry (e.g. interviews A, D & E, appendix A).

failed attempt to sell Red Star it was *'sold to an MBO team for a peppercorn'* (Gourvish, 2002, p419). (Gourvish, 2002, p419; Harris & Godward, 1997, p102-103). Access charges for freight had proved a difficult issue within the privatisation process and a balance was needed between Railtrack's profit potential and the ability to sell the freight companies (Gourvish, 2002, p417-418). Agreement was reached between BR's Freight Group and Railtrack on 31 March 1994 in the form of 200 contracts between the freight companies and Railtrack (Gourvish, 2002, p418).

2.5.3 Ensuring safety

The safety regime in the new industry structure was centred on safety cases; these are statements of how safety would be handled by the organisation. All users of the network had to have their safety case validated by Railtrack (and Railtrack's was to be validated by the Health and Safety Executive (HSE)) (Gourvish, 2002, p428). The standards and safety directorate, set up as part of OfQ, moved to Railtrack to operate as a ring-fenced activity (Gourvish, 2002, p428). This led to Railtrack having the *'responsibility to ensure new trains introduced to the network did not increase safety risk.'* (Interview record F, appendix A); insufficient information within Railtrack about its network made decisions about technology changes difficult immediately after privatisation[26].

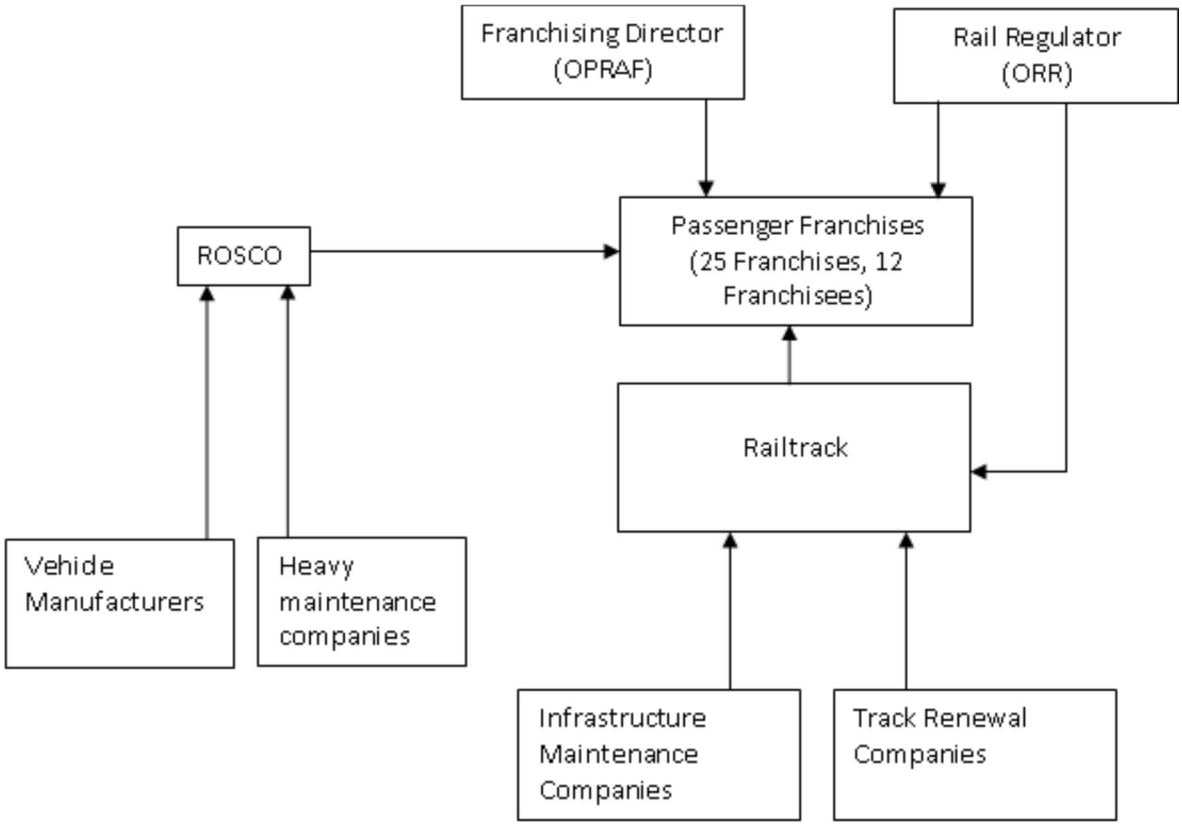

Figure 2-1 Industry structure in 1997 adapted from Gourvish (2008, p2) and Harris & Godward (1997, p85)

[26]Interview record F, appendix A.

The core organisations had been launched into the private sector by the end of 1997. A representation of the new industry structure for passenger operations is shown in Figure 2-1[27].

Throughout this period of restructuring the core industry the supply industry was also developing. The orders for new rolling stock had ceased but manufacturers started building up maintenance and vehicle development capabilities ready for the new industry launch. Technical Service Companies (TESCOs) were set up, often with purchases of engineering elements of BR, and they and existing multi-industry consulting engineering companies also built up capabilities, with a number of acquisitions, strategic restructuring and collaboration agreements being announced in these years.

2.6 Post-privatisation

The industry structure had not remained static during the intervening years; adjustments included several significant changes which had originated outside of the operational industry.

As early as 1998, following the election of a new government in 1997, plans emerged to make some structural changes to the industry. These proposed a change to the regulation setting with the introduction of the Strategic Rail Authority (SRA). The purposes of the SRA, described in the Transport Act 2000, were *'...to promote the use of the railway network; secure the development of the network; and contribute to the development of an integrated system of transport of passengers and goods.'* (Gourvish, 2008, p87). The organisation incorporated OPRAF and took over responsibilities for franchising, a process that was about to start again as initial franchises came to an end. It was also to generate a strategy for the industry and to co-ordinate its implementation. However, as these plans were being formed a series of railway accidents, all resulting in passenger fatalities, occurred: Southall, September 1997; Ladbroke Grove, October 1999; Hatfield, October, 2000.

Post-Hatfield developments in the industry affected both the plans of the SRA as it was establishing itself and the behaviour and financial position of Railtrack (Gourvish, 2008, p59). The period with Railtrack at the centre of the operational railway ended soon after: *'..the Secretary of State, in a surprise move, placed the company in administration on 7 October 2001.'* (Gourvish, 2008, p97). Having been created in shadow form in 1999, the SRA was fully launched and gained a new Chief Executive in 2001; the failure of Railtrack was to follow within months.

In 2002 it was agreed that the new Railtrack would be a Company Limited by Guarantee (CLG) and a deal for the purchase of Railtrack by Network Rail was agreed with the Government and Railtrack's

[27]For simplicity, safety arrangements are not included; they, also, are not directly involved in system output, they oversee the actions of others.

shareholders (voted to accept in July 2002[28]). The structure of the industry developed in this period is shown in Figure 2-2.

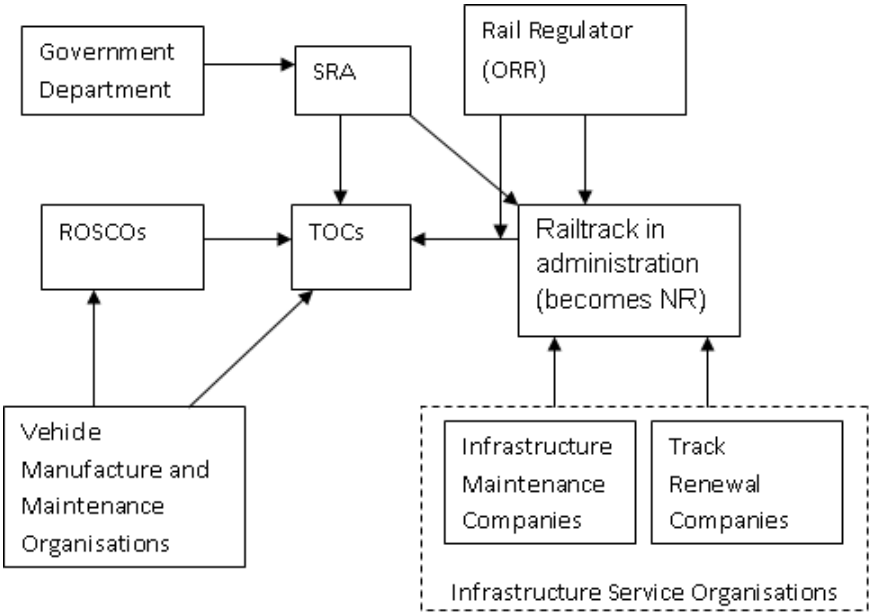

Figure 2-2 Industry structure at the end of 2001

Some significant within-industry changes got going between 2002 and 2004. Network Rail started to change the way infrastructure was managed in the railway system. In its early days Network Rail set up a new internal structure; it published a business plan in March 2003 indicating that between 2002 and 2004 its aim was to secure stability (Gourvish, 2008). During this time, reports indicated considerable infrastructure work being carried out; comments on the number and disruption of track blockades feature in the industry press. There is also evidence of Network Rail learning about its infrastructure with increased use of systems which can provide records of the infrastructure[29], the initiation of a project to create a national asset management database[30] and a decision, announced in June 2003, to bring some track maintenance works back in-house; attributed to a need to increase its understanding of the work being conducted on the infrastructure[31]. Further restructuring follows and the decision is made to bring all infrastructure maintenance in-house.

The structure of the railways continued to change. Important developments included the Railways and Safety Bill, passed in 2003, which, amongst other things, provided legislation to establish a Rail Accident Investigation Branch (RAIB) which was recommended in Cullen's second report into the

[28]http://news.bbc.co.uk/1/hi/business/2267597.stm (retrieved 13/01/2012)
[29]For example, Modern Railways, August 2003 – Omnicom engineering is contracted to use its system to create a visual and positional record of the infrastructure. In addition several measurement and visual inspection developments are referred to in interviews, so is intelligent infrastructure work by NR, (Interviews: G, M, Q & U, Appendix A)
[30]Modern Railways, April 2004
[31]Modern Railways, August 2003

Ladbroke Grove accident. A further development in 2003 was the creation of the Rail Safety and Standards Board (RSSB) that has responsibility for the management of the Railway Group Standards and that takes an important role in research and pre-competitive collaboration. A review of the industry in 2004 generated the White Paper: The Future of Rail (Department for Transport, 2004) that led to the SRA being abolished and its functions taken within the DfT as well as other structural changes.

2.7 Railway system phases

The review of the industry's development over privatisation above highlights that there have been sudden changes initiated in the system's environment; the most dramatic of these is the decision to privatise and restructure the core industry, which came from the Government, at the beginning of 1993. This research considers the system's development, and changes in development processes across railway privatisation. Three phases of system form are selected to study the system's development over this period[32]; they can loosely be considered to represent before, during and after the privatisation and restructuring of the industry. These phases are described below and summarised in Table 2-1.

The phases described below are bounded by significant changes to the system that have originated outside it and that lead to different conditions existing within each phase. This leads to their treatment here as three embedded cases of system development[33]. The system-environment developments that represent phase boundaries here are not the only system-environment interactions, these are those that bound different structures and/or regulatory arrangements that would be expected to change the way system development and operation decisions are made across much of the system.

Phase 1 begins with the paring down of BR by separating off subsidiary businesses, in particular the vehicle manufacturing organisation. This moved the system boundary and created a clearer division with a vehicle supply industry. This initiated a period where the core system, that will be restructured as part of privatisation, is run by the BR Board. This phase ends with the result of the general election because railway industry privatisation was in the government's election manifesto and so will now be pursued.

Phase 2 is a period of transition where the core industry is privatised. These structural decisions were made principally outside the industry. The BR Board was involved in executing changes and the BR organisation provided an incubator for new organisational structures to operate in before their launch into the private sector; at this stage tensions and issues could be resolved with the guiding hand of centralised decision makers. While the focus was on restructuring, issues arose around the continued

[32]Historical accounts of the industry have been used to define the phases. Of particular importance are Gourvish's (2002; 2008) histories of British Rail and the railway during the SRA years; these histories focus on the political and organisational events leading to change in the industry and provide authoritative accounts of system-environment interactions including those forming the phase boundaries identified here.
[33]Langley (1999) calls this temporal bracketing.

development of the system. For example, orders for new vehicles dried up, which had an effect on the vehicle manufacturing capabilities held in the UK; many redundancies and some closures followed. The end of this phase is marked by the launch of the core organisations into private ownership in 1996 and 1997. Because this happened in stages there is an overlap between phases 2 and 3.

Phase 3 presents an operating, newly-privatised industry; the core organisations had been launched into the private sector and were beginning to find their modes of operating. Industry publications and interviews show a period of high activity: rolling stock orders resumed; with new actors involved there are examples of new approaches being taken. The supply industry also responded: new products and services were being promoted including examples of entry into the market by overseas firms. This phase is concluded by structural changes being implemented by a new government[34]. The launch of the SRA and the failure of Railtrack occur within months of each other. Both are significant structural events for the system and the influence of both changes is present from 2001 onwards; these events are combined in the phase boundary that ends phase 3.

The use of these phases to distinguish between the different organisational and institutional structures present in this system at different times draws on the theoretical perspectives introduced in chapter 1. The structural differences[35] between the phases are expected to affect the way the system operates and develops. Both the MLP and LTS models of system change acknowledge the potential changes in system development that are represented in these phase boundaries. However, the LTS theory of change is system-centred whereas the MLP framework focuses on system interactions with its environment. In this research the MLP is used to acknowledge phase boundaries while the LTS theory is applied to within-phase development[36]. The strengths, weaknesses and complementarity of these two theoretical frameworks are discussed in chapter 3.

The phases shown in Table 2-1 are treated as embedded cases in the methodology used to study the system in this research. Samples are used to examine development behaviour within each phase and to allow comparison. This is introduced in chapter 4.

[34]Implementation, not decision, is used as the phase boundary here because the announcement is not of a fundamental change in operating principles (as with privatisation) and is no reason to believe the announcement itself will have a system-wide effect upon development. However the structural changes being implemented will change development processes and decision-making so their implementation is considered part of a phase change.
[35]Phase 2 can be considered a hybrid phase between pre-privatisation and post-privatisation, but as a result will not necessarily have development characteristics entirely consistent with either of them; it is a transition phase.
[36]This includes system response following the system-environment interactions at phase boundaries.

Table 2-1 Phases of system operation: before, during and after privatisation

Phase	Dates	Initiation	System developments
1: The core system	1989 – 1992	Sale of BR's subsidiary businesses; in particular the vehicle manufacture and overhaul organisations.	This is a period where the system that will be privatised is being operated and developed under the BR Board. One important development is the BR Board's restructuring of the organisation into a functional structure: Organising for Quality (OfQ).
2: System is privatised	1992 – 1997	Decisions on privatisation and the new structure were taken by government following the general election in May 1992. They resulted in the Railways Act 1993.	This phase includes the processes involved in constructing the new industry structure: Railtrack, TOCs, two regulation organisations supported by ROSCOs and infrastructure service companies. Contracts and franchising agreements between these organisations were created. In addition, throughout this period the system continued to operate, and develop, under the BR Board.
3: New privatised industry	1996 – 2001	Launch of the principal organisations into private sector; the main activity was 1996-1997.	Industry operation and development is continued by a restructured and privatised railway industry. In 2001, the system is altered again with the creation of the SRA to provide strategic overview of system development, a series of serious railway accidents and the placement of Railtrack into administration.

3 CHANGE AND STABILITY IN MATURE SYSTEMS

This chapter builds upon the theoretical background introduced in chapter 1. It considers how existing frameworks can be used to understand the privatisation and restructuring of an infrastructure system as well as its response. The privatisation and restructuring of Great Britain's railways described in chapter 2 is considered a possible opening for reduced system stability. The MLP and LTS frameworks are used together to examine these developments.

3.1 Establishment and stability

Long-established infrastructure systems like railway, energy and water distribution networks can appear unchanging. However, within these systems there can be a great deal of innovation activity and change in the way things are done. What these systems have is a stable identity and architecture[37]. This is not to say that either the architecture[38] or the perceived purpose of the system is static but simply that they change gradually.[39] An important stage in consolidating system identity and architecture is the building and operation of these systems; as discussed below, development that does not build in some way upon the existing system is less likely once the system is installed and in operation. Therefore, although the systems of focus in this research have been in operation for some time and can be expected to have even higher inertia, the term 'established' is used to refer to the existence and operation of an installed form of the system.

Writing on the product lifecycle talks about learning, with the design and manufacture of many units, leading to increasing stability in product form and in user expectations (Utterback & Abernathy, 1975). With the reductions in uncertainties in the market and establishment of product form and identity some rigidity has been created. Extending these ideas to complex product systems (CoPS), Davies (1997) identifies progress through the product lifecycle to be linked to increased stability in product architecture, and Bergek et al. (2008) highlight the importance of 'after-launch redevelopment' (work to ensure the performance of new products once they are installed) for these capital-intensive and complex products. In CoPS industries radical innovations involve significant changes in product architecture (Davies, 1997; Henderson & Clark, 1990[40]); however, in these industries, such changes appear to be overseen by incumbent firms (Davies, 1997; Bergek et al. 2008) meaning that even major

[37]Henderson & Clark (1990) introduce the idea of architectural innovation in complex products and Davies (1997) considers its place in the product lifecycle for CoPS.
[38]Product or system architecture refers to the structure of subsystems and their relationships.
[39]As noted in chapter 1, the model of a trajectory is often used to consider product development (e.g. Dosi, 1982); this is based on path dependency in knowledge development: the state of knowledge at time t_1 is related to the state of knowledge at time t_0. In these established infrastructure systems development trajectories can change but a new trajectory tends to continue from the old.
[40]Henderson and Clark (1990) note the importance of architectural change as part of radical change in complex products; this includes but is not limited to CoPS.

changes in product form will see new knowledge introduced alongside and building from the existing knowledge base.

In their work on the product lifecycle Utterback & Abernathy (1975) are clear that movement towards stability, or maturity, is neither linear nor uniform for each product. There will be reversals and loops back to earlier states; the model proposes a tendency towards rigidities and lower uncertainty, not a uniform and universal journey. This part of the product lifecycle model is further emphasised in its application to CoPS (Davies, 1997; Bergek et al., 2008). For LTS, it is these loops and reversals that can offer potential insight into trajectory changes in high-momentum infrastructure systems.

In large technical systems the barriers to starting afresh are even higher than for CoPS. In addition to the retention of and building upon existing knowledge seen in CoPS industries, systems like electricity networks have existing knowledge embodied in high-value and highly connected[41] physical systems. Although it is possible that all traces of an infrastructure could be removed in dramatic fashion to allow a new technological approach it would be unexpected. More commonly radical changes happen gradually in these systems (Summerton, 1994); this represents the redirection of an existing trajectory (referred to as system transformation) rather than a new trajectory superseding the incumbent (transition) (Geels, 2007).

Instances of LTS transformation appear even within Hughes's (1983) account focussing on the first 50 years of electricity system development. Significant changes in electricity system development were occasioned by the changed priorities of wartime (Hughes, 1983). A further example is the 'battle of the systems' where a seemingly intractable reverse salient within the more established direct current system was overcome with the complementary use of a hitherto competing system, that of alternating current (Hughes, 1983). In longer-established LTS understanding such movements between relative stability and instability in system development becomes even more important (Summerton, 1994; Coutard, 1999).

Once installed, LTS go through periods of stability and instability (Summerton, 1994). They continue to develop. This can involve incorporating technologies developed elsewhere (e.g. Russel, 1998) and adapting to changes in user expectations (e.g. wartime development, Hughes (1983)). It can also incorporate changes of direction or trajectory of system development that will involve architectural changes (e.g. Davies, 1996; Geels, 2007; Mulder & Kaijser, 2014).

Focusing on the reshaping of established LTS, Summerton (1994) identifies three types of LTS reconfiguration and two more are added in the works of Tarr (1999) and Kaijser (1999):

[41] i.e. requiring standardisation across geography.

- Systems crossing political borders (either using integration with another system or extension), for example the integration of the telecommunications systems of East and West Germany following the fall of the Berlin Wall (Robischon, 1994)
- The interconnection of different functional systems. Examples are discussed by Mulder & Kaijser (2014), including the co-development of electricity and railway (for electricity consumption and railway propulsion)
- The reorganisation of monopoly systems into new structures introducing competition and open access. This is the situation studied here and the liberalisation of the electricity sector in Europe is another example (Markard & Truffer, 2006)
- An installed system being transferred for use by 'a different but still related form of energy' (Tarr, 1999 – on gas supply)
- Kaijser (1999) highlights a LTS restructured as a result of the discovery of a new source of a natural resource in his study of changes to the gas industry in the Netherlands.

This list incorporates two themes. There are three different types of system integration; in each case a change in goal is to be expected for the future development of the elements of the incumbent system, now elements of a redefined system. This altered system boundary is likely to mean changes in the identity of system-builders as well. There are also two different triggers, both from outside the system, for the restructuring of systems; restructured systems will experience changes in the actors developing the system and this could also be an opening for shifts in the system goal. Focusing on the case of privatisation and restructuring, these ideas are discussed further below.

This research seeks to improve understanding of development in these long-established LTS by studying the development of an established and stable infrastructure system. Two approaches are taken. The first approach considers a within-system point of view and looks at mechanisms for system development in use in an established system. Hughes's (1983; 1987) model of LTS development is used as the basis for this work. This theory considers how LTS change. It is discussed and developed for application to established and stable systems in the next section. The second approach focuses on the idea of changes in system stability. This is an important element in understanding the privatisation and restructuring of established infrastructure systems. The MLP is incorporated into this discussion in section 3.4. Its focus is on how changes in trajectory, or changes in the way systems change, occur. The MLP and LTS frameworks are summarised in Table 3-1 below.

Table 3-1 LTS and MLP frameworks

	Large Technological Systems (LTS)	Multi-Level Perspective (MLP)
Focus	The creation and development of large technological systems, including infrastructure networks.	Technological transitions or transformations in industries (including but not limited to infrastructure systems)
Research question	How do LTS develop?	How do transitions or transformations occur?
Initial empirical focus	Historical research focused on the activities of key inventor-entrepreneurs and their successors (Particularly Edison's development of an electricity delivery system between 1880 and 1930 (Hughes, 1983)).	Retrospective case studies of technology transition, e.g. developments in the shipping industry between 1780 and 1900 (Geels, 2002).
Strengths[42]	Develops a theory of system development that can be applied across time, setting and system.	Provides a framework to consider different types of interactions between a system and its environment. In addition, MLP considers change in the way a system changes.
Weaknesses[43]	This theory is system-focused. It does not provide the tools to consider system reconfiguration and outside influence except as individual occurrences.	Operationalising the concepts discussed in the framework is challenging and the empirical evidence and its use in this research have been heavily criticised (this is discussed further below). This framework does not contain a mechanism for system change and it does not explain transition or transformation but observes patterns within these events.

[42]For their application in this research
[43]*Ibid*

3.1 Applying LTS research to established and stable systems

Hughes's (1983; 1987; 1992) theory of change in Large Technological Systems is expected to apply to change in infrastructure systems even once they are established (Hughes 1983; Summerton, 1994). However, it has most often been used for the study of invention and early expansion stages of system development (Summerton, 1994; Geels, 2007). This section looks at several areas that are particularly important in mature systems or that offer something contradictory in this setting: growth, system goal, momentum and system identity. In section 3.2 these ideas are pulled together to apply them to studying change in established infrastructure systems.

3.1.1 Growth and decline

Hughes (1992) is clear that his theory of system development through reverse salient correction is intended for system growth and changes involving some form of progression rather than changes for stagnation or decline. However, the term 'growth' presents some problems: what dimension of expansion does this refer to and how is one to tell what should be considered a stagnant or declining system? Particularly with older systems, part of the system can be removed while another area expands, all with the intention of moving a system closer to its performance goal. In this study reverse salient correction is considered an appropriate model where advances towards a system goal are occurring.

There is some variation on the interpretation or application of the term ('growth') within Hughes's own writing. In work focusing the invention and first installation of an electric lighting system in the USA, Hughes (1983) appears to use growth as if it were consistent with geographical span whilst also introducing concepts directing system development which are focused on increasing the intensity of use of capital goods: load factor and economic mix (e.g. Hughes, 1983: 369). This indicates that despite references to geographical extension, growth here is really about network usage; in the early stages of any network this is about connecting users, which in these systems is broadly consistent with geographical reach. Where Hughes discusses the development of the 'universal system' (featured at an exhibition in 1893) and then of regional systems of supply in the 1920s, geographical and usage expansion are often referred to together (e.g. Hughes 1983: 368-369). Discussing these later phases of development in the epilogue Hughes asks, '*How did close attention to load factor cause system growth?*' and explains territory expansion by utilities managers as follows:

> '*The objective was not simply size, as crude explanations for the large scale of modern technology and business insist, but expansion to encompass the diversity of loads that brought fuller round-the-clock utilization of generating equipment. ... System builders knew that the diversity of load that allowed load management, a resulting improvement in load factor, and a lowering of unit capital cost was likely to be found in a large geographical area where the population engaged in a wide variety of energy-consuming activities.'* (Hughes, 1983: 463)

Here, growth was focused on improved system performance through load management; that needed diversity in the system's load which was to be acquired through geographical expansion. So 'growth' is being used, although in conjunction with geographical expansion, to describe advancement towards the system's goal. In a 1987 book chapter Hughes refers to *'...evolving, or expanding, systems'* (Hughes, 1987: 50), which appears to be synonymous with 'growth' and supports an interpretation of where to apply reverse salient correction mechanism as being to within-system change towards the achievement of a goal for system performance

Indeed, in later writing, Hughes (1992) assigns both geographical expansion and increasing patronage to part of a systems goal within the system development model rather than treating them as inherent characteristics that might be required for its application:

> *'Reverse salients emerge so frequently in modern technology because large systems have become common and because those who preside over them push them towards goals, the most obvious among which are territorial expansion and quantitative growth.'* (Hughes, 1992: 99)

That system growth can refer to more than geographical and even usage growth, meaning advancement towards the system goal, is not always acknowledged by those working with LTS theory. Several studies seeking to consider system stagnation or decline have attempted to identify the transition of systems into that state using geographical or usage measures (e.g. Golkap, 1992; Magnussen, 2012). This dissertation does not seek to consider stagnant systems *per se*; however, when dealing with established infrastructure it is necessary to acknowledge that local expansions and contractions can occur as part of a system's continued development. For example, an-out-of date and increasingly costly technology might be removed and replaced in some locations but result in closures at others.

Development towards a goal for system performance is the interpretation of system 'growth' used here. Were a system being consciously managed for decline or were it not being developed to improve its performance at all it would not be considered to include growth and the reverse salient correction model would need to be adjusted accordingly[44]; where there are attempts for advance, however low their frequency or small their impact, the reverse salient correction model should apply.

3.1.2 System goal

Extending this idea further, for systems which last for many decades, it is sensible to expect that system goals do change. The process by which the goal, and the understanding of it held throughout the system,

[44]One way of modelling system stagnation/decline using the reverse salient correction approach (which one might expect to continue to fit with system-builder motivations) could be to incorporate an intention to manage system stagnation/decline into the system goal. Empirical work would be needed to test whether this an appropriate way to represent system change in decline.

changes would not be covered by the reverse salient correction mechanism; the consistent mechanism of change (reverse salient correction) can be expected to apply to system activities advancing towards the system goal held at any given time.

The idea of a system goal is an important part of system trajectory generation using Hughes's reverse salient model (1983; 1992); this model of change features a mechanism for development that is targeted by a performance goal for the system. The concept of one part of a system performing ahead or behind another section depends upon there being a common goal understood by the system-builders:

> '*The reverse salient will not be seen, however, unless inventors, engineers, and others view the technology as a goal-seeking system*' (Hughes, 1983: 80).

A system's goal is the performance ideal or aim; important elements can be economy, efficiency and growth. In Hughes's (1983) description of inventor-entrepreneur system-building the system goal appears as a reference point, for the system blueprint being developed, held in the head of an Edison-like figure but expressed through performance calculations and briefs discussed with scientists and engineers working on system design. In the case of the electric lighting system developed by Edison and his associates, the system can be seen developing for its context as system architecture is formed around performance targets related to the system's incumbent competitor, gas lighting (Hughes, 1979). This account sees Edison working on economy as much as technology; he considers interdependence relationships within the system to develop an architecture that can deliver a level of economy competitive with pre-existing gas lighting systems. This also illustrates that system goals will change over time and place, varying with context, competitors and available techniques that do not remain static.

In more mature systems being developed by many hands a commonly understood goal will be needed: it is the goal as understood by decision makers and those with roles in system building that will be acted upon. Further, Hughes states: '*The definition of goals is more important for young systems than for an old one, in which momentum provides an inertia of directed motion.*' (Hughes, 1983: 15).

Hughes (1983: 16) writes about systems being redirected by contingent elements; in considering existing infrastructure systems, which have often existed through significant societal changes, such alterations are to be expected. Hughes's (1983; 1987) descriptions of system development during wartime provide illustrations of goal shift and momentum disruption. For example, Britain's electricity systems before the First World War tended to be smaller than those in Germany and the United States because of the importance of local government power in that setting. During the war Parliament, driven by the need for efficiency in the face of lower resources, overrode local control and '*forced interconnection of small electrical systems*' (Hughes, 1983: 73). Hughes (1983: 15) notes that some of these elements continued into system development in peacetime; the establishment of the National Grid came in 1926 (Hughes, 1983: 323).

3.1.3 Momentum

Hughes (1987) discusses increasing maturity in large technological systems. Similar to the product lifecycle discussed above, Hughes (1987) proposes a pattern of phases through which systems go (not necessarily in order) as they evolve: invention, development, innovation, transfer, growth, competition, and consolidation. These phases of growth are also about changes in uncertainty for the system as it becomes established, including, for example, the choices of system-builders to grow the system to gain control over elements formerly in the environment and influence the system (Hughes, 1987), i.e. reducing uncertainty in system operation. Hughes (1983; 1987) talks about systems acquiring *momentum* as they develop, move through these stages and mature.

The concept of momentum or inertia of a system is linked to the idea of *path dependence*. System momentum is about the entrenchment and inflexibility that comes into the trajectories of development with increased maturity of the system. It is about the extent to which the range of changes within reach is constrained by connections to past decisions: '*Concepts related to momentum include vested interests, fixed assets, and sunk costs*' (Hughes, 1987, p77). As referred to above, Hughes (1983) discusses the impact of the First World War on electricity systems; in terms of system momentum he describes it as containing '*forces strong enough to disrupt the momentum of systems*' (Hughes, 1983, p285) but he also notes that the physical system in place at the end of the war brought aspects of the wartime environment into the peacetime system: momentum is once more being accumulated.

> *'Old systems like old people tend to become less adaptable, but systems do not simply grow frail and fade away. Large systems with high momentum tend to exert a soft determinism on other systems, groups, and individuals in society.'* (Hughes, 1987, p48).

This idea shows, once more, the expectation of an unbroken trajectory of system development once it has been installed. The established infrastructure systems that are the focus of this research can be considered high-momentum LTS.

3.1.4 System boundary

What is in the system and what does it do? When considering complex systems over time beyond their launch and initial operation the question of what is within the system becomes a more difficult one as its control mechanisms and its components and boundaries are liable to change. For example, in considering the privatisation of the railway industry the question arises as to whether the privatised industry is a system and whether it is the same system changed or a new one formed from old components.

As Grundmann (1999) highlights, under LTS thinking, systems are not defined using solid boundaries describing which components are inside but rather these are fuzzy boundaries liable to change with the systems. However, the reaches of control are related to a system's boundary and identity (Hughes, 1987;

Grundmann, 1999). Hughes (1987) discusses system boundaries moving over time, for example as sources of uncertainty formerly within the environment are brought within the system (Hughes, 1987, p47). '*Technological systems are bounded by the limits of control exercised by artifactual and human operators.*' (Hughes, 1987, p48). The reach of control is developed with the system (Hughes, 1987; Nightingale et al., 2003).[45]

Hughes (1987) clarifies the link between system control and boundary further by identifying interdependencies between system components as being bi-directional (i.e. each influences the other) whilst environment-system interactions are in one direction only: the system component either influences the element in the environment or it is influenced by it. These bi-directional connections refer to direct interactions between two system elements. So, for example, a national government can make governance changes to an infrastructure system but the infrastructure cannot adjust the government's structure. Although the LTS could have indirect influence upon the government, for example if the electorate were to use infrastructure performance as one element in assessing the government's performance, the government is part of the infrastructure system's environment.

In the case of Great Britain's railway system post privatisation, it was still being operated using centralised control; the signalling system, like much of the physical system, was not altered in the organisational restructuring and system operation was mostly conducted in the same way following privatisation just under different organisational titles. Development of the system would be changed by the restructuring of BR; actors in system development and their incentives were changed by privatisation. However, even here, many of the individuals remained; it was rather the connections between actors that were altered or removed and needed to be re-forged for new organisational structures. And, in terms of both operation and development, the system was still considered a national railway network by actors. As a result, this is considered the same system being adjusted by contingent factors: decisions made in the system's environment. As described in chapter 2, the privatisation decision came from government and, although the BR Board was consulted in the process, it did not have direct influence in the structural decisions leading to the industry's new form that flowed from the 1993 legislation (Gourvish, 2002).

[45]Juhlin (1994) highlights that, particularly in long-established systems, control is not necessarily centrally held (with operation being directed from a single point); a standard operational principle can offer a basis for system wide but distributed control. See also Davies (1996).

3.2 Change in high-momentum systems

As indicated in Chapter 1 the reverse salient correction mechanism is the basis of system change in the LTS theory and this should apply across system, time and place (Hughes, 1992). Here, part of the system that is holding back system performance becomes a focus for system development; this reverse salient, defined relative to the system goal, is developed into a critical problem or set of critical problems as part of the correction process (Hughes, 1983). A representation of this mechanism of system change is shown in Figure 3-1.

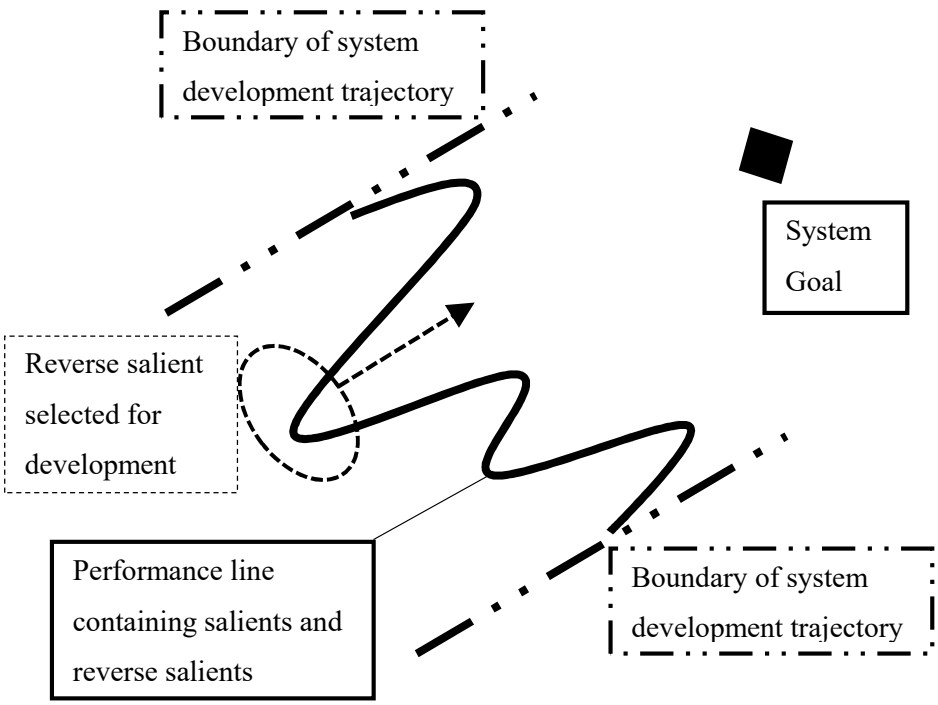

Figure 3-1 Representation of reverse salient correction

3.2.1 The interconnectedness of components and their reverse salients

The idea of a system's components being represented as a single line of performance relative to the system goal emphasises their collective goal and the interconnectedness of the many components in attempting to meet it. The line as the representation highlights the possibility that reverse salients may come in all shapes and sizes; the correction of the most severe hold-up will often reveal new reverse salients created by its correction (Hughes, 1987:67): see Figure 3-2A. In addition to new reverse salients being formed by the performance of one component being improved leaving others as the most backward point, it is also possible that the change in performance in one component will make the performance of its neighbours less effective, thereby placing new demands upon them; this is illustrated by Hughes's (1987:67) example of improving the efficiency of a generator leading to adjustments being needed to the characteristics of a motor so that it will function optimally with the generator. This is represented graphically in Figure 3-2B. The notion, represented in this example, of reverse salients being introduced into system performance is not dwelt on or discussed in detail within the LTS

literature; it is useful, however, when considering potentially momentum-breaking changes initiated in the system's environment, and this idea is used in this research.

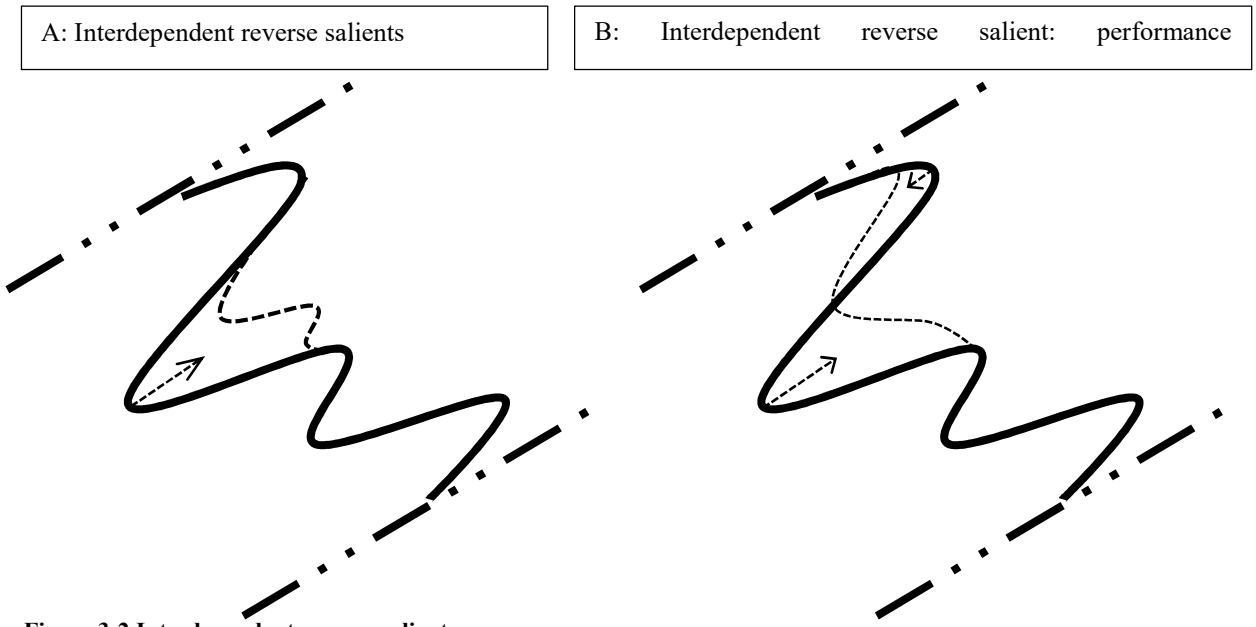

Figure 3-2 Interdependent reverse salients

3.2.2 Scale

LTS concepts have been used to consider industrial systems of production (Hughes, 1992) as well as regional and national infrastructure systems. So, reverse salients must exist on different scales and be defined by the performance of adjacent components and the scale of interest to system-builders. In considering a reverse salient or a set of reverse salients, system-builders can select the boundaries of the resulting project as part of critical problem definition. For example, track, signalling and power

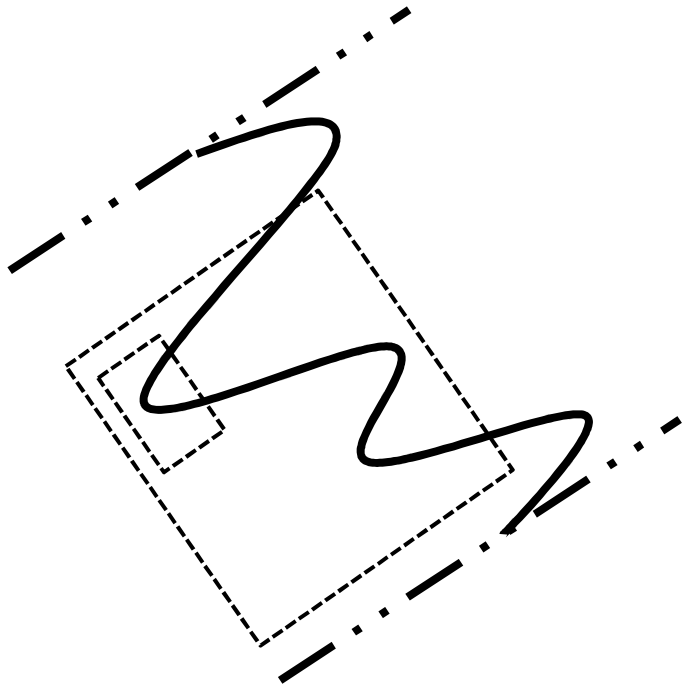

Figure 3-3 Tackling different scales of reverse salient

supply on a railway line could be tackled as three separate projects or they could be combined into a single renewal project for the line that would incorporate some additional elements to connect the subsystems. This decision is represented in Figure 3-3.

System development can progress through adjustments to very small components as well as through redevelopment of large sections of the system. This research will need to capture as much of the development activity as possible and to be aware of reverse salients and development activities on different scales.

3.2.3 Operational versus development reverse salients

An innovation can be new to the world, new to a setting or new to those working with it; considering established infrastructure systems leads to new questions for LTS theory over what is considered a reverse salient. In Hughes's (1983) detailed writing on system development he uses the development and installation of the first electric light system by Edison and his associates for illustration; the line of system performance refers initially to the system architecture and design ideas held in the minds, notes and drawings of the inventor-entrepreneurs. There is then a stage of representation through system (or partial-system) models before referring to a newly installed embodiment of those ideas. In considering an established – especially a long-installed – system with long subsystem lifecycles, a considerable difference between the installed system and the best available system (were it being recreated today) can be present. In different parts of the same system there can be installations that are the latest technology newly implemented, some are older technology but have been maintained or reconditioned to as-new quality and still others that (recent or ancient technology) are nearing the end of their usefulness as they wear out: which system state should be studied?

Figure 3-4 Two performance lines: blueprint and installed system

Thinking about different actors, there is perhaps more than one system performance line in existence for these established systems. Technology developers working in R&D laboratories will be concerned with the best possible system were it to be installed afresh today; this is equivalent to the blueprint line that inventor-entrepreneurs would have been working with shortly before and just after the initial system installation. However, not all system change will come from these actors. For system users and system operators, today's installed system and its operation will form the basis of a performance assessment; knowing that one piece of equipment is beginning to affect system performance as it wears out or that an out-of-date design is keeping the performance of a section of the system from what is possible could be the trigger for changing that installed system.

So, for established infrastructure systems, the use of two performance lines is proposed. As illustrated in Figure 3-4, this features one *system blueprint* line that represents the state of the art that would be installed if the system were to be rebuilt today and an *installed system* line that represents the system installed and this should include variations in design and technology according to geography. So, operationally, the most pressing reverse salient to be addressed could be a worn-out installation in a rural location or it could be the potential of updating the technology installed in a high-usage part of the system. Innovations in the system could come from the needs of the installed system or from addressing reverse salients within the system blueprint. An added feature of this model which would not be represented in Hughes's (1983) theory is that the installed system line will move away from the performance goal as a newly installed section of it degrades over time and use. The analysis described and discussed in Chapter 5 refers to this two-line model and finds examples of each line being used for system development; the interaction of the two lines in development is also found.

3.2.4 Persistent reverse salients

Hughes (1983) expects that system reverse salients that cannot be resolved will lead to performance problems and provide openings for a solution to come from outside the system in the form of a competing system; a clear example from Hughes's study is the limitation on a direct current system of the uneconomical cost of long distance transmission that led to the emergence of a competing alternating current system (Hughes, 1983: 15). In research using different theoretical foundations but studying the operation and development of established and high-momentum, systems the possibility also arises of some unsolved problems leading to system failure; in the electricity system setting blackouts are the evidence referred to (Künneke, 2008; Künneke et al., 2010). And, in any setting, failure could mean operation cessation or it could mean malfunctions leading to accidents (see, e.g. Perrow, 1984). In the system restructuring discussed below this is developed further.

3.3 What's driving system change?

In addition to the mechanism of system development by system-builders discussed above, more recent literature building on these ideas has added in ideas about the economic drivers providing underlying patterns in types of system change. Infrastructure systems are capital-intensive (Hughes, 1983; Nightingale et al., 2003). In operational systems development is about providing a service which is more appealing in some way or about lowering the cost of providing the service. Much of the development in such systems is driven by lowering unit costs through more intensive system use, either through adding more capacity (using as low a cost per unit added as possible) or through using more of that already installed.[46]

Within Hughes's (1983) work, this is represented in the focus, when considering regional systems, on Load Factor and the Economic Mix (e.g. Hughes, 1983:369; see also Hughes, 1979). Considering innovation in the telecommunications system from the 1960s onwards, Davies (1996) follows Chandler's (1990) argument for the importance of economies of scale and scope in explaining change across sectors; he highlights the importance of these economic drivers of change in mature infrastructure systems. Nightingale et al. (2003) follow suit in examining developments in control systems for infrastructure systems; these often aim to increase the exploitation of installed capacity.

In his work on the organisation of production systems, Chandler (1977) added to the long-established concepts of *economies of scale* and *economies of scope* that of *economies of speed*; Davies (1996) then adds a further concept in the same vein, that of *economies of system*. Applied to the expansion of infrastructure systems these concepts refer to increasing the capacity installed (with lower unit costs following the addition) or increasing the use of existing capacity (thus increasing the spread of the high capital costs). The four terms can be defined as follows (drawn from Chandler, 1977; Davies, 1996; Nightingale et al., 2003):

Economies of scale: Gaining lower unit costs from building bigger systems. More traffic is accommodated and more potential users are connected to the system so that the cost per unit is lower.

Economies of scope: Gaining lower unit costs from expanding the range of services provided. Different types of traffic or users are added to the system, spreading costs over a greater number of users.

Economies of speed: Gaining lower unit costs by increasing throughput through faster processing of units. Traffic is pushed through the system faster, thus increasing capacity.

[46]Offner (1994) refers to extensive and intensive developments in established LTS.

Economies of system: Gaining lower unit costs by increasing throughput through more effective processing of traffic using control systems. More system capacity is used through improvements to the way decisions are made about routing and co-ordination.

These concepts provide four dimensions of system development: Scale, Scope, Speed and System. These are used to classify different system changes in the empirical study of Great Britain's railway described in chapter 5.[47]

The reverse salient correction model is used as the foundation of a method developed in chapter 4 to study mature systems changing from within. And the empirical study of Great Britain's railway system through different phases of governance in chapter 5 further explores some of the themes important for established systems that have been analysed above. In order to consider the nature of the privatisation change for this system and others, literature on changes in the stability of system development, including the MLP framework, is explored in the next section.

3.4 Privatisation: an opening for system transformation?

Internally generated and governed system developments are not the only means for system change. More dramatic, momentum-breaking changes can be initiated from outside the system. The setting studied in this research features the privatisation and restructuring of the system, a development initiated in the system's environment. This section investigates what existing literature has to say on characterising this kind of event and on studying the system's response.

The central theory discussed above, LTS, is system-focused and, although acknowledging the system's environment, analysis of the interplay between the system and its environment has not been developed extensively. Another framework that has been used in studying change in infrastructure systems (Markard, 2011) which considers an industry or system within a broader socio-economic landscape is the Multi-Level Perspective (MLP). As highlighted in chapter 1 the MLP builds on similar foundations to LTS theory of evolutionary economics and science and technology studies. It was created to consider the process of technology transition; it is applied to more than infrastructure sectors. It has been developed to consider significant changes in system development (transformations) (Geels, 2007).

Hughes (1983) acknowledges and describes radical innovations where one system is replaced by another; a radical innovation comes from a persistent reverse salient in the existing system that requires

[47]In this application it is acknowledged that changes in these dimensions can go in either direction: system scale can be increased or decreased. It is also noted that often developments do not solely contribute to one category; for example, improvements in control systems can produce increases in capacity use through both speed and system advances (Nightingale et al., 2003).

or opens up opportunities for performance development in another system[48]. In considering the process of technological transition, Geels (2002) asks how such a change occurs. As described in chapter 1 the MLP framework uses three levels of activity: niches (protected spaces of experimentation and development), sociotechnical regime (the current structures and processes through which the existing system develops) and sociotechnical landscape (the environment within which a system sits and which it serves). For transition (Geels, 2002) or transformation (Geels, 2007) to take place these three levels all need to change, reinforcing one another as they do so.

3.4.1 MLP model for trajectory generation

Like the LTS view of system change, the MLP conceptualises a system's development as moving along a trajectory. However, in this framework, the trajectory is generated by the system's unique sociotechnical regime (Geels, 2002); any performance targets and mechanisms for selecting and enacting change are subsumed into this concept. MLP studies consider when and how changes to the trajectory-directing sociotechnical regime occur; in empirical work researchers are looking for changes in the way the system changes, something that can be hard to identify consistently in data. For a major change in system trajectory a significant change in sociotechnical regime is needed and for that to be sustained it will also need to have established fit with the landscape and niche levels (Geels, 2002).

The LTS model of system change, the reverse salient correction mechanism, is one way of structuring the concept of sociotechnical regime. This mechanism applies across settings and can be used to compare sociotechnical regimes and the development activity they generate. A first trial of this approach is described in chapter 6.

3.4.2 Societal and system change

There is an important stream within the MLP literature that focuses on transitions or transformations for sustainability (Kemp, 1994; Kemp et al. 1998; Markard et al., 2012); it seeks to understand how shifts to lower the environmental impact of economic activity might be generated. Work developing the MLP has tended to use the framework to structure the narrative of an historical case study of a transition or transformation finding new patterns (e.g. Geels, 2006). Geels (2005b) illustrates the application of the MLP to infrastructure systems and highlights the close connection between these systems and the landscape level of analysis by framing them as sociotechnical systems to fulfil sociotechnical functions, such as transportation. And, in discussing societal transitions for sustainability, Loorbach et al. (2010) suggest infrastructure system transformation, because of the connection between infrastructure systems and society, can be a trigger for wider societal change.

[48]Hughes's (1983) example of the battle between ac and dc illustrates that radical innovation in established systems does not necessarily encompass change in all components and knowledge bases. An altered system function and/or how it is achieved will be visible at the level of the system.

3.4.3 Privatisation: response to mismatched system and landscape?

Considering the privatisation of infrastructure systems using the MLP framework provides some insight into how they might be characterised and system development charted. There were changes to the governance and organisational structures of many formerly nationalised infrastructure systems in the UK and across continental Europe around this time. The railway privatisation studied in this research was one of the later interventions into nationalised industries in the UK. The 1980s was a time of increased attention to capitalism and private enterprise. One interpretation of these privatisations is that nationalised monopolies were no longer appropriate forms of governance for this landscape. And that it was in response to a mismatch, between the expectations/structuring of activity in the landscape level and the nationalised monopolies retained in infrastructure systems, that these infrastructure systems were restructured for launch into the private sector.[49]

As discussed in chapter 2, decisions over privatisation in the UK railway system were made by the government elected in 1992. The privatisation saw the creation of over 100 different companies (Harris & Godward, 1997) from the former controlling organisation, British Rail. Both operational and development processes for the system will now cross organisational boundaries where they did not before; as newly formed organisations forge identities and roles within a new structure it should be expected that development attention and processes will be altered. Some of the reliance on accepted practices and past decisions could be broken by this kind of restructuring, leading to a reduction in system development momentum (or the strength of path-dependence).

This momentum disruption is found by Markard and Truffer (2006) in their study of privatisation in the European electricity industry. They find that the restructuring and privatisation of this system has an effect on technology preference. Markard and Truffer (2006) argue that this should be interpreted as evidence of liberalisation generating a loosening of the existing technological regimes that, in turn, lead to changes in search and innovation processes; they go on to discuss new technological options which are emerging in the system following restructuring. Magnusson et al. (2005) find that liberalisation changes lead to weakening of established relationships between infrastructure operators and suppliers as well as new organisations appearing in electricity generation.

Studying the same industry, though using a different theoretical framework, Künneke (2008) characterises the post-liberalisation industry as having a mismatch between institutions and technology, and expects one to adjust to meet the other. Like Markard & Truffer (2006) and Magnusson et al. (2005), Künneke (2008) highlights the emergence of new technologies that could offer significant change to the system if they came to break through. These studies do not link the emergence of the niche technologies to the decision to liberalise the industry, however it is implied that the loosening of the

[49]In LTS terms an adjustment in system style was needed.

system's sociotechnical regime appears to have lowered barriers for the establishment and consideration of technologies developed outside the core system, in niches – it might even be the case that liberalisation encouraged these developments.

In this case of restructuring, it seems that the adjusted infrastructure system and its sociotechnical regime need to begin operation to get the system functioning and developing through the new regime and to set up new interaction paths with the landscape and niche levels in order to fit the three levels together once again.

Within the innovation literature several cases of infrastructure system restructuring and privatisation have been studied and the pattern of development is not always the same. Davies's (1996) study of the telecommunications industry highlights that, in the liberalisation of the industry in the USA, industry users and equipment suppliers from outside of the core systems formed a coalition and lobbied for regulatory change which allowed service innovation that then challenged AT&T's monopoly. Viewed through the MLP lens the organisations seeking changes in industry regulation which led to the liberalisation of the industry can be characterised as organisations at the centre of niches seeking to challenge the existing system sociotechnical regime. This indicates that the liberalisation of telecommunications industries (early privatisations amongst infrastructure systems) when viewed in an MLP framework present a different process of change from the privatisation of BR. Telecommunications liberalisation appears to have come from landscape actors directing system changes having received encouragement from actors working with development in niches that were ready to interact with the system under an altered sociotechnical regime.

In the case of the railway system, introduced in chapter 2, and those of telecommunications and electricity systems referred to in literature on change in infrastructure systems, the decision to restructure and privatise the system has come from the system's environment and it is these landscape actors who have been making the decisions. However, in the state and role of technological developments, perhaps already being worked on and tested in niches, these three examples differ. In Davies's (1996) account of the telecommunications system, alternative technologies were already embodied and had sufficient identity to have those ready to lobby for them. The influence of these vested interests of niche technology actors in getting the landscape actors to open up the existing system regime potentially, then allowing it to reshape itself in a way that incorporated their technology is perhaps a classic MLP study. It certainly sets up the change with three sets of actors ready to interact through transformation to reach a new stability. In accounts of electricity system privatisation referred to above, pre-existing technology operations are not involved in privatisation but the disruption of the regime appears to provide an opening for technological change to go with the organisational and institutional changes; both accounts note new technology options coming to the fore but that the

system's development pattern and the direction of change have yet become set: more than one route is available.

In the case of the UK railway sector there does not appear to have been a ready-made set of technology options poised to respond to and encourage a sociotechnical regime shift. In the early stages after privatisation ideas emerge there are different technological elements coming into play but routes for change do not appear to be ready and efforts to implement changes (i.e. exercising a new sociotechnical regime) appear to meet obstacles. A schematic of the three privatisations is shown in Figure 3-5. This framing of privatisation movements illustrates the usefulness of the MLP framework in discussing different environment-system interactions (as in these three) and that it can provide a language for cross-case analysis.

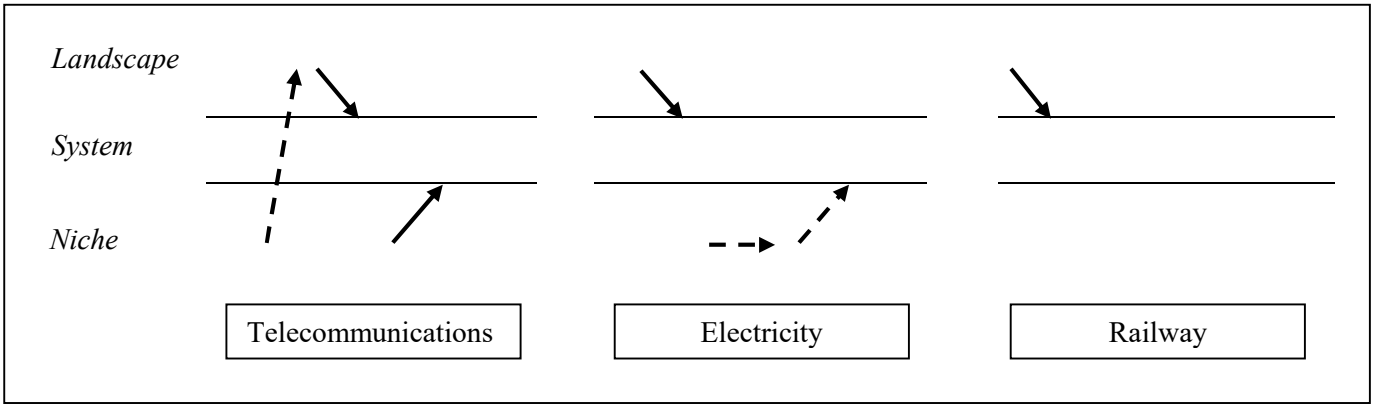

Figure 3-5 Schematic, using the MLP framework, to describe the three privatisations discussed above.

3.2 MLP Weaknesses and opportunities

The MLP framework has been heavily criticised for methodological weaknesses in existing cases and, related to that, the problems with operationalising the theory (Genus & Coles, 2008; Smith et al. 2010). When dealing with transitions there are many false starts: it would be impractical for researchers to examine industries in real time, searching for evidence on transition. This demands historical cases are used and so raises the issue of researchers imposing patterns on the data. Problems include how to define a transition (when does it start and when does it end) (Genus & Coles, 2008) and what researchers are looking for in the data. This latter issue links to the characterisation of MLP as an "outside-in" theory looking first at the overall pattern of system innovations or transitions and leaving the more detailed mechanisms of change to other theories (Geels, 2005b; Shove & Walker, 2007; Geels, 2010). Several papers suggest using an additional theory to provide these internal dynamics (e.g. Genus & Coles, 2008; Geels, 2010).

MLP is a useful framework for discussing momentum-breaking events generated in a system's environment in order to consider system response. The privatisations that have occurred in

infrastructure systems also provide useful cases for developing MLP understanding of system transformation events. Framed as breaking open the momentum of an established sociotechnical regime, these restructuring events provide potential openings for transformation. This means that cases to study can be selected before their outcome is known; completed transformations and instances where the system's trajectory doesn't change plus all variations in between can be studied: these cases offer an opportunity to counter the success bias problem in studying system transformations.

The MLP framework, providing a common understanding to consider different settings for transformation, and the LTS theory of change, which offers a consistent mechanism of within-system change across time and place are complementary. The method, centred on LTS theory, developed in chapter 4 can be used in conjunction with MLP-framed cases as the additional theory providing internal dynamics of system change suggested by Genus and Coles (2008) and Geels (2010). This method allows established infrastructure systems to be studied using contemporary accounts of system change,: thus reducing the influence of retrospective bias in transformation studies. Combining these two frameworks to examine privatisation events provides a start point for a potential transformation, and the means to study it from contemporary accounts in a way that allows systems' internal development behaviour to be compared and within a framework that can assess similarities between privatisation events in different settings: this provides the basis for the conduct of a set of rigorous case studies compiled by researchers across infrastructure systems to explore general transformation questions that could contribute to the sustainability, as well as other policy-focused, work.

4 METHOD DEVELOPMENT

The careful examination of change in mature infrastructure systems has its challenges. These are large and complicated systems which need to be examined over time. In this chapter a method is developed which offers a systematic approach to the study of change in these mature complex systems; it can be applied at different levels of detail and over varying time periods. This method uses Hughes's (1983; 1987) reverse salient theory of system change as a framework to extract data from specialist industry publications which often exist in mature sectors in order to provide a contemporary record of system development. This publication data is used with complementary data from interviews and other sources in the empirical work presented in chapters 5 and 6.

4.1 Process Research

The method developed below builds on a tradition of process studies which examine change over time and in context (Pettigrew, 1990; Van de Ven, 1992)[50]. Advocates of process studies in management research of change often emphasise a real-time approach (Pettigrew, 1990; Van de Ven, 1992); however, historical cases can also be used (Pettigrew, 1990; Griffin, 1995). Real-time data-collection removes concerns over retrospective bias and offers the opportunity to observe developments which might not be recalled by observers. However, judgements over time can be uncertain where studies also need to make design decisions in real-time. The approach developed here seeks to draw on strengths of each approach by using archival sources. It features contemporary accounts of system change but the long periods of time needed to consider infrastructure change can be covered in a single research project, and the focus and timespan of the study can be selected by the researcher[51].

Some approaches to process studies simplify the narrative of a process being studied by examining events and build a process forward to outcomes of that chain of events (Van de Ven, 2007); events are theoretical constructs which contain several incidents, recorded as data (Van de Ven & Poole, 1990; Van de Ven, 2007). Certain kinds of events can be selected *a priori* (Van de Ven, 2007). This research seeks to build on and extend the application of Large Technical Systems (LTS) theory; the event construct is taken from this theory and the data structured around it: an event is activity around a reverse salient. However, these data remain qualitative in nature and would need further adjustment to make quantitative analysis feasible.

[50]A definition of process offered by Van de Ven (1992, p169): "a sequence of events that describes how things change over time".

[51]This could be where the researcher knows the outcomes, although their sources will not. Alternatively, it is possible that the existence of a phenomenon can be seen from the present whilst outcomes are yet to be established.

4.2 Limitations of existing methods for studying system change in established systems

Mature infrastructure systems have high momentum; they do not tend to change direction quickly or effortlessly. In order to incorporate longitudinal analysis, historical studies are required. These systems are also large and complex, which places high demands on researchers in terms of identifying changes and connections between them. It is difficult to cover all of an established and complex large system in a detailed historical study. Recent empirical studies often use one of two approaches. The first is to constrain the study to one element of the system, for example a project (e.g. Geyer & Davies, 2000), a particular reverse salient (e.g. activity around control is studied by Lehtonen & Nye (2009)) or a technology area (e.g. smart grid development is studied by Erlinghagen & Markard (2012)). The other frequently used approach, particularly for the study of a full system undergoing transformation or phase change, is a descriptive account of change across the system; this is compiled using existing historical accounts, studies and descriptive statistics about the system (e.g. Markard & Truffer, 2006; Geels, 2007; Magnussen, 2012).

Each of these approaches has a contribution to offer, however each falls short for considering the different ways a system can change in a particular phase of development. The selection of a small part of the system allows detailed and careful historical cases to be constructed of a particular change phenomenon but filters out other changes that could be connected to the origins of the observed development activity. It will, thus, fall short as an approach for considering where the direction for change in the system coming from. The broader, historical case studies often seek to show patterns of change across a system, but they are open to the criticism (see Genus & Coles, 2008; Smith et al., 2010) that patterns are being imposed upon the data in analysis. Both retrospective and success bias are concerns when case studies need to be defined and composed from selections made from existing historical accounts, and through interviews with actors who have lived through the outcome as well as the process of system change.

New methods are starting to be applied in this arena. For example, in their study of work around smart grids within electricity systems in mainland Europe, Erlinghagen and Markard (2012) compile and analyse a database of all smart grid projects since the idea became seriously acknowledged. A similar method is developed in this chapter. In order to examine many examples of system change across the large scope of an infrastructure system an approach is needed to isolate and focus on examples of change as they occur.

Hughes's (1983) original study of change in large technological systems was the work of an historian of technology and the period of study was 50 years. However, a significant advantage in studying the creation and early growth of a system is that its development begins under the stewardship and control

of a few individuals; this gave Hughes his starting point: he studied the development of the technology and organisations around Edison and other key figures. Studying these systems once they are established does not offer the same focus; there are now many actors operating and developing these systems and their development is no longer directed by a few inventor-entrepreneurs.

4.3 Opportunities for studying established LTS systems

The size and complexity of mature systems mean their development cannot be captured easily from the accounts of and events surrounding a few individual developers. However, these systems are established, their scope tends to be accepted amongst actors and there are groups of individuals that will identify themselves as system actors. Because the systems are now large, complex and established they often have a dedicated industry press that aids communication of developments in different parts of the system. This system-level record provides description and discussion of changes within a mature system which reflects the interests of system actors (who form the sources and the audience for the publication) and that is created as events unfold, not afterwards. These industry specialist publications offer a source of data for examining system change.

In Hughes's work on the development of electricity systems he identifies a principle of system change that applies across systems, their life-stage, sociotechnical regimes, time and geography (Hughes, 1983; 1987; 1992).[52] Hughes (1983) views a system as a collection of many interdependent elements performing a task and the system is developed and changes are made in order to get closer to a goal for system performance. The mechanism for system change is the identification and alteration of elements which are holding back the system's performance relative to the goal. An area of the system which restricts system performance is referred to as a reverse salient.[53] This mechanism of system change through reverse salient correction gives a framework for focusing attention on change events in order to generate data on system development from records of the system provided by specialist publications. Evidence of attention to reverse salients and of work being done to correct them in the system record can be identified by researchers and data generated around these reverse salients. For example, the news sections of a publication might identify a research project which has been set up to investigate a particular problem; this gives evidence of the reverse salient and the critical problem developed. Where evidence of activity around a reverse salient can be found, system change is being attempted. This means that contemporary accounts of a system can be used to provide data on system change; and that, as it is not necessary to know what outcome will be achieved to know there is change to investigate, both successful and unsuccessful change activity can be recorded, giving a better representation of system development.

[52]A similar theory is expressed from the point of view of the economic historian in Rosenberg's (1969) study.
[53]Rosenberg (1969) uses the term 'bottleneck'.

As discussed in chapter 3, reverse salients are obvious to those working in or developing the system. This is not something open to manipulation but is easily identifiable for system developers considering performance relative to a collectively understood system goal (Hughes, 1987). This means that, within the system, reverse salients are not a matter of opinion; in addition, reverse salients are best identified by those that understand the system goal, rather than an external observer in another place or time. This makes the industry specialist publications an excellent source for their identification by a researcher in another place and time.

The process of addressing a reverse salient is where agency enters into system development: in response to a reverse salient a critical problem is defined and the solution to that problem removes or reduces the reverse salient (Hughes, 1987). Hughes (1983) highlights that at different stages in a system's life different types of actors are likely to have control over this process and to direct its progress. This emphasises that a reverse salient can be addressed in a number of different ways and so this method searches for evidence both of reverse salients and of projects for system change. It is possible that more than one project would be addressing a reverse salient and that one project might be having an impact on more than one reverse salient. The mechanics of the reverse salient-focused data-generation are described in the next section.

4.4 How data are generated

At each point of potential development activity in a system there are two types of evidence of that development point which could be observed in published material. Firstly, there is a reverse salient, an element in the system which can be identified as a problem or an opportunity by those working with the system (for example safety concerns with a particular component). Secondly, there are projects which are being set up to deal with that reverse salient (for example R&D work on the cause of the safety concern, a component design project to remove the safety concern or a legislative project to adjust operational behaviour to prevent incidents linked to the safety concern).

As demonstrated by the example given above, there can be several activities which could be developed in response to the same reverse salient. This method acknowledges this. The data are structured around reverse salients and either of these types of evidence can be used to initiate a 'reverse salient' entry in the database. The structure of the entries is shown in Table 1. Different fields might be needed for different research projects, these have been selected to investigate change activity across the infrastructure of the UK railway system. The intention is to incorporate projects of different sizes and in different areas of technology.

The publication is read in chronological order. Decisions over selecting the source and which parts of it to use will depend on the system and the phenomenon being studied. For this research the news

sections of the publication and the central topics of featured articles are used to identify reverse salients and/or correction projects which are active.

Depending on the research question and the system concerned, the method can be applied at different levels of detail. For example, it might be that every maintenance procedure conducted on a system is relevant or that it is projects that are given names and allocated staff within the developing organisations that are of interest. The researcher needs to consider their interest in the system and to understand the constraints there might be in the source material. The research in Chapters 5 and 6 aims to capture the perception of the reverse salient/project structure held by industry participants and commentators. The origins of change activity are of core importance here and so where sub-projects have been created within a bigger project, it is the higher level project that is of more interest; however, if activity becomes focused into the sub-projects as the work develops these may also be captured in their own right.

A variety of sources can be used for this approach. The original idea was that one authoritative industry specialist publication would be used to identify reverse salients and gather information on them. However, several publications could be used to identify reverse salients or national newspapers could be used if the focus of the research were on government and organisations' activity regarding systems. A useful extension might be to use publications to identify reverse salients but to supplement the information gathered about them with policy documents, patents, interviews and other publications. The way the method has been used in this research on the UK railway sector is outlined in the next section and detailed decisions in data sample generation are described in appendix B.

Table 4-1 Fields in each datum record

1	Reverse Salient reference number	Identification number
2	Entry description	A reference title for the datum
3	Reverse Salient	Issue being worked on as characterised in a news item or as the central topic of an article.
4	Project or Change	Project for change or change being implemented as described in a news item or as the central topic of an article.
5	Cost (£ millions)	Information found on proposed and/or actual costs.
6	Installation completion date	Information found on intended and/or final launch of the change.
7	Set up correction	Information found on the way the reverse salient has been identified and/or the project/change has been initiated.
8	Doing work for correction	Information on the process used for reverse salient correction, for example project structure or phases, information on the organisations involved in the project or innovation.
9	Sources	Each point entered in fields 2-7 is referenced here. 1) Month, year, page number, magazine section, information on the article's remit. e.g. In the Manchester Metrolink project: *2) March 1993 140 Newsfront (On figures for Greater Manchester transport)*
13	Links to other Reverse Salients	This is a reference column for the analyst; where there appear to be links to other projects these can be recorded here (e.g. track work to allow channel tunnel traffic is linked to the creation of the Channel Tunnel)

4.5 The case of the UK railway system

These studies consider change in the UK railway system and they investigate the influence of the industry's privatisation and restructuring on how it develops. Chapter 5 asks how change happens within an established system and investigates this by considering similarities in the railway system before, during and after the governance changes of privatisation; the focus of this research is on a system being developed by actors within it. Chapter 6 considers the potential for system transformation as a result of privatisation; the analysis looks for changes to the processes and settings of system change over privatisation[54].

Both projects consider how this mature system has developed under different organisational structures and governance regimes before, during and after the central privatisation event; to do this, as consistent a viewpoint as possible from which to observe developments is needed. Although many individuals remained employed by the railway sector in its new form, the structure of the sector itself was altered significantly, funding mechanisms and incentives were changed and both operational and development processes changed; over the following years even the administering government department changed its title, structure and remit. This means that it is difficult to identify a vantage point from an organisation or set of individuals not themselves altered by the change which is to be studied. However, this is a sector with a well-established and specialist press. Even this was not fully isolated from changes flowing from privatisation: the publication with the highest circulation[55], *Rail*, underwent significant editorial and format changes in the lead up to privatisation. Therefore, as stability of format is relevant here, the longer-established and second most popular railway industry specialist publication is used in both of these studies.

Modern Railways magazine has run since the mid-1960s and was operated independently from BR. This publication is aimed at industry professionals and observers; it covers both management issues (including policy changes, funding decisions, reports of acquisitions) and engineering developments (there are some technical articles, major product launches are reported and technology development projects discussed). It is published monthly. The magazine's structure includes news sections, feature articles and commentary through editorials and columnists' pieces.

4.6 Method and study design

In this research the reverse salient-focused method, developed above, is applied to the infrastructure elements of the UK railway system. This encompasses the elements of the railway system which form

[54]This is an operationalisation of the sociotechnical regime; chapter 6 considers changes in that.

[55]*Modern Railways*'s approximate circulation is over 16,000 copies per month (http://www.keypublishing.com/portfolio/advertise.asp?publicationID=37 (accessed 24/09/2014)); *Rail* magazine's is over 21,000 copies per fortnight (http://www.abc.org.uk/Certificates/18772490.pdf (accessed 24/09/2014)). *The Railway* magazine has a higher circulation but its focus appears to be towards the enthusiast market.

the network or consistent interface with vehicles that operate it[56]. This includes the track, the signalling system and the organisations that develop and operate them. In the data collection, elements that directly interact with the network infrastructure are also included. Accordingly, stations feature where there are changes to the platform, track or signalling but not where the information system or car park is upgraded. In the same vein, changes which are linked to vehicle access to the infrastructure (for example, in terms of access charges) are recorded whereas changes in vehicle usage patterns are not (there will be an indirect effect on infrastructure, in terms of wear and tear, but that, and its effects, should be reported only where it directly prompts changes).

4.6.1 Sample selection

In order to examine system development in an established LTS under different conditions the reverse salient-focused method is used to sample infrastructure system development over several single-year periods. A sample length of 12 months is chosen to be long enough to come across many reverse salient correction examples, to see several reports on the most active projects as they progress and to eliminate any systematic seasonal variations that might exist either in activity or in reporting.

The system phases, outlined in Chapter 2, are treated as embedded cases of system development; they are used to guide the selection of one-year periods that would not be expected to be distorted by significant, externally generated changes and that can highlight differences in the selection and correction of reverse salients for the development of the same established infrastructure system but under different governance conditions. Care has been taken to generate guidelines and boundaries for dataset construction which produce the appropriate level of detail for the study and which deliver consistency both within and between the three samples. These decisions and the rationale behind them are discussed more fully in appendix B.

The samples used are shown in Table 4-2, along with the total number of data in each sample. The total data in each sample increase across the three samples. Although the magnitude of change is noteworthy, this change and the increase in the number of publication pages used for each sample is approximately comparable (see Table B- 5 in appendix B).

[56]It is a definition based on the concept of the *permanent way* discussed in chapter 2.

Table 4-2 Embedded cases: the time periods considered

Case	Start issue	End issue	Purpose of embedded case	Date selection	Total Data
1	January 1990	December 1990	See development processes under British Rail, before privatisation is a serious possibility.	Sale of the subsidiary businesses is complete and a new Chairman arrives. This sample captures a period before OfQ and before the privatisation idea becomes more serious. [57]	228
2	June 1992	July 1993	See development processes before structural changes have begun but after they have been initiated.	The first reference to the outcome of the 1992 general election is referred to in the editorial of the June issue, 1992.[58]	293
3	October 1998	September 1999	To see development following privatisation and restructuring[59].	Privatisation has been completed but some significant rail accidents are about alter the system's behaviour. This sample concludes before the Ladbroke Grove accident, 5 October, 1999.	377

4.6.2 Method demonstration

This method seeks to include information about the processes of system change and to capture development activity whether or not ideas reach implementation. Some illustrations are shown below.

Table 4-3 and Table 4-4 below show examples from the 1990 dataset that are competing projects or alternative solutions to the same performance issue. Table 4-4 also shows development activity having been conducted and then terminated on one of these developments in favour of the other. These examples show it is possible to study development activity using this method and not just successfully completed projects.

[57]Selected dates before most of the implementation of OfQ (the first stage was due to be completed by April 1991). Privatisation raised by Malcom Rifkind, who moved to DTp May 1991.
[58]Issues of *Modern Railways* are published on the 1st of each month and so the June issue is sent to the press in May.
[59]An early alteration of Railtrack's Network License Agreement had already come into effect in September 1997.
[60]There are changes in 1997 around the time final parts of the industry are being launched, including a new government and the Southall rail accident, but this is the best opportunity to see the new system in operation. Furthermore, it is assumed that the effects of these events will take time to impact directly upon the system's development. The accident report by Professor John Uff was not made public until February 2000 (Gourvish, 2008, p14). Potential changes being considered by the new government were not immediate; the White Paper entitled *A Deal for Transport: Better for Everyone* was not published until July 1998 and the railway system was only one element of the plan and so major changes were unlikely to happen straight away (Gourvish, 2008, p15); the shadow Strategic Rail Authority began operating in Summer 1999 (Gourvish, 2008, p34).

Table 4-3 Data from the 1990 sample showing two competing development options

Ref.	Project	Set up correction	Sources
40	Leeds automated transport system	Leeds City Council decided not to lodge a bill for this in 89/90. It's an 'elevated people-mover proposal'. It had met with opposition. Other concepts may be reconsidered. (1)	1)January 1990 48 News Briefing Bullets (Decision not to submit Bill)
41	Leeds Light Rail	Alternative to the above is 'West Yorkshire PTE's original light-rail proposals'. (1)	1)January 1990 48 News Briefing Bullets (Decision not to submit Bill)

Table 4-4 Examples of different approaches to the same development problem (1990)[61]

Ref	Project	Delivery Date	Set up Correction	Doing work for correction[62]
83	WCML trains and track for speed	(The train could enter service in 1994 (2))	InterCity is planning to replace locomotive-hauled (or pushed) Mk 3 stock on the West Coast main line with 250km/hr fixed formation sets'. Track improvements could be part of the package (1)	Project directors have been appointed for the train and infrastructure. (2) (4)
169	New railway to replace WCML	~2001 (1)	InterCity has considered but rejected a completely new railway to replace its West Coast route. It would have cost over £2 billion, taken 10 years to build and have had major environmental implications, while the present line is the most direct, serving important towns and cities, and is capable of substantial improvement, according to InterCity.' (1)	Instead a project to introduce new trains (IC250) and upgrade signalling and track is being set up. (1) (2)

[61]Fields included here do not all contain all of the information in the datum.
[62]The reference numbers in this common are specific to the datum and refer to difference references in different rows

An example of projects interacting is given in appendix C. Three major projects and their interdependence, illustrated in their initiation, are charted across the three data samples: Channel Tunnel Rail Link, King's Cross redevelopment and Thameslink 2000. The samples also contain examples of one reverse salient correction leading to new development activity. The Channel Tunnel is an excellent example: some of the development activities linked to the Channel Tunnel development from the 1990 and 1992 samples are shown in Table 4-5, below.

Table 4-5 Examples of development activity linked to the building of the channel tunnel (1990 and 1992)

	1990	1992
Channel Tunnel	#78 Channel Tunnel (Breakthrough expected end 1990 and service start in 1993)	#2 Channel Tunnel (Opening expected late 1993 and services start mid-1994)
Work to upgrade existing railways ready for the additional traffic	#10 Improvements to existing NSE railways for Channel Tunnel traffic (several subprojects are also included)	Features in the form of a series of subprojects. Examples include electrification (#197), resignalling (#147), track change (#62) and radio system change (#154) projects.
A dedicated high-speed link	#33 CTRL (Aim to get into operation in 1998; activity around route plans and funding)	#1 CTRL (Bill anticipated late 1993; activity around route plans and funding). BR also sets up a subsidiary for this development (#98)
Arrangements to allow freight use	#76 Channel Tunnel Freight plans	Several projects including a freight inspection facility (#60) and a number of Euroterminals.
Terminal developments	#151 Waterloo changes for Channel Tunnel terminal (and King's Cross #2)	#62 Cheriton terminal construction (and King's Cross #44)
Maintenance facility for passenger vehicles	#153 North Pole Maintenance Depot: for maintenance of passenger coaching stock for Channel Tunnel trains	#156 North Pole International Depot (First Super Depot)

The examples in Table 4-5 also illustrate the changes in focus shown over time. These data allow the integration and disintegration of projects or reverse salients to be captured. For example, the development of existing railways to accommodate Channel Tunnel traffic has been referred to as a single development project and as individual correction projects as appropriate. This is something that is shown very clearly in the introduction of proposals for privatisation. In the 1992 sample the introduction of privatisation is quickly broken down leading to sub-tasks (such as determining the role of the regulator) being reported upon individually; this is discussed further in chapter 6.

4.7 Limitations of the method

This method is liable to pass on biases that are present within the source material. Efforts have been made to reduce this effect in this study by carefully selecting the relevant sections of the publication and by guiding the analysis to avoid commentary in reverse salient identification (reverse salient identification is only recorded where those with relevant ability to impact the system discuss it; the journalists' opinions and campaigns by pressure groups outside the system are excluded). This is explained further in appendix B. This characteristic of the method can be a strength for some research questions. For example, the focus on debates and issues important to system actors, and the ability of the publication to provide the appropriate level of detail to communicate system developments to actors in specialist areas of the system, are important parts of the use of this method in this research. A further measure for reducing the impact of any bias in the source material, recommended for future work, is to conduct this kind of analysis using more than one source publication.

In applying this method over a long period there is also a risk that the publication or its market placement will change. Differences found in the data can be as a result of changes in reporting rather than changes in behaviour. It is likely that changes in reporting that are not easily observable are changes in the interests and focus of system actors and therefore, in this study, their inclusion in the data is beneficial. However, it is also possible that editorial changes could generate changes in reporting independent of system change. This needs to be considered in publication selection (see for example the exclusion of *Rail* magazine as a source publication, above) and should be considered in data analysis as well.

One strength of this method is the possibility it provides of studying large systems over long periods. It also allows a wide range of development activities to be considered; this gives the analyst the opportunity to investigate and to demonstrate the most active areas of development. However, care needs to be taken in the use of quantification in analysis. It can provide indications of areas of activity, however these are not data suited to detailed quantitative analysis: an important component of their application in this research is the ability to include activity in the same part of the system whether or not it is successful and to show changes in the treatment of reverse salients or development projects, particularly, as discussed above, with respect to the level of detail.

The analyses in this research attempt to take these limitations into consideration and to apply the method to its strengths.

4.8 Application of this method in chapters 5 and 6

In both empirical studies presented in the next two chapters the data samples generated from archive material are used in conjunction with additional data. Secondary data, in particular the histories of the system by Terry Gourvish (2002; 2008) that focus upon the management and governance of the sector, and a series of interviews conducted with senior managers and engineers in the privatised industry between 2007 and 2009[63] are used in both studies.

The phases of system development, discussed in chapter 2, that form the embedded cases in this research design and the sample selection within those phases (see table 4-2 above) were defined using secondary sources. This structure is used in both studies. Both studies focus upon how the system changes, they do not seek to measure or compare the extent or success of system change at different times.

The study presented in chapter 5 uses the archive datasets as the primary data; the secondary and interview data are used only for corroboration. This study focuses on the reverse salients in the archive data to examine the system change activity of a mature system. The reverse salient data is coded to identify different types of development activity and different actors at work. Rather than generating a detailed history as Hughes (1983) did in his original work, these coded data allow a breakdown of different types of activity and an analysis is conducted that examines and compares that activity within and across the three samples of archive data.[64]

The research described in chapter 6 uses the archive data samples as snapshots of the system's sociotechnical regime in action. This analysis searches for ways in which the way the system changes has changed with the privatisation and restructuring of the system. In this study the secondary and interview data are used to supplement the archive material. These data provide evidence of continued development alterations between the data samples and, in particular, after the end of the third sample. The data also include some explanations for the changes observed across privatisation. In this study the additional data can be used to rule out observations of change resulting from changes in reporting in the data source (between 1992 and 1998) rather than system change. In the final part of this study interview and secondary data are used to develop longitudinal studies of developments following important changes to the system created with privatisation that were highlighted in the analysis of the archive data.

[63]Details of the interview data are given in appendix A.
[64]Tables describing or presenting parts of the data and breaking it down are presented in appendices C-H.

4.9 Contributions

The method developed here has the potential to be applied across systems and research projects. It provides a systematic approach to study the development of these large and complicated systems over time. The use of contemporary records of system change and the ability to include change activity whether or not its output is successfully implemented reduce concerns over retrospective and success biases in these studies. Using samples this method is applied and tested to two different research questions in the two empirical studies presented in chapters 5 and 6 of this dissertation. It is also intended that this method could be applied longitudinally and some examples of its use in this way is shown within the three samples.

Chapter 5 considers development activity in established infrastructure systems. The data are coded to distinguish between different types of development activity and characteristics of reverse salient correction particular to established LTS are identified. Chapter 6 focuses on the impact of system restructuring upon system development and investigates changes to the way the system develops. The data are used to represent sociotechnical regimes in action and evidence of alterations in development goal, system-builder and performance characteristics are found.

5 DEVELOPMENT OF AN ESTABLISHED LTS

Established infrastructure systems come in many forms, shapes and sizes. The earlier parts of this dissertation have discussed the mechanism for system development identified and described by Thomas Hughes and have considered its form in the development of established systems. The method, developed in chapter 4, to study mature system change through capturing reverse salient activity is applied here to the infrastructure sections of the UK railway system. The possibility is raised that systems can be built from more than one source of system-building activity. The study presented in this chapter shows the importance of the installed system in the development of established infrastructure systems. Developments focused on each of the installed and the blueprint performance lines, introduced in chapter 3, are observed and these two types of performance are seen to interact in the initiation of system change activity.

For the case of established infrastructure systems existing research does not explain who the system-builders might be and patterns of reverse salient selection and critical problem construction are not understood. Recent research considering transformation of infrasystems, whether that is for sustainability (e.g. Loorbach et al., 2012) or investigating the liberalisation of infrastructure systems (e.g. Markard & Truffer, 2006), would be better able to understand these significant and highly visible changes if the different options for within-system change in mature systems were understood. This study seeks to extend existing LTS understanding by examining change activity within an established infrastructure system.

5.1 The railway sector

Railway systems across the world tend to show high degrees of complexity and relatively tight coupling in terms of the responsiveness between components. The original template, in terms of the technological blueprint and the accompanying mass-transit business model, for these systems was created in the UK. The UK railway system was initiated and grown by private enterprise, but it was gradually consolidated into a national system. The system has continued to have its technology updated, for example with advanced signalling systems and remote monitoring of infrastructure components. However, its basic physical form has remained consistent for many years, it has not undergone either rapid expansion or contraction for some time, and it can be identified as a system with high momentum (Hughes, 1987): the UK railway system can be characterised as a mature or established infrastructure system.

As a result of its privatisation and restructuring in the mid-1990s this system has been governed and developed in different ways over a relatively short period of time; there was an abrupt change between nationalised, vertically integrated system-building organisation and many specialised organisations interacting with and developing parts of the system through market arrangements. This work looks at how system development occurs by considering reverse salient correction activity and the natural

experiment of privatisation provides the opportunity to compare within and across several phases of governance for the same established infrastructure system.

5.2 Analysis

The method and samples described in chapter 4 are used in this study. Once recorded, the reverse salients identified were coded. Three principal categories of code were used to consider system development activity: types of action, the type of system change and the origins of system change[65].

5.2.1 Types of action

The generated datasets contain several types of activity. As anticipated in the discussion of mature system change in chapter 3, many of the changes noted were specific to the local system rather than abstract in character, for example an electrification project for one section of the network rather than development of electrification technology. These projects, directly adjusting the installed system, could be about the implementation of technology already developed, but they could also be solutions being generated for individual local problems. Upon closer examination four types of action for development were identified. The *general* and *specific* codes discussed below are related to the blueprint and installed system performance lines introduced in the theory discussion in chapter 3. Activities coded *general* represent projects that address the blueprint performance line. Those coded *specific* are activities focused upon a point upon the installed system's performance line.

The frequency of these codes in the three data samples used here are shown in Table D- 1 in appendix D. The majority of development entries (75%) were coded as *specific*. This figure includes a small number of projects that could be clearly linked to more abstract changes and were the implementation of *general*, or even occasionally *indirect*[66], changes into part of the operational system. The high frequency of changes focused on the installed system could be entirely a reflection of the industry's interest in operation-focused performance. However, even if these projects were only to reflect the diffusion of centrally developed and defined technology[67], they would be considerably more numerous and appear much later than the accompanying *general* project. In these samples, as illustrated by the examples in Table 5-1, the relationship between *specific* and *general* projects is more nuanced; *general* projects are often initiated by problems identified locally in the installed system and specific projects, even where they take on a more *general* concept (such as electrification or station regeneration), can involve considerable development within the project. *Specific* projects can also be generated entirely for developments to improve local performance; these might, but do not necessarily, draw upon more

[65]A geographical code was also applied, using Network Rail's route plans to sort development activity. However in this analysis this code was principally used as a check.
[66]These refer to several data in the 1998 sample that show changes in the nature of inter-firm relationships, and in the case of new forms of infrastructure maintenance contracts, their application into the operational system.
[67]For example, the technology and designs for electrification would be developed by a central R&D function and then built in different locations when possible.

general ideas. The installed system does appear to be an important focus point for improvements in system performance; more than would be the case if diffusion of centrally developed changes were the principal mechanism of development.

As illustrated in Table 5-1, below, the *study* projects identified take several different forms. Studies can be focused on one or more specific problems or projects, potentially forming the starting point for development projects to follow. However, they also take a role in assessing and selecting problems and projects. There are *study* data in these samples that support all three types of system change: *general*, *specific* and *indirect*.

As shown in Table D- 1 in appendix D, the distribution of the frequency of these different types of action in the development of the UK railway infrastructure is remarkably consistent across the 1990 and 1992 samples[68]. The higher proportion of *non-specific* development activity in the 1998 samples could reflect a change in the system's development. However, it could also be caused by changes in the visibility of different types of project following restructuring: there are supply organisations and newly independent consulting organisations seeking to publicise their activities and sell their products or capabilities to the organisations now operating the system. However, these activities themselves reflect the new organisational and governance structure and an increased importance for these developments, to be seen by others, would be expected to generate a consistent focus here for these organisations.

[68] The difference in proportions, for *specific* code, for 1990/1998 and 1992b/1998 is statistically significant at p=0.01, whereas for 1990/1992b it is not significant (see appendix D).

Table 5-1 Types of action for system development

Code	Description	Examples
Specific	Reverse salients or projects that relate to specific part of the installed system. This includes entries that reflect a set of such changes and entries that refer to both a specific site and a general technology (e.g. pilot projects or diffusion projects)	King's Cross Station redevelopment project (1990, #2; 1992, #44)
		Infrastructure changes to support the Cross Country franchise (1998, #328)
		Pilot signalling project for PC-based signalling control system at Eastbourne (1998, #145)
General	These data focus on more abstract development opportunities or projects. This includes technology development for the system and national projects focused on a particular issue.	Development of embankment reinforcement techniques (1990, #165)
		Developing a standard Europe-wide railway digital radio system for voice and data traffic (1992, #56)
		Inspection 2000: initiative aiming at automating track inspection (1998, #146)
Indirect	Across all three samples there are also a variety of changes to the system that do not directly affect either the operational system or the ideal or blueprint version of it. These are changes to incentives for development[69], to non-operational organisations[70], and to the technology or processes of system change. Changes to industry structure as part of privatisation are included here.	Capital spending budget for BR set by Treasury (1990, #36)
		BR creates a safety-benefit index to rank projects (1992, #154)
		Launch of an industry-wide database for accepted products: Parts and Drawings System 2000 (PADS 2000) (1998, #254)
Study	It was also found that some development activity records are best described as studies. These include investigations considering specific projects and work examining development options (for the operational system and its governance). These can precede and/or recommend development projects later initiated.	Study of electrification between Edinburgh and Aberdeen (1992, #84)
		'Project Elephant': study to assess opportunities for heavier freight vehicles to run on the network (1998, #270)
		Transport Select Committee report on Government plans for transport (1990, #190)

[69]This includes the setting of performance measures and fines for aspects of underperformance.
[70]For example, mergers amongst industry specialist consultants.

5.2.2 System Change

These codes identify different types of system change. This is not about the motivation or origin of an activity but an observable set of different alteration activities. Their application is within the *general* and *specific* 'types of action' codes identified above. For activities that directly alter the installed network, three deductive codes are used: scale, scope and throughput. These are inspired by the concepts in the literature looking at the economic drivers of system change: economies of scale, scope, speed and system. These ideas highlight different types of alteration a system can undergo. Here the speed and system changes are combined under the *throughput* code. These are defined for the railway network as shown in Table 5-2, below. Speed and system are combined because for a railway network they overlap considerably. A faithful use of Chandler's (1977, p281) work would suggest that speed should be considered as referring to journey time, rather than average speed over a section or a velocity profile. However, Davies (1996) and Nightingale et al. (2003) suggest that a change in system can, through improved control, decrease journey time and/or decrease gaps between vehicles.[71] This makes a distinction between speed and system changes both difficult and not particularly enlightening.

[71]This difficulty of overlap between the concepts is not present within the sector for which the economies of system concept was developed: telecommunications (Davies, 1996); here, data speed and its routing can be separated because speed is treated as a characteristic of a given connection (that can also be upgraded as such) rather than including control innovations.

Table 5-2 Deductive codes for types of system change

Change Code	Description	Operationalisation for Railway infrastructure
Scale	System changes that extend or reduce its scale, including in the case of railways potential passengers reached.	This is focused on adding entry points for traffic in the network. i.e. adding traffic/activity through new lines, stations and facilities. Decreases in scale are also included under this code.
Scope	Changes to the system that increase or decrease the use of the infrastructure through adding or removing different types of use.	For infrastructure this code is restricted to changes made to add or remove the use of different types of vehicle: passenger, freight, light rail. Here different categories of freight vehicle are relevant but different designs of the same type of vehicle (in any category) are not.
Throughput	System alterations that extend its capacity without adding to it, in terms of either scale or scope.	This includes infrastructure changes to reduce journey times, new control systems to reduce gaps between vehicles and layout changes to allow better use of routes through the network. Although theoretically changes that reduce throughput would be included under this code, these are rare as capacity is more likely to remain unused (the cost of this is likely to be low relative to other options).

Types of activity for system development not directly acting upon or generating knowledge for the installed technological system are also included in the dataset, even within the *specific* and *general* 'types of action' codes described above. There are some changes to the system, such as organisational restructurings and ownership changes that do not fit into *scale*, *scope* or *throughput* changes to the operational system; these are listed under '*other*'[72].

These codes were applied to the three samples; within this category of codes, projects are sometimes featured at a level of detail where more than one type of change is included; for example, a freight line being converted for passenger use (scope) and new stations being added (scale). In most cases a single code is assigned for simplicity, based upon the emphasis available within the descriptions[73]. An

[72]*Specific* and *general* actions that fall into the 'other' code for the type of change include: organisational and governance changes within the organisations within the operating system (e.g. change of ownership for an IMC or contract disputes) as well as contingency issues and reverse salients to which the solutions have not yet taken a form.

[73]These decisions are noted in a coding notes field within each of the spreadsheets.

exception is made for the building of new light-rail or other self-contained systems; these developments can be characterised as a scope change as they allow provision for a new type of vehicle (and journey) but they also add significantly to new access points to the network. As a result, and because they are uniform in this condition, they are allocated a category of their own, '*Metro*'.

The system change codes described here are applied to the *general* and *specific* types of action described above and the full datasets can be described using the system change codes and the *indirect* and *study* types of action for development. These frequencies are shown with the change initiation codes, introduced below, in appendix D.

5.2.3 Change initiation

This is a category of codes that looks at the origins of system changes. These were developed inductively by looking for patterns in the types of actors involved in reverse salient identification or project initiation. In addition to the system owners and operators, sections of central and local government make decisions about and direct action towards the railway system.

It is important to note that there are many types of initiation activity that include having the idea, developing plans, providing funding and approving work to go ahead. These data do not contain sufficient information to allow useful discrimination between these elements and so they are combined in the codes; this does lead to a lower level of precision but patterns of activity can still be captured. A datum is assigned a code when evidence of initiation activity is included in it. Quite often more than one code is applied; a recurring example is where both BR and local government organisations were involved in setting up and defining the scope of a project but it was not clear which, if either of them, was the more active or the earlier actor.

Table 5-3 Change initiation codes

Initiating actors/patterns	1990 & 1992	1998
Central government is identified within the initiation of change activity; this could be highlighting reverse salients for action or specifying work to be done (approving the plans of other actors is excluded from this code)	Central	Central
Local government organisations (including PTEs) are involved in setting up projects.	Local	Local
The core operational industry. BR before privatisation and Train and Freight operating companies, Railtrack, consultants/contractors with a link to the industry, infrastructure maintenance companies (IMCs). Firms working with the railway to ship their goods are referred to as logistics members.	BR	Industry: key players listed
Private here refers to organisations, excluding suppliers, that would not be permanently be identified as part of the system: these tend to be land development organisations.	Private	Private

Changes installed into the system sometimes come from opportunities picked up on by the supply industry.[74]	Supply	Supply
System changes initiated by the regulating organisations are noted and captured using this code. These include HMRI and HSE as well as the Rail Regulator and OPRAF.[75] Data where regulators appear only to approve plans or work done do not have this code added.	Regulation	Regulation
Reaction. An additional element noted in the initiation of some change projects was the need to respond to unexpected events or requirements. These were often to do with safety but could also be a result of non-safety critical system failure, for example storm damage or breakdown.[76]	Response	Response

Combined codes were much more difficult to avoid within the change initiation category. Although kept separate within the data, for the purposes of looking at coding patterns, aggregations of mixed codes were made and these are given in Table 5-4. The *BR/Local* combined code was often present within the data and this is preserved as a category of its own.

Table 5-4 Groups of codes to highlight activity[77]

Name	Codes and combined included
Central	Central, Central/BR, Central/Local, Central Response
Local	Local, Local/Private, Local Response
BR	BR, BR/Private, BR Response, BR/Supply, BR/Regulation, BR Response Regulation, BR/Supply Regulation.
BR/Local	BR/Local, BR/Local Response
Private	Private
Supply	Supply
Regulation	Regulation

A further category is required for both sets of change codes: that of *not enough (NE)* information for a code to be assigned. This rarely occurs for the deductive *type of change* category, however there are entries which feature identified reverse salients that do not yet have information given on critical

[74]In the first two samples this was originally coded within the '*Private*' code; however, there is more evidence of this route in the final sample and so, because it is clearly different in character from the private development activity also captured there, a separate code was created and applied back to the earlier data.
[75]Where there is evidence that safety or regulation organisations have had a role in the identification of a reverse salient or the initiation of a project, this code is applied; more often than not it appears with other codes.
[76]There is substantial overlap between *BR Response* and *Regulation* however it is not complete for either code. *Response* is not added to purely regulation codes; this is assumed as part of a regulation process.
[77]Where *BR* is used, *Industry* is a direct substitute in the third sample. These are not included separately in this table.

problem definition that implies the type of system change that will be used and in these cases a type of change code cannot be assigned. For change initiation codes, however, not being able to assign a code from the information contained within a datum is not uncommon. '*Not Enough*' (*NE*) is a further category recorded to keep track of these cases.

The frequencies of the change initiation codes, the system change codes and their interactions are shown in Tables D-2 to D-7 in appendix D. The relevance of the throughput code is shown and the main actor for throughput developments is BR or the industry.

The process of defining codes and applying them to the structured data generated in three samples allowed data to be grouped according to system change and development initiation characteristics. Patterns could be identified and evidence was found of several centres of development activity; these are described in the next section.

5.3 Findings: Development activity in an established infrastructure system

5.3.1 The interaction of *specific* and *general* development activities

The data show different types of development activity. In particular, two approaches to directly addressing system performance are identified under the *general* and *specific* codes. A distinction is made between those developments addressing general or blueprint reverse salients and opportunities and those dealing with the immediate or local performance of the operational/installed system.

One model for these different types of development activity and how they interact is to extend that implied with the development of new systems: development activity is based upon the underlying blueprint in its best current form and changes are then developed to fit that blueprint before being implemented into the operational system. However, these data show a more significant role for the installed system. The 1990 data sample is used to illustrate some of the interactions between blueprint and operational system development. Examples are given in Table 5-5. General developments can be triggered by performance measures as well as performance ideals (e.g. punctuality figures); opportunities for performance can be local as well as system-wide and they can tackle a mix of performance opportunities. The operational system offers a place for trial and feedback as well as straight diffusion of centrally generated developments; general projects can also be triggered by local needs (e.g. space constraints). Extensions of performance requirements can come from operationally experienced contingencies (e.g. weather resistance work) as well as growth ambitions. Operational failures are also found to trigger both local and system-wide developments; means of identifying points of failure include accidents as well as poor performance.

Table 5-5 Illustrations, from the 1990 sample, of system development through specific projects and the relationship between *specific* and *general* activities

Responding to new opportunities (performance led and/or technology driven)	• Leeds-Manchester remodelling: Raising linespeed on North Trans-Pennine to allow 90 mph running where possible. Project provides for the higher speeds of new vehicles (Class 158s), reduces journey times and increases capacity. (#21, 1990) • Aluminium/Stainless Steel conductor rails: Aluminium provides better resistance (particularly important for regenerative braking) but experiments by BR in 1965 showed too high a rate of wear; more recently stainless steel cladding on the top surface has been tried and has been installed elsewhere in the world. It has now been installed on a 5-mile stretch of the Solent Link project. (#140, 1990) • Embankment reinforcement developments by BR Research '...may mean less land-take for new lines and realignments.' (#165, 1990)
Responding to failure/ underperformance in the operational system	• Ribblehead viaduct repair: phase two (#184, 1990) • Investigation and safety measures for DMUs not triggering track circuits; problem identified by and project initiated by BR (#101, 1990) • Reverse salient: BR's understanding of 'the complex hydraulic behaviour of water courses' (Problem raised in Railway Inspectorate report into the collapse of the Glanrhyd railway bridge) (#143, 1990)
Diffusion type activities	• Platform lengthening for extra capacity on the Southeastern sub-Sector of NSE (#6, 1990) • Carstairs electrification project: between Edinburgh and Carstairs. This is an infill electrification project linking to the WCML from Edinburgh. (#59, 1990)
Responding to contingencies	• Changes following electricity industry privatisation (#54, 1990) • The replacement Ness Viaduct at Inverness following its destruction by flooding (#100, 1990) • Operation Cleansweep: To clear railway surroundings of vandalism/ derailment risks (#175, 1990)

There are *general* type development activities initiated by blueprint system reverse salients (e.g. aluminium/stainless steel conductor rails) and diffusion type implementations of general developments (e.g. electrification projects and platform lengthening). There are *specific* type developments to the operational system triggered by installed system reverse salients that do not touch upon the blueprint system except, perhaps, to draw from its ideas (e.g. Leeds-Manchester remodelling). However there are also interactions between these two system forms, the blueprint and installed.

General developments can be triggered by *specific* reverse salients; this can be local performance issues, (e.g. embankment reinforcement developments) or from failures in the installed system (e.g. BR's understanding of 'the complex hydraulic behaviour of water courses'). *General* developments can also interact with their installations or diffusion through trials and further learning (e.g. the trial of aluminium/stainless steel conductor rails on the Solent Link project).

In addition to triggering *general* developments, s*pecific* developments can respond to the solution of *general* reverse salients (e.g. electrification). However, the importance of the readiness of the local site is highlighted by the examples in Table 5-5; for example, platform lengthening uses long-established technology but it is only implemented when a local need arises.

Applying these observations to understanding the development of established LTS invites further exploration of the double performance line put forward in chapter 3; this is discussed further below. And, in considering the added performance line for the installed system, a new possibility arises: reverse salient generation. This idea and its implications for the interactions of the installed and blueprint system performances are explored below.

5.3.2 Reverse salient generation

Accidents and contingent effects (such as unexpected weather events) illustrate the possibility that the performance of the operational system can deteriorate. The immediate effect of an accident can involve parts of the system being, usually temporarily, removed[78]; even if this is for a short time the performance of the system at that moment has had a reverse salient added. Weather events, in addition to having a similar effect to accidents, for example by generating closures or speed restrictions, also present the idea of changes to the performance requirements of a system: new or increasing instances of a particular type of event will lead to a need to resist its effects. There is another means for the addition of reverse salients in the operational system: wear and tear. System performance will deteriorate as elements of the installed system do and with such high asset values and long life-cycles this is not always a short term shock. It can be the gradual emergence of a persistent gap between the performance of the installed system and that of the same technological system installed as new.

Table 5-6 presents a range of examples, from the 1992 sample, of reverse salient activity initiated by generated reverse salients in the operational system. Sometimes these feature in the development data where the system is simply returned to 'as-new' condition[79] but as shown in Table 5-6 various levels of further development also occur.

The examples in Table 5-6 below show a range of development outcomes from *specific* reverse salients where the installed system performance had deteriorated, producing a gap between installed and 'as-new' system performance. In addition to the completed developments shown, there is also an example of the consideration of one of these reverse salients that was captured during decision-making; this shows a worn-out asset being identified as a reverse salient and that it has opened up a range of

[78]Even if it is only whilst the damage is repaired.
[79]It is expected that many examples of this kind of change will be missed in these data as they will be considered routine and not necessarily generate notice in the industry press.

responses and presents an opportunity for further changes; there does not appear to be an expectation that 'as-new' rectification is the norm for tackling it.

Table 5-6 Different levels of change in the correction of generated installed-system reverse salients

Extent of change	Example
Return to 'as-new' condition	Project to repair the Highland line around Dalguise, including replacing an embankment washed away, following flooding caused by sudden thaw and heavy rain. (#218, 1992)
Local improvement	Repair and track lowering for Arley Tunnel: stabilisation work to counter mining subsidence and track lowering that will allow 9ft containers from the Channel Tunnel to pass through; once complete, the speed limit can be increased to 70mph up from 10 mph. (#50, 1992)
Blueprint development	Renewal of the unballasted track on the Forth Bridge; stocks of special Forth Bridge rail, used since opening in 1890, running low and it is expensive to have more milled. The old rails were secured to longitudinal timber beams; renewal replaced timber beams and special base plates have been designed to allow standard, 113lb rail to be secured. (#90, 1992)
Diffused blueprint development	Programme for replacing relays affected by silver migration. It was a factor in an accident featured in the 91-92 Railway Safety report; It affects relay-based multiple-aspect signalling systems installed in the 60s & 70s and it can lead to unanticipated short circuits followed by their removal, potentially generating theoretically impossible sequences of signal lights. (#153, 1992)
To be determined: an opening for change	Reverse Salient: worn-out asset - signalling between Meadowhall, Barnsley and Penistone. This was identified as a 'choke point' in SYPTE strategy document and 'several schemes have been drawn up…' (#195, 1992)

5.3.3 An installed system change issue: throughput developments

The *scale* and *scope* (and *metro*) changes shown in these data do not appear conceptually very different from similar changes within newly installed systems. However, in these data on the development of a mature system a considerable number of development ideas and alterations for the installed system focus on throughput improvements. These activities are focused upon using existing infrastructure more efficiently; for example, this could be by adding to it, by renewing it or by reducing costs. It is a type of development that would automatically be considered of more importance in the change of established infrastructure systems than in nascent ones; this reflects the importance of the installed or operational system, and its adjustment, in development activity in established systems.

The tables in appendix D show the high frequency of throughput development activity across all three data samples; *throughput* changes represent 40-50% of changes in each of the samples. It also appears to be predominantly the preserve of industry-initiated developments.

These are changes that adjust the installed system. However, as demonstrated above, that does not exclude the possibility of a project being driven by or influencing the blueprint system. In fact, with the long asset lifecycles in action and technological developments continuing, both inside and outside the system, there are likely to be sections of the system where upgrade would be expected with replacement. Signalling appears to be such a section over the period of this study. For example, with the open change (#195, 1992) featured in Table 5-6, there is also a range of signalling developments referred to within these data and the justification of their inclusion or exclusion is sometimes recorded Semaphore signalling systems are being replaced and new signalling centres (and, in the 1998 sample, Network Management Centres (NMCs) are being introduced). Amongst this, one indicative example is #178, 1992: the aging signalling equipment on the London, Southend & Tilbury line is due to be replaced, a route modernisation had been planned but due to the peaky[80] nature of the service a financial case for new trains could not be made; resignalling would go ahead but with conventional Solid State Interlocking and an Integrated Electronic Control Centre (IECC). In signalling, it seems, new technological options had been developed and opportunities for installation were being sought.

There is an indication, here, that these projects can be complex and far-reaching. The larger projects rarely appear to be focused on only one parameter for improvement. Electrification projects, like the Birmingham Cross-City line (#20, 1990 & #43, 1992), involve new trains and electrification equipment but they can also incorporate new track layouts, signalling upgrades and vehicle maintenance facilities. If one element of a route is being redesigned that can open up the possibility of or necessity for other changes.

As described above, some of these projects are developed around necessary equipment replacement; however, this is not the only circumstance for throughput changes. There are examples where capacity or service provision needs require adjustments to be made to existing routes. See, for example, platform lengthening for extra capacity on NSE (#6, 1990), North Leeds electrification scheme where patronage had grown, more capacity was needed (#26, 1992), and ATP roll-out was required to assist in accident prevention (#16, #17, 1990 & #76, 1992 & #158, 1998 (TPWS)). These three throughput changes are also examples of the *economies of system* concept (Davies, 1996) in action.

The complexity of some of these throughput change projects for the installed system indicates that it may be beneficial to co-ordinate changes to the installed railway system. There are likely to be

[80]Meaning that the capacity demands on the service are significantly higher in the morning and evening rush-hours.

economies of scale and scope within projects: in the alteration work, closing the railway is expensive, but they would also be expected in the design work. If track realignments can be done as part of the signalling redesign project there may be efficiencies to be gained for both parts of the change. This shows system interdependencies at work (this can be within the blueprint and the installed system but overlap may not be complete); the presence of interdependencies in the data developed here is discussed further in the next section. It also highlights a potential shift, due to the consideration of the installed system's needs, in project definition in established systems. Whichever system is being considered, where a reverse salient is selected to be corrected the boundaries of the development project may not be set at that point; there could be adjacent elements[81] that should be incorporated into the development work. The examples above indicate that in established systems there can be implementation and design interdependencies to consider in project definition: it is best not to dig up the road twice.

5.3.4 Interconnectedness of components and their reverse salients

There are many examples of connections between components and therefore their development in these data. One development project can highlight others to follow as improvements in one part of the system leave other elements behind or demand more from them. The extent of interconnections between developments, even at the planning stage, is shown in the intersections shown in the data on three major development projects: the Channel Tunnel Rail Link (CTRL), the King's Cross redevelopment project and the project to increase capacity on the Thameslink line (Thameslink 2000); these interactions and core developments of the three projects as shown in the three data samples are presented in Table C- 1 in appendix C. In these high-level change projects each project's aims, as well as their means of achieving them, are altered by decisions on the timing and reach of the other two projects. The King's Cross redevelopment project is on the verge of getting a Parliamentary Bill but is waiting for CTRL decisions and a crisis for the CTRL project stalls its progress. The financing of CTRL is linked to deliveries anticipated from the other two projects, neither of which is fully formed by the time CTRL decisions are made. Even such major developments as these three large-scale change projects cannot always be bounded by clear interfaces with the broader system.

There are also interdependencies between system components involved in the same journey. A visible and recurring example within these data is between infrastructure and vehicle[82]. There are examples of joint infrastructure and vehicle adaptation projects, such as the NSE Networker project where the infrastructure was adjusted for the longer trains (#15, 1990; #25, 1992) and works included longer platforms, loading gauge changes and adjustments for Driver Only Operation (DOO).[83] There are

[81]These could be less urgent or less severe reverse salients or they could be elements that interact strongly with the proposed changes.
[82]As these data focus on infrastructure development it is the influence of vehicle needs upon the infrastructure that is recorded
[83]It is worth noting that another way of getting long trains to fit with platforms that are too short for them, a vehicle based solution, is selective door opening.

instances of unexpected adaptation projects, such as movements to CCTV and mirror provision for DOO with a changed driver position (#112 & #154, 1990). The data also show points of interaction failure, for example trains not triggering track circuits (#101 & #163, 1990). Finally, found here in the post-privatisation sample, there can also be interface definition and/or management developments such as the publication of the Railtrack & Railway Inspectorate joint guidance on stepping distances (train to platform) (#18, 1998) and developments in vehicle/product acceptance processes (#20, #254, #312 & #373, 1998).

The management of interdependencies is a challenge in the continued development of established systems, as in their early development. However, there is the additional consideration of local and historically generated variations within the installed system and how newly developed sections will fit with existing components. Without rebuilding the full system, the new will have to fit with the old as well as adjacent developments.

5.3.5 Reverse salient selection: the role of studies

Across all three data samples, studies are found being used as part of the system development process. Studies are used in several ways; the following sub-codes were used for entries coded as studies. They can be used to set up a particular project or consider an installed system reverse salient (*study/specific*). Several projects can be assessed or options to address a blueprint-level reverse salient studied (*study/general*). There are also studies that look at system development processes or development directing forces (*study/indirect*). As shown in the tables in appendix D, most of the different types of organisations were involved in initiating studies; there is a noticeable increase in the percentage of study activities initiated by industry organisations in the post-privatisation sample.

Studies appear to be a vehicle to aid system-building between several actors. Included in the above (at both *specific* and *general* levels) there are strategy documents which deal with a vision for some or all of the system and prioritise development options. This will be about communicating about the goal as well as development openings.

Looking at other *specific* and *general* studies changes can be centred around an aim (e.g. electrification between two points), an asset (e.g. how to best develop a particular line), a local reverse salient (e.g. more capacity needed) or a national issue (e.g. system safety performance or signalling renewal)[84]. They often consider the best way to tackle a problem or opportunity; studies can be used to set up and make a case for particular projects in the installed system; this can include going some way to defining them, i.e. translating a reverse salient into a critical problem.

[84]A further use for studies is in accident investigation.

5.3.6 System-builders

British Rail and its board hold a central and co-ordinating position within the mature system in both the 1990 and 1992 samples studied here. However, they do not appear to fulfil all of the system-builder role. This analysis shows several different system development roles in operation even before the industry was privatised. British Rail is the co-ordinating organisation that will be involved in almost all projects and takes a role in connecting development projects into the system and, one would expect, co-ordinating their implementation[85]. However, several mechanisms exist for system development and they involve different types of actors.

The voice of the people

One clear mechanism for development is linked to public organisations that seek to develop parts of the system. Local authorities and Passenger Transport Associations/Executives (PTAs/PTEs) identify and fund projects. There is also evidence that these organisations can look at rail as one subsystem within a local transport system, thus providing a different focus and aim for system development; it is likely, too, that interests and approaches will vary between regions.

British Rail does take a role in these developments. There are instances when development plans appear to come from British Rail to be considered by the local governing organisations and examples where the evidence indicates that the local executive organisations are driving changes. The BR/Local code is linked to many examples of developments where both of these organisations are involved and it refers to a similar process no-matter which of the two organisations initiated a change. There are examples of joint initiatives and shared funding for these development activities between local organisations and British Rail.

These are changes which consider the needs of a local transport system and/or those of its potential passengers in terms of social needs and/or political success rather than through following the drivers of a national system. As such they differ in character from the central system-builder approach that one might expect the system's nationalised owner, developer and operator to take.

Some of the different types of reverse salients or correction projects that had the involvement of local actors are presented in Table 5-7, below.

[85]For example, the implementation of electric propulsion; shown in the 1990 sample in Regional Railways electrification planning (#220).

Table 5-7 Range of infrastructure changes tackled by Local actors

Adding new transport systems and services, some connecting across modes	• Midland Metro Line One (1990 #5; 1992 #27; 1998 #2): linked to reducing traffic congestion (1990) and promoted (1990) and commissioned (1992) by WMPTE (Centro) • Strathclyde PTE's re-opening of Northern Suburban route (1992 #86) • New station at Prestwick Airport (1992 #229): Talks going on between Prestwick Airport and local authorities about 'the possibility of funding...' the station • Developers have been appointed for Doncaster Metropolitan Borough Council's intermodal distribution centre (1992, #97)
Keeping lines open and improving services	• Local authorities have paid for level-crossing modernisation & other repairs around Humberside to protect these routes (1990, #34) • Signalling alterations on the Paisley Canal line that will allow the introduction of a half-hourly service (Strathclyde PTE) (1992, #87) • Reinstatement of double track between the station platforms at Newton and the Cathcart line following service halt as a result of the Newton accident. Project implements first recommendation of HSE report on Newton. Strathclyde PTE obtained Regional Council approval to fund the project. (1992, #220)
System externalities that have local effects	• Railside Revival environmental improvement initiative for the Stansted airport-London corridor (1992, #48). Launched by NSE, the Hertfordshire Groundwork Trust and Hertfordshire county council. • South Fife to Edinburgh Strategic Rail Study (1992, #103) considers ways of encouraging a switch to rail, to relieve congestion on the Forth road bridge. Commissioned by Fife and Lothian regional councils, ScotRail, the Scottish Office and Fife Enterprise.

The examples above show a range of interests. These developments are not only about new light rail systems; they include improvements to services to attract passengers, repairs to keep parts of the network in operation, and connections with other transport facilities. Local organisations' projects are not only involved in extending the network through *scale* and *scope* changes but also incorporate service improvement projects that can involve new signalling or electrification.

The roles taken by the local organisations and BR vary between projects. From the evidence available it is difficult to definitively divide these projects into local or BR initiated developments. It seems that their characteristics in common also appear to outweigh a consideration of which organisations initiated each project.

Table 5-8 Different roles can be taken by the local organisations and BR.

Local actions	• Centro (WMPTA) has identified new station sites on the Wolverhampton line including St Vincent Street'. Centro has allocated resources for detailed design work. (1992, #215) • Manchester IECC proposed to replace aging signalling installations. PTE working on a formula to share costs with other track users in the area, aim to report back to PTA in Sept. BR advised GMPTA of proposed staging for the project (9 stages). (1992, #232) • WYPTA has paid for additional electrification (to North Leeds electrification options) including electrifying platform 10 at Leeds station. (1990, #103)
BR actions	• Central Scotland electrification study (1992, #28). ScotRail reached agreement with the three regional councils served by the route to fund the study jointly. • Work by several organisations considering reducing car journeys into Cardiff (1992, #38). BR is investigating gradual electrification of the Valley Lines, with Light Rail Transit on shorter routes sharing tracks with heavy-rail services to the heads of the Valleys. • Proposed resignalling around Leeds station, to replace aging equipment with SSI, would be jointly funded by InterCity, Regional Railways and West Yorkshire PTE. (1992, #123) • Birmingham Cross-City line electrification: This is amongst Provincial's (BR) non-rolling stock investments. WMPTE will pay £13m towards the cost of the fixed electrification work and BR will pay the rest (1990, #20)
Collective work	• Improvements to the Barnstaple line 'have been announced in a joint initiative between British Rail, local authorities, and the Countryside Commission.' (1990, #29) • Sleaford-Spalding line: …once a candidate for closure but now secure. It is the subject of a joint development strategy between the county council and Regional Railways. (1992, #278) • BR working with Nottinghamshire and Derbyshire County Councils and other elected bodies on resurrecting the Robin Hood route (1992, #276)

Sometimes local organisations are involved to subsidise centrally developed ideas but, as illustrated in Table 5-8 above, they also take a role in directing changes and in selecting projects. They commission studies and set up projects: they appear to have a system-building role. It might be characterised as a socially motivated system-building role. Further examples from the 1990 and 1992 data samples that illustrate a range of actions, in studies or more concrete development proposals and projects, are given in Table 5-9 below.

Table 5-9 Local organisations as system-builders

Studies	• Rail Strategy for 21st Century by South Yorkshire PTE. Key Objectives set are: reducing road congestion, with associated environmental benefits; assisting economic regeneration of depressed areas; improving access to town and city centres; improving regional links. Plan includes objectives, proposes studies. Infrastructure work to be concentrated on 'choke points' (IDs problems to be addressed e.g. track capacity locations). (1992, #186) • Northamptonshire County Council published a 10 year railplan (1990, #229) • GMPTA has awarded Transmark a contract to examine engineering and operational options for rail lines in east Manchester (1990, #111) • Study on Trans-Pennine transport: 'All the local authorities (West Yorkshire, South Yorkshire, Greater Manchester and Merseyside PTAs, North Yorkshire, Derbyshire, Humberside and Cheshire County Councils) involved with Trans-Pennine have met and have agreed that Transportation Planning Associates, appointed by the Department of Transport to consider Trans-Pennine roads... should also consider rail investment alternatives (including electrification) across the Pennines…' (1990, #110)
Developments	• SYPTE strategy document highlights worn out signalling between Meadowhall, Barnsley and Penistone. 'Several schemes have been drawn up, including one to control Penistone-Meadowhall from a small power-signal installation at Barnsley' (1992, #195) • Package of road and rail spending proposals, developed from integrated transport studies, submitted to the DoT by WMPTA & local highways authority (1992, #74) • Re-opening (Stirling to) Grangemouth branch line to passenger traffic: "..the branch has heavy freight traffic, and planned resignalling offers the opportunity to restore a passenger service in 1995,…". The regional council has reached agreement in principle with Forth Valley Enterprise and Falkirk district council to share the costs. (1992, #34) • Central Regional Council published a consultative document of transport proposals, includes medium-term proposals and longer-term ideas requiring safeguarding measures. Programme would be funded partly by cancellation of road projects. (1992, #158) • Study, for Derbyshire, Leicestershire, Northamptonshire, Nottinghamshire and Sheffield councils, on Midland main line electrification concludes that cost-benefit analysis makes a 'clear case' for the project. 'The consortium of councils is now seeking the views of British Rail (which co-operated with the study), and representatives of rail users and industry, before meeting regional MPs and approaching the Transport Secretary in July.' (1990, #113)

BR's approach, considering a national system, also includes a more economically centred and efficiency-driven approach to system development. It makes sense that socially driven system developments would be linked to organisations connected to society's political and electoral selection mechanisms. In the tables above there are illustrations of two system-building approaches, that of local

transport and social systems and that of the national railway system, being co-ordinated through the joint development work featured under the BR/Local code and representing the overlap between the two types of system.

There is evidence even within the 1992 sample that this local approach to system-building will be disrupted by privatisation.

- *The project to re-open the Northern Suburban route (Glasgow Queen Street to Milngavie via Maryhill) (1992, #86) was put on hold by Strathclyde Regional Council's decision to freeze capital investment worth £52m in Glasgow local rail network. It was unfrozen 'following reassurances from Transport Minister' that the Council 'would have a role in selecting any franchisee'.*
- *The North of England Rail report from North of England Assembly of local authorities (1992, #181) warns on possible consequences from privatisation and from the uncertainty, 'there's already a detectable reluctance to put cash into local lines'.*

This, and other effects on system development following privatisation, are discussed further in Chapter 6.

At a national level there are some examples of central government taking a similar role to that taken by the local organisations for flagship projects such as High-Speed Rail developments. See, for example, the CTRL (also known as HS1) within these data and in current developments High-Speed 2 (HS2) is a project with significant central involvement that is being co-ordinated with developments within the existing system but developed by separate organisations.

The centralised development of a national infrastructure system

In addition to the co-ordinating role for local systems described above, BR does take a system-building role for the performance of the national rail system. As is often the case for national infrastructure systems the central operating and developing organisation does not have full scope to determine its own role and that of the system it oversees. These data highlight that British Rail received both its budget and performance targets from central government. This institutional arrangement allows government to frame the reverse salient correction activity of BR through the crystallisation of certain measures that reflect parts of the system goal. It is to be expected that such targets will affect reverse salient priorities and correction approaches. However, it is BR that holds the technological knowledge on this system; it has engineering departments and a research and development organisation, BR Research, that feature in the 1990 and 1992 data samples. Even if all performance requirements and major project ideas came from external government organisations, BR would be co-ordinating the underlying knowledge and design issues: it would determine the detailed form taken by the system.

5.3.7 System Goal

Each reverse salient correction responds to part of the system goal and so the goal is represented in these data through references to areas for improvement, for example projects addressing reliability problems or reducing journey times. These references highlight the view of the system goal that is held by the system developers and the points upon which they are acting.

There are also some development activities captured that are more explicitly linked to a central vision of performance. For example, in the 1990 sample, BR's 5 year Corporate Plan[86] (#49, 1990) is identified. This includes targets and budgets for the system and its subsectors, and references to it are found in other development activities (e.g. Network South East's developments to meet demand (#51, 1990)).

In the 1990 and 1992 samples a small number of activities expressing or forming a development goal principally refer to central government or BR Board actions such as the five-year Corporate Plan and the Secretary of State setting new targets for BR (#248, 1992). Further, projects responding directly to these codified versions of the system's goal were the preserve of BR. However, a safety-reporting function and projects to adjust performance in safety measures are also referred to and here it is HMRI/HSE monitoring BR's performance and responses (e.g. #272, 1992).

In the 1998 sample, references seem to be to measures rather than to targets: the regulator reviews access charges (#77, 1998), Railtrack sets KPIs for infrastructure contractors (#88, 1998), and train delay figures (#255, 1998) (allocated to causing organisations) are used as a performance metric to be improved upon[87]. These are still focusing development activity but their status appears to have changed. This sample also contains developments by the Government to create a Strategic Rail Authoriy '*to promote rail use, plan the strategic development of the network, and promote integration between transport modes*'[88].

All three samples refer to central visions, or targets or KPIs being generated for the industry or parts of it. These are representations, or attempted representations, of the system's goal. These data do not distinguish between the pre-existing central vision as codified in performance measures or strategic plans and the notion that the system's goal is created by the articulated measures or strategy. That these codifications of a system goal are found in established infrastructure systems is not surprising and seems to fit with the political and social importance of these systems. The need, ability and acts of goal articulation are going to change with system maturity and momentum; these points of activity can be characterised as points of communication between a complex, socially important system and actors in its environment with interests in its development. Further, it is likely that the extent to which a goal is

[86]This includes the Government's requirements for the BR Board.
[87]These measures can also be seen emerging within the *Privatisation* developments in the 1992 sample.
[88]Modern Railways, August, 1999, p542.

generated, or added to, rather than being merely articulated through such means, varies between infrastructure systems and over time.

5.4 Conclusions

The findings above consider some of the development activities revealed in this study of an established infrastructure system. These observations include concepts linked to LTS development in action in mature system change. The importance of reverse salient generation, throughput types of system change, the role of studies in reverse salient selection, and different formats for the system goal are all discussed. These alterations to the form of system development seen in established systems can be captured in two themes: shared system-building and the significance and role of the installed system.

5.4.1 Shared system-building

Even under the nationalised British Rail the UK railway system had more than one focus for system development and more than one system-builder. Local government organisations seek to develop the system in places as part of local transport systems but British Rail takes responsibility for the technological development and the national standardisation and control.

Through all three phases the core railway industry does not have full determination of its goal(s); whether important performance parameters and targets result primarily from system momentum or external demands, government takes a role in articulating them. Hughes (1983; 1987) expects that an agreement on a system's goal is less important in maturity because its development acquires momentum that fulfils that role. These data show both the application of a goal (through the motivations and benefits expressed for changes made to the system) and articulations of a system goal through performance measures and central strategies for change. It is conceivable that, precisely because of an established system's momentum, the ability to adjust a system's goal from outside is limited but that, in its articulation into a central document or its codification into performance parameters, some margin for alteration or extension is provided or generated.

The system's goal is open to articulation and influence from outside actors. This could be from its passengers as well as from government. Government has always had an influence on the place infrastructure systems took in society; see, for example, London's electricity systems aligning with local government structures (Hughes, 1983, p229). However, a significant role in articulating relevant performance measures that will then translate into an important piece of a system's development goal is reserved for mature systems[89].

The division of the system-builder role, between goal-setting functions, local transport integration and development, and national system development (technological and operational), leaves needs for

[89]Nascent systems are too fluid for that to be a practical role taken by government organisations.

communication and negotiation. Studies appear to take an important role here: through strategy studies, they are a means for translation between goal and development; through reverse salient or project-focused studies they can connect the blueprint and installed systems. An extension of their role in communication and consensus-building into the privatised system might even be behind an increase in industry-initiated studies post privatisation: this is an opening for further investigation.

Although the same components identified in LTS theory are found in this study, it seems that the system building role can be, and might even be expected to be, distributed in established infrastructure systems[90]. System momentum, through a system's accepted basic form and function, will be part of what makes this possible. The distribution of system-building raises questions of whether this is inherent in mature systems[91], what patterns exist in the way this role can be segmented and how different forms influence system development. More studies that consider different system forms and studies that compare development in several infrastructure systems would be needed to explore this issue further.

5.4.2 Importance of the installed system.

The separate *installed* and *blueprint* lines of system performance – with their different reverse salients, introduced in chapter 3 to aid understanding mature system development – are visible in these data through the different types of development activity applied to them. These are coded as *specific* and *general*. Looking more closely at these development activities it is also clear that the relationship between these two performance lines is more complicated than a simple diffusion lag from blueprint to installed system. System development decisions and knowledge building is not all focused within the blueprint system; the installed system is more than an embodiment of the blueprint and changes to it are not simply a lagged rebuilding of it to match its form to that of the blueprint.

In established infrastructure systems it seems that, most often, it is within the installed system or through assessing its performance that reverse salients are sought. Systems are not judged on their theoretical, or even 'as-new' performance; it is the installed system that represents all the design and development knowledge held in the system, even if that knowledge would combine better if the system were built today. This proposed adjustment to LTS theory of system development to extend its application to the development in established infrastructure systems adds an additional performance line to the conceptualisation of system development used by Hughes (1983 1987; 1992); this line represents the performance of the 'installed system'. This is illustrated in Figure 3-4 in chapter 3.

Hughes's (1983) focus was on the creation and establishment of infrastructure systems and the principal study used to generate his theory of LTS development covered only 50 years, and a time of rapid geographic expansion and functional extension. This was not a time for re-building, updating or even

[90]This is supported by other empirical work (e.g. Caerteling et al. (2008))

[91]Once a system is established it is often treated as some form of a regulated monopoly; that is likely to be accompanied by a separation of goal articulation and system development activities.

significant impacts of wear and tear. Any distinction between a system's installed and blueprint forms that might affect development was, therefore, assumed away. In the study of established systems, that needs updating to respond to needs and developments in both their technology and their use, the assumption that the difference between these versions of the system is negligible can no longer hold.

Once the relevance of a distinction between blueprint and installed system is accepted, the importance of the installed system for system development can be considered. The analysis described in this chapter finds that the installed system is of great importance to system change. The installed system is assessed to determine system performance, its failure can generate local or general development work. Development focused upon the installed system and its interaction with blueprint development are shown.

Clear illustrations of the interaction between installed and blueprint system forms are found where care is taken to establish the readiness of both system forms in order for a system change to occur. An appropriate site and need are required of the installed system to accompany knowledge and blueprint adjustment. Examples include technology development waiting upon the identification of appropriate trial sites, development diffusion being contingent upon opportunities for installed system renewal and the existence of development needs within the installed system which are not identified through analysis of the blueprint system. These two forms of an established infrastructure system advance differently but not independently: their coordination appears to be part of system change.

This study finds that distributed system building and two relevant system forms, installed and blueprint, are features of the development of a mature infrastructure system. These appear to be important characteristics of mature systems that affect their development. A mechanism is also identified in this research which assists development in navigating both types of divide. Studies, for system development, perform a communication and translation tool across the system-building function. They also often assist in navigating the different components in the mature system development model proposed here. Studies, initiated from either side, can form a matching function between blueprint and installed system forms. Various sorts of strategic plans also connect installed and/or blueprint forms of the system with a version of the system goal. This finding of the importance of studies in mature system development, along with the development focus explanation expressed above, connects back into a further aspect of Hughes's (1983; 1987) work. Hughes discussed the types of system-builder that would be prevalent at different stages in a system's life; these include the observation that financiers and consultants would be important actors for development in maturity (Hughes, 1979; 1983). Consultant organisations appear to take an important role in development activity in this system, particularly after privatisation. They become an important vehicle for technological knowledge of the system; studies, often commissioned

by actors affiliated with the installed system, are an important channel of action for these consultancy organisations.[92]

5.5 Summary and contribution

The study of the development of a mature system described in this chapter applies the method developed in chapter 4 to the UK railway system across its privatisation in the 1990s. Different types of system change, *general* and *specific*, are found that correspond to development activity focused on system form: installed and blueprint. The blueprint system form refers to the best version of the system (how it would be installed were it to be rebuilt today); the system blueprint is what Hughes's (1983; 1987; 1992) performance line refers to. In established infrastructure systems there can be a significant and important gap between the installed system and a system blueprint; this prompts the inclusion of two system performance lines in a model for LTS development when it is applied to established systems. Further, it is found here that the installed system can be an important focus for some system development activity and that interactions between these two performance lines have a role in development within established systems.

This study of established system development also observes a distribution of Hughes's (1983) system building function; the system-building activities are spread between different actors both before and after the privatisation of the UK railway system. Combined with the identification of the importance of installed system performance for established system development described above, this observation also suggests an explanation for the role of studies observed in this research. Studies provide a communication and persuasion vehicle that navigates the different elements of the established system development model referred to here: installed and blueprint system forms and the system goal.

The application of these extensions to the LTS theory of system change, for its consideration of mature system development, provides some insights that can assist an examination of the privatisation event (see chapter 6). A divide in system-building activity that includes actions to influence a system's goal coming from an actor that is not a system knowledge holder or designer, as identified here, is significant for the study of potential for development trajectory redirection implied in the system restructuring that accompanied its privatisation. The reconceptualization of development in established systems as the interplay of two system performance lines highlights the possibility for reverse salients to be generated in the installed system, for instance through wear and tear; extended to consider privatisation it is possible that restructuring could, itself, introduce performance reverse salients not present before.

The next chapter considers changes to the way this system developed. It uses these samples as a starting point to consider points of influence for momentum adjustment. The findings described in chapter 6

[92]Evidence on the role of these organisations and its development since privatisation also appears in interviews (e.g. interviews B & L in appendix A)

emphasise the likelihood that the privatisation process affected the system's performance, its means of development and its goal, that defines reverse salients.

6 PRIVATISATION: AN OPENING FOR TRANSFORMATION?

Following on from the focus on system change in established LTS in chapter 5, the analysis in this chapter looks for evidence of change, across privatisation, in the sociotechnical regime that is directing system development. The data samples discussed in chapter 4 are used as snapshots of the sociotechnical regime in action and additional interview data is used to provide a complementary perspective on changes at privatisation and information on developments since.

The privatisations of infrastructure systems experienced, relatively recently, in Western Europe can be characterised as potential openings for system transformation. In the UK railway and electricity systems the incumbent organisations, and consequently the way the infrastructure system were both operated and developed, were broken apart in the restructuring that accompanied privatisation in each sector. The systems' development processes or their sociotechnical regimes do not appear to have been reinstated or redesigned but left to reform to fit with the new organisational and governance structures[93]. This provides an opening for system transformation. If transformation is to occur the system's sociotechnical regime and the developments it produces will undergo a change in character. The analysis described below looks for evidence of this change using the datasets generated from the archive-based method described in chapter 4 and interviews conducted with system actors[94].

The LTS theory of system change adapted in chapter 3 for better application to established LTS is used to structure this analysis. Evidence of changes are found in the *blueprint* focused development activity and in the *installed* system development. Changes are noted in the system goal and evidence of reverse salients being introduced is also identified. Both the system and its sociotechnical regime were changed with privatisation.

6.1 Structure of the analysis

Firstly, the 1992 sample captures the early stages of restructuring planning; this allows the development of two systems in parallel to be observed. This provides insight into where this unusual transformation initiation process should fit into MLP and LTS studies.

Next, the three snapshots of the system pre-privatisation initiation, immediately after the announcement of privatisation and post-privatisation (but before further major changes implemented from the system's landscape) are used to provide a basis for sociotechnical regime comparison. The LTS framework used in data generation provides a focus for the comparison. After building upon the observations on local system-builders and goal articulation by government in the previous chapter, the sociotechnical regime

[93]As discussed in chapters 2 and 3.
[94]The interviews were conducted between 2007 and 2009; more details are given in appendix A.

is studied for blueprint focused and for installed system focused developments. Alterations are found in the developments applied to each performance line.

Finally, the 1998 sample is used to provide insight into two important changes introduced with privatisation and development activity around them. The first is a change to the operational system that provides a challenge for both its performance and its development: the relationship between infrastructure owner and infrastructure maintainer (an organisational interface created at privatisation). The second change does not affect the operational system at first but it does represent a new challenge for a sociotechnical regime to continue to build the system: the knowledge gap on the form of the installed system and its effect upon product introduction.

The three samples of development activity are used to identify key points of change in the way the system changes. And a set of interviews[95], conducted with engineers and technology managers from across the system, combined with the use others' published accounts of the industry provide reflection on system changes and some of the links between developments. These combined data allow the identification and exploration of several points of interest for both sociotechnical regime and system change and they give insight into how these privatisation stories fit into LTS and MLP accounts of system development.

6.2 Initiating transformation: the early stages of privatisation

The 1992 data sample captures system development activity[96] in the year after privatisation was initiated by the outcome of the 1992 general election. The decision to privatise was reached without structural and governance decisions having been made and so following the formation of the new government a design process started. The coverage of these changes starts in Modern Railways with a special section on privatisation in the September 1992 issue[97]; at this stage there are still questions over the privatisation options, the role of Railtrack is being described and there are details of the regulator's role and that of the franchising authority that are to be developed in parallel with the Privatisation Bill rather than being specified within it. Consultants are not due to report back (to BR and the Department of Transport) on the privatisation of rail freight until mid-January 1993 (#79, 1992).

At this stage the proposals for the new industry structure are still rather freeform and this is reflected in the type of reverse salients identified. These reverse salients are not projects with clear boundaries or clearly defined performance issues; they are identifiable through the focus of discussion and activity,

[95]Described in appendix A.

[96]These data focus on the infrastructure elements of the system and the decision was made to incorporate system wide changes (even where infrastructure effects are not specifically referred to) for privatisation changes. Changes only affecting non-infrastructure elements of the system are not included here but the character of the privatisation process is shown. (Within the whole system data information points are included that refer only to non-infrastructure developments).

[97]This is released on the first of the month so these articles will have gone to press during early to mid-August.

they are the pressing issues for actors. The actors here are policy officers in the Department of Transport (DoT) and existing regulating organisations and their consultants; actors from the pre-existing system are also involved but rather within activities than initiating them.

These data also show the emergence of the first areas for development within industry restructuring; what starts as an overarching issue of privatisation begins to be broken down into several reverse salient issues/key areas of activity: access charging, safety arrangements, the role of the regulator etc. This is not dissimilar to the way some reverse salients are described in Hughes's (1983) study of the creation of the electric lighting system and fits with his ideas of the forms of development work done by inventor entrepreneurs. However, here, the system-builders are civil servants, with the assistance of consultants and some (old) industry actors. And the goal the system-builders are aiming for is also different in character; development is guided by an outline of an approach to privatisation from a party manifesto and certain performance elements, taken on from the existing industry, such as safety requirements. There may also have been additional informal but understood aims in play; for instance it is sometimes implied that lower costs/achieving gains for the taxpayer is an important factor in decision making (e.g. Glaister, 2004).

Once the policy level changes have been set up there then follows consideration of how a new industry is to be created from the old one. The 1992 data include the formation of Railtrack (#243, 1992) and BR's resulting restructuring (#260, 1992). Railtrack is created in a shadow form, senior management is announced and then the company's form, staff and procedures are filled out from there. It is due to be launched to start making decisions about the system from April 1994; to begin with the new organisation will procure services from various remaining parts of BR (#243, 1992).

This shadow arrangement, that is seen again for the creation of the Strategic Rail Authority in the 1998 sample, could be considered as a special kind of niche, a concept used, for transition emergence, within the MLP framework (see for example Kemp et al., 1998; Geels, 2002). In the case of shadow organisations the niche is made purposefully to provide a trial environment/dry run for a new system structure. This is to say that it is known at the outset that this model is intended to replace the existing form and to do so entirely: long term parallel running or a battle of the systems is not on the cards. Another distinction from the traditional conception of a niche for transition/transformation is that the existing system is adjusted to *make space for* and *interact with* this protected development arena.

The 1992 sample shows the early development of the privatisation process, considered above, alongside the majority of the data that show system development running along similar lines to the contents of the 1990 sample. There are some of the same projects being done and new projects are being created by the actors operating in the existing system.

6.3 Characterising the pre and post privatisation sociotechnical regimes

6.3.1 Reverse salient correction as a basis for comparison

Tracing development activity using the reverse salient correction model shows what Geels (2002) calls the *sociotechnical regime* in action. The reverse salient correction model can be seen as an underlying mechanism of change within each sociotechnical regime and comparing its application across settings can highlight differences between sociotechnical regimes, or at least the development activity produced by them.

This work compares development activity across the three samples. The 1990 and, with the exception of the developments coded *privatisation*, 1992 samples give two snapshots of pre-privatisation development and the 1998 sample works within a post-privatisation period before further structural changes are applied to the system. The restructuring of both operational and development organisations in the industry privatisation, introduced in chapter 2, lead to the expectation that both the way the system operates and mechanisms for system change will have been changed within privatisation. The reverse salient data shows these sociotechnical regimes in action.

Using Hughes's LTS framework directs the analyst's attention to points where there is scope for changes in the process of system change. As highlighted in the introduction of LTS theory in chapter 1, the identification of reverse salients is not open for construction, they are obvious to system developers. However, what the privatisation developments described above emphasise[98] is that system developer's view of the system's goal might change and that, with the distribution of system building activity as organisational interfaces are introduced, it may even not appear to contain the same priorities to all system developers.

Other differences in the application of the reverse salient correction model that would highlight sociotechnical regime changes are changes in the actors applying it and in the way critical problems are defined in response to reverse salients. Changes in the system developers involved in reverse salient correction are to be expected with the reorganisation but it is difficult to know *a priori* which actors will take a lead and how different their motivations and behaviour will be to the integrated organisation that existed pre-privatisation; this is particularly relevant where many individuals remained in the system following its restructuring.

To aid comparison of these aspects of the application of the reverse salient correction model across the privatisation of this system the three data samples are broken down. First the system changes that have been focused on the blueprint form of the system are considered. This is done by selecting the data coded under *general, general/specific* or *study/general* for type of action. This generates three datasets

[98]As discussed in chapter 3, Hughes (1983) did not explicitly discuss this but presents a framework that accommodates it.

described in Table E- 1 in appendix E and that are analysed in the next section. A focus on the blueprint system form is a natural extension of the way system change is treated under both LTS and MLP frameworks, it is, after all, a representation of the knowledge and design frontier for the system. However, the study described in chapter 5 highlighted the importance of the installed form of the system for system change in established systems. Changes in installed system development are explored by looking at the role taken by the TOCs; these are a new entity created from BR as part of the restructuring and they are infrastructure users that are no longer connected to its provider. Changes are found in the character of system development, for developments that come from blueprint system-focused activity and installed system focused change.

The changes in the system development activity and the ways it is structured and initiated that are identified within the reverse salient data samples can then be further investigated using accounts of system development changes with privatisation. These are provided by a set of interviews conducted with system developers following privatisation[99]. These interviews were conducted to explore the innovation paths in place several years after privatisation, they include discussion of the changes to innovation processes that were brought about by privatisation. Here, these data are not used to identify changes in the sociotechnical regime but to confirm/contradict and provide additional background to observations from the reverse salient data; they also offer some insight into further changes to come within the sociotechnical regime and provide some information on developments between samples.

First, though, the presence of local system building activity and of a government role in goal articulation, that were observed in the previous chapter, are explored further. Their presence in the post-privatisation development activity, or sociotechnical regime, is examined; both have changed across privatisation.

6.3.2 Background: Pre-privatisation activity

Local system building

Pre privatisation BR was the vertically integrated, nationalised system owner-operator. All changes to the national network were administered, or at least approved, by BR. However, BR was not the sole actor involved in system building. As discussed in chapter 5, in addition to the goal articulation role of government, there were local transportation system-builders (the PTA/Es and local authorities) that requested, sometimes purchased and/or co-ordinated local system needs and developments with the national system through BR. The goal for these local system-builders will have been local transport systems approved of by their electors and rail and metro systems were an element within this.

[99]Details of these interviews are given in appendix A.

There are already indications that this local transport system development, well its role in railway system development, will be altered by privatisation in the 1992 sample, as highlighted in the following evidence from chapter 5 (see section 5.3.6).

- *The project to re-open the Northern Suburban route (Glasgow Queen Street to Milngavie via Maryhill) (1992, #86) was put on hold by Strathclyde Regional Council's decision to freeze capital investment worth £52m in Glasgow local rail network. It was unfrozen 'following reassurances from Transport Minister' that the Council 'would have a role in selecting any franchisee'.*
- *The North of England Rail report from North of England Assembly of local authorities (1992, #181) warns on possible consequences from privatisation and from the uncertainty, 'there's already a detectable reluctance to put cash into local lines'.*

This is followed by a lower level of *Local* and *Industry/Local* change initiation activity represented in the 1998 sample (1998:~12%, down from 1990: ~35% and 1992:~27%; see appendix D). Taking a closer look at the Local, Industry/Local, Local/Private and Central/Local codes in the 1998 sample reinforces this finding. These data are broken down in appendix F; although there are still some projects that could fit within the local system building activities discussed in chapter 5 there is little evidence of local system building as the development presence it was before privatisation[100]. Local government organisations still appear in the data, particularly as part of projects involving input from many organisations but there is little evidence of the directing role in local system development; TOCs could have taken some of this role, (see for example the contents of 1992, #86, described above, & 1998, #45 & #83, in appendix F) but their interests are different from those of local government organisations: a local transport system across modes is not their focus and a TOC's attention is directed to users and potential users only, not other affected parties. So this is a change in the sociotechnical regime that can be expected to have an effect on the form of the system produced.

Goal communication from government

Also referred to in chapter 5 is a goal communication role that is taken by government pre-privatisation. As discussed in section 5.3.7., in all samples there is evidence of the system goal being shaped, or at least articulated, by the Government rather than the system developers; it is suggested in chapter 5 that this is a characteristic that can distinguish the development of established systems from the early stages of infrastructure system development, where system goal definition and articulation comes from the Inventor-Entrepreneur (see Hughes, 1983). However, looking between samples there is also evidence of differences in the goal articulation activities being undertaken before and after privatisation.

[100]This finding is even stronger if the roles of the Scottish & Welsh Office are highlighted; see appendix F.

Before privatisation BR had responsibility for the installed system, it was working to a government set budget and to targets that government, and the BR board, had a hand in setting. BR held much of the technological knowledge for the national systems and development activities were triggered both from responding to need and opportunities in the installed system and from technological needs and opportunities identified from the blueprint system and technological developments outside the system. Following privatisation the rail regulator was responsible for overseeing the infrastructure owner, in particular in ensuring Railtrack *'did not abuse its monopoly position*' (Gourvish, 2008, p3); however, Glaister (2004) observes that in privatisation the Government stepped back from a directing role in the railway. The 1998 sample shows evidence of performance measures (e.g. the generation of train delay figures (1998, #255)) and of their relevance to system development. The case of delay/punctuality is explored in appendix G; it shows punctuality performance affecting system development in several ways.

A further development within the 1998 sample is the decision of the new Labour Government (elected in 1997) to introduce the Strategic Rail Authority (SRA) (1998, #15; Gourvish, 2008). The Integrated Transportation Bill is to introduce the SRA (1998, #14; 1998, #197) also makes changes to the roles of the Regulator and the Franchising Director; the SRA is to take over some or all of their responsibilities (respectively) (1998, #15) and the Regulator was made subject to the guidance of the Secretary of State for Transport (1998, #197). The creation of the SRA is linked to Government concerns over the industry's leadership and focus and its concern over the lack of control it has over government funds going into the railway system (1998, #15: reverse salient field).

These findings indicate that the structure and institutions introduced at privatisation reduced government's input into the system's development, including its role in shaping the system's goal. The guiding role of government in system development was then reintroduced using further legislation and the creation of the SRA.

The interviews, described in appendix A, conducted with industry actors several years later refer to these changes and they extend the story further. The government's decision to set up the SRA is linked to concerns about the industry's direction of development. In addition, these interviews were conducted within a period of further developments for the role taken by government in this industry. The SRA was no more, its functions had been absorbed into the Railway section of the Department for Transport (DfT Rail) which had recently developed the Railway Technical Strategy (RTS) and the Railway Industry Research Strategy (RIRS)[101]. In the interview records there are many references to the RTS, to a lack of central vision for the system up until now and some linking this to technology development problems. There is also evidence of a range of system influence routes being opened up by the DfT Rail

[101]Both were published in 2007

organisation; these include the RTS, development requirements being put into franchises, a new vehicle procurement project (direct from the DfT) and research commissioning.

6.3.3 Changes to interactions with the blueprint form of the system

Analysis of data coded as *general*, *general/specific* and *study/general* across the three samples allows a comparison of activities focused on the blueprint form of the system at the different time points. A description of these data is shown in appendix E. Here the 1990 and 1992 samples appear to show a similar pattern of use for the codes; the sociotechnical regime is expected to be little changed between these samples and so this is as expected.[102] The 1998 sample shows a higher proportion of these activities in the full sample and the *Industry* to *Non-Industry* ratio is further increased; in addition the percentage of blueprint entries involving *regulation* related or *response* elements is much lower than in either of the pre-privatisation samples.

Looking more closely at the contents of these samples further differences are clear. The 1990 sample contains changes that address safety concerns (e.g. ATP Pilot projects (1990, #16 & #17) and Train-to-signalbox radio (1990, #82), recommended in the Hidden Report); developments that improve the economic performance of the installed system in some way (e.g. simplified management structure (1990, #64) and development of a dry-slide base plate (1990, #166)); work that responds to contingencies or externalities (e.g. Changes following the privatisation of the electricity industry (1990, #54) and work on noise insulation standards (1990, #141); as well as strategy-type studies. There are no entries that deal with maintenance processes. A similar picture is present in the 1992 sample, though with some operational work (a study on piggyback freight (1992, #138) and new procedures for opening up the network to operators of international services (1992, #182)) and two maintenance projects: Reorganisation of infrastructure rolling stock (1992, #17) and the purchase of an automatic distribution machine for ballast (1992, #247).

In the 1998 sample, post-privatisation, the presence of many more infrastructure maintenance developments is noticeable. Several of these can be grouped together as linked to high-output maintenance equipment (like the ballast distribution machine referred to above (1992, #247). A high output strategy from Railtrack is one entry, and there are seven examples of high-output machine purchases[103], coded as *General/Specific*, and one *General* machine development project.[104] However, in addition to the high-output equipment changes, there are several other maintenance process and co-

[102]Looking more closely at the data in the samples one qualitative difference is noted; the 1992 sample shows more (7) strategy-type studies (e.g. South Tayside Rail Study) than the 1990 and 1998 samples (3 each). Most of these studies are regional and linked to local transportation plans; the higher number in 1992 is likely to be a result of the recently completed general election.

[103]These are not one machine each but refer to what is being treated as the project level, so different organisations making similar purchases are entered separately.

[104]Once the sample is complete and these are seen altogether they can be reinterpreted as work around one or several closely linked reverse salients; an altered description table taking this approach has been added to appendix E.

ordination changes; these are shown in Table E-2 and Table E-3 in appendix E. Table E-2 shows changes to maintenance processes or co-ordination; these include several developments towards automating track assessment (#94, #146 & #179) that might be considered a parallel development to the high-output equipment for renewal and maintenance. In addition, Table E-3 includes asset changes targeted at reducing maintenance work. Combined, these tables include 21 developments focusing on maintenance of the infrastructure[105]. Further, there are a few developments focused on reliability (e.g. punctuality problems: minutes attributable to Railtrack (#119) & Insulation mat to break circuits caused by birds hitting electrification equipment (#302)).

The 1998 sample still contains safety, economic and contingency/externality focused work (e.g. #302 referred to above). The additional development work around maintenance efficiency described above is also accompanied by a number of projects on signalling systems and their renewal[106]; looking across the three samples signalling projects feature as follows: 1 (1990), 6 (1992) and 8 (1998).

These data show changes in the blueprint focused development activity in the system across privatisation. The increased interest in/work around signalling appears to pre-date privatisation and, although privatisation may have changed the approach to it, this is a reverse salient with opportunities regardless of the privatisation process. However the changes to maintenance processes and how these activities are organised does not appear to be independent of privatisation. The high-output equipment (earlier versions at least), so important in the 1998 developments, existed well before privatisation[107].

So what might be behind these changes in system development activity? Privatisation could have led to a change in reporting on these types of developments; previously such changes would have been found within British Rail, there would not necessarily have been an interest in publicising advances in this area. The structural changes in the system could have led to new requirements in maintenance performance. Or they could have provided new opportunities for advancements (e.g. making it easier to bring certain knowledge sources together).

Although a change in reporting is worth taking into account when concerned with the tone and number of reports, looking at other sources it appears that there is more than a reporting change being shown here. Interviews (see appendix A) show the importance of reliability in technology development for vehicles, operations and infrastructure and they highlight the creation of a delay penalties system at privatisation; the Rail Regulator has responsibility for allocating blame for delay minutes and companies need to financially compensate each other accordingly. This process is a logical element of

[105]22 (including the high-output equipment reverse salient) is 40% of the 54 (adjusted for the more conservative approach on the high-output equipment).
[106]This excludes the switches and crossings developments referred to above, and focusses on central control element.
[107]Tampers were introduced onto the network before 1960 (Dow, 2014); a range of maintenance equipment is referred to by Gourvish (2002, p213) as having been purchased in the 1980s.

a multi-operator system and these data show that it has had an effect upon the system's sociotechnical regime that has redirected development activity and its output.

> *'These high penalties give a business case for innovation to reduce the occurrence of delays.'* Interview record F, appendix A.

Further changes to the sociotechnical regime are highlighted by looking at the organisations that are involved in initiating development activities (see in Table E-1, appendix E). The 1998 sample exhibits a different pattern for development initiation from the pre-privatisation samples: a much higher industry to non-industry ratio is seen and within that the presence of suppliers in the blueprint development activities is much higher[108]; plus there appears to be a much lower place for responsive and/or regulation initiated changes.

There is evidence here that both the system performance goal felt by developers and the origins of development activity have changed as a result of the restructuring and privatisation of the system. The sociotechnical regime has changed and so has the character of some system development activities.

6.3.4 Changes to installed system development

Chapter 5 finds that in the mature infrastructure systems an important element in system change is development activity focused on the installed system and its interaction with blueprint development. The actors operating this system were changed at privatisation. This provides new development mechanisms.

Looking at the input of TOCs into infrastructure development in the 1998 sample the following types of change feature: new stations/lines; adjustments to enable service patterns; adjustments for vehicle access and performance focused infrastructure development. These developments are shown in table H-1, appendix H. Many of these types of project are also present in the 1990 and 1992 samples.

New stations and lines projects (and their closure) were initiated by BR as well as through *Local* projects; examples include InterCity's Heartlands project (1992, #274) and a Regional Railways and *Local* project to reinstate a passenger service within the Ribble Valley (1992, #222). Infrastructure adjustment for vehicles' requirements are also found; examples include Regional Railways' rebuilding of Shoreham by Sea station with clearances for new Class-158 trains (1992, #8) and Network South East's infrastructure section of the project to introduce new Networker (class-465) trains (1992, #25).

Infrastructure adjustments for service patterns also happened before privatisation. Examples from Regional Railways' developments in the 1992 sample include: 'Remodelling and resignalling at Grimsby and Huddersfield' (#125) and 'Project to speed up Cambrian main line' (#279). There is an

[108]There is also evidence for an increased role for suppliers in system change following privatisation in interviews.

opening for a change in emphasis for these projects in privatisation. The TOCs are focused on service patterns and performance alone; in the 1998 sample depot openings with TOC involvement are clearly linked to the service benefits they will bring (something not found in the pre-privatisation samples) and the examples given above also suggest a shift in presentation has happened away from asset focused to service driven language but it could also become a focus change for infrastructure development.

The possibility of a focus change for system development is clearer in the final category of TOC involved work: 'Development focused on performance'. The projects to improve reliability or punctuality on particular lines do not appear to be represented in the same form in the pre-privatisation samples. The only related examples of this type of project are Regional Railways' projects: '*Utterly Reliable Railway* concept for Penistone Line' (1992, #161) and Replacement of unreliable signalling equipment at Heaton Lodge Junction (1992, #126).

The introduction of the new (punctuality) performance incentive and new service-focused organisations at privatisation appear to have combined to produce this kind of performance focused development work between TOCs and Railtrack. It is not possible to tell from these data whether these projects respond only to the privatisation changes or that projects like these will continue to be set up to keep adjusting infrastructure for service performance improvement under the new industry structure.

A further observation is that the TOC involvement in *Industry/Local* projects in the 1998 sample has all but disappeared[109]; where these types of project remain in this sample the *Industry* input has come from Railtrack.

This examination of the role of TOCs in infrastructure development following privatisation shows some changes to the mechanisms generating infrastructure system changes. There are indications that service focused organisations driving infrastructure adjustments can change the character of projects. As discussed above, the *local* system building activity is lower following privatisation and does appear to have been affected, but the service-operator input is, almost completely, absent. These findings show that installed system, as well as blueprint system, focused developments have been affected by privatisation: this part of the sociotechnical regime also shows signs of change.

6.4 System response to abrupt changes introduced as part of privatisation

Examples already discussed above indicate that not only have goal and development activity been altered by the privatisation and restructuring of this system but the performance profile of the system might itself have been altered. An explanation for new depots being created, particularly where there is

[109]One unusual and cross-industry project (Proposed East-West Railway between Oxford & Cambridge (1998, #45)) features TOC involvement.

an emphasis on service benefits, could be that new divisions in vehicle paths introduced with the restructuring also bring increases in travelling for maintenance with accompanying operational impact. So a reverse salient is created in the installed system by the restructuring and a solution proposed is a new or relocated depot that allows better utilisation of vehicles and, perhaps, additional services.

Performance change suddenly introduced in this way is not focused on in either system development literatures considered by this research. The possibility of reverse salient introduction can provide insight into how these systems are treated. As discussed earlier in this dissertation, although reverse salient introduction becomes visible in privatisation-type system changes, the notion that reverse salients can emerge will feature in more system change scenarios, particularly for established systems, and efforts should be made to incorporate it into system change theories.

Another type of abrupt change is discussed in this section as well. This is a change introduced as part of privatisation that does not directly affect the operational system but the way it changes, the sociotechnical regime. This change can be less visible and, perhaps, its effect less immediate than the introduction of a reverse salient but, the case below highlights, that as much effort and learning can be required to address this performance issue as it is to correct a reverse salient.

Two introduced changes that are discussed below both went on to have serious effects upon system development. The infrastructure owner-maintainer relationship sits within the installed system; despite several developments intended to improve the performance of this reverse salient the sociotechnical regime did not succeed in correcting it and it has been linked to failure of the operational system. In contrast the problems around safety acceptance into the system and the gaps in the system owner's knowledge of the installed system did not immediately affect system performance but the ability to develop the system was affected but is also being addressed.

6.4.1 An abrupt change to the system: the infrastructure owner-maintainer relationship

The 1998 sample highlights an introduced reverse salient that, it turns out, was not so easily corrected: the infrastructure owner - infrastructure maintainer relationship. As discussed in chapter 2, privatisation involved Railtrack and a series of infrastructure maintenance companies being created from British Rail; Railtrack opted to be a firm low on engineering expertise and to function as '*an access, capacity management, and sales organisation…*' (Gourvish, 2002, p402) but it also had a central role to play in system safety. Developing contracts between Railtrack and the infrastructure maintenance and renewal functions that had been reorganised in to 14 British Rail Infrastructure Services (BRIS) units was difficult; a line needed to be taken that provided sufficient profit opportunities for the BRIS units to make them appealing for sale whilst also giving Railtrack gains from the potential of competitive sourcing (Gourvish, 2002, p404). At this stage '*over a hundred draft contracts worth about £1.2 billion*' (Gourvish, 2002, p404) were drawn up to supply maintenance and renewal for Railtrack's zones:

'*Difficult negotiations on pricing, benchmarking, performance, and other elements continued throughout 1994 and into 1995*.' (Gourvish, 2002, p404).

The 1998 sample shows further changes being made to the contract covering this relationship. The Infrastructure Maintenance Contracts (IMCs) start to come up for renewal and a new approach to the contracts (1998, #50) is put forward in attempt to ensure relationships that are not adversarial: 'The new approach will seek to make it in both parties' interest to achieve value for money with a sharing of rewards by both parties in the case of any expected cost-efficiencies that arise in the course of the project.' Janette Anderson, (Director, Railtrack Scotland)[110]. The first contracts to use this new approach are South and South West Scotland and First Engineering is selected as preferred bidder for both (1998, #49).

Railtrack conducts further activities around the maintenance relationship reverse salient. It seeks to adjust its supply chain ('Railtrack working to qualify a new maintenance firm' (1998, #87)). It also conducts a review of its supply chain position (1998, #89); outcomes include the possibility that Railtrack will move from an asset management specification role to that of maintenance manager.

The original new approach to infrastructure contracts develops into a formal change to be implemented as the contracts come up for renewal: Infrastructure Maintenance Contract 2 (IMC2) (1998, #209). These contracts were to alter the areas used for contracting maintenance on the network (forming 35 areas) and to represent a new more hands on approach to maintenance procurement from Railtrack; the first set were to begin April 1994 and all the IMC2 contracts were to expire together in 2004 and to make way for a further contracting set up (IMC3) based on total asset management (1998, #209)

However a further change in direction is seen. At a press conference on 4 March 1999 Railtrack unveiled another approach to start April 2000: IMC2000 (1998, #262). This approach will see the network divided into 15 larger areas for maintenance contracting. The structure is based on contractors having costs reimbursed for their work (using a guaranteed maximum price (GMP)) and a fixed fee being paid to cover overheads and profits; where costs savings are made the difference between the cost and the GMP will be shared between Railtrack and the contractor.

Thus, those first to be renewed Scotland South and South West contracts actually become part of a single maintenance contract to cover all of Scotland (1998, #267); this is referred to as a strategic alliance between Railtrack and First Engineering and is set up to run for five years from 1 April 1999. Another strategic alliance arrangement is also shown before the more formal processes begin: Alliancing agreement between Railtrack LNE zone and Balfour Beatty for infrastructure maintenance

[110]Quoted in October 1998 (p688) issue of Modern Railways.

(1998, #273) this covers the ECML north contract until April 2001 and the Sheffield contract until April 2000.

The implementation of the new infrastructure maintenance approaches are also seen within the data. IMC2 contracts are set up for West Anglia/North London (#277) and South Wales (#364). The first Railtrack zone to be let under IMC2000 contracts to be let is selected as London North Eastern Zone (#301).

These changes to the contracts themselves sit next to the activities shown in Table 6-1 that identify maintenance problems within the system and attempts to improve performance.

Table 6-1 Development activities around the infrastructure maintenance relationship in 1998 sample.

54	RS:Track not safe at Bexley. (Fines for accident February 1997)	The HSE investigated the accident and found the primary cause to be poor track condition. HSE brought charges against Railtrack (for failing to ensure the track condition was safe); South East Infrastructure Maintenance Company (for line maintenance failings) and Southern Track Renewals (for overloading a wagon: a secondary factor in the accident).
272	Derailment (September 1997): fine for breaking Health & Safety at Work Act	Train was found to have derailed because of substandard track caused by maintenance failings. Balfour Beatty were fined £500,000. Work was underway to rectify slurried track; summing up the judge refers to failures, by those working the track, to use safe method of work and to have all essential pieces of equipment the track, and adds that the workers : 'were not properly monitored or supervised' His Honour Judge Watling QC quoted in Modern Railways (May 1999, p321)
256	Fines for breaches of the Health and Safety at Work Act	Following the tunnel collapse during construction of London's Heathrow Express railway… 'Balfour Beatty was fined £1.2m, and tunnelling specialists Geoconsult £500,000.' (April 1999, p222)
343	Work to resolve contract disputes	Railtrack and Jarvis PLC working to 'address historical unresolved disputes surrounding the contracts.' Railtrack statement quoted in Modern Railways, August 1999, p563.

180	RS:infrastructure reliability Great Western Zone (1)	Railtrack has been criticised by the Regulator for delays caused by infrastructure in the Great Western Zone and a 20% reduction in 1999-2000 in train delays caused by Railtrack in this area has been demanded. Infrastructure reliability is one cause of delay that has been identified and is being tackled
200	HSE 97-98 Safety report	Highlights that, despite a fall in the number of significant rail accidents and in the number of derailments, there are still too many caused by poor track maintenance. 'We have therefore challenged Railtrack to demonstrate their commitment to improving both track condition and their control of contractors.' Vic Coleman, Her Majesty's Chief Inspector of Railways quoted in Modern Railways (February, 1999, p79)
210	Track quality improvement programme	Published by Railtrack 15 January 1999 and covers period to April 2001.
311	Project Sentinel: Central database recording competence and certification of Railtrack's contractors.	The new system sees the introduction of a smart card system for individuals and a central database recording individual's certification. There is a 24-hour call service to check the validity of certificates - so on site a contractor can check with the central registry immediately.

Unfortunately these efforts and those made in later years were not sufficient to tackle the reverse salient of the relationship between the infrastructure owner and maintainer. Problems with the relationship have been found to have played a part in serious rail accidents between 1999 and 2002. Attention is drawn to the relationship by the Rt Hon Lord Cullen as part of the inquiry into the Ladbroke Grove accident on 5 October 1999 in which 31 people died[111]:

> *"The evidence in regard to the use of contractors, most notably by Railtrack, was a source of considerable concern. I find, first, that the current process for the award of*

[111]Cullen, 2000, p193.

> *contracts was not being operated with due regard to the amount of training and 4 preparation of the contract workforce. Secondly, the controls in place for the management of the work of contractors and sub-contractors were inadequate. Thirdly, there is a need for an immediate and sustained improvement by the industry in the manner in which the employees of contractors and sub-contractors are controlled. Fourthly, the argument for reduction in the number of contractors is well founded. Further, it is clear that contractors should work to exactly the same safety standards as those directly employed. Competence is of vital importance."* (Cullen, 2000; paragraph 1.7, p3-4)

Referring to the privatisation and Railtrack's decision to contract out maintenance work the Office of Rail Regulation report into the derailment at Hatfield on 17 October 2000 states:

> *"The Board considered that this arrangement proved to be unsuccessful with Railtrack failing to control the contractors, losing control of the condition of the track (its main asset), the quality of the maintenance, and also losing control over its costs."* (ORR, 2006, paragraph 11.2, p133)

This evidence indicates that the failure to remove the reverse salient, introduced with the restructuring at privatisation, of the infrastructure owner-maintainer relationship has led to a failure of operational system. Künneke et al. (2010) would refer to this as a *critical transaction*; a point that needs careful stewardship because its failure can lead to system breakdown[112]. However, using LTS theory, this point can also be highlighted as a reverse salient and one that was created within the privatisation process; the reverse salient introduction was not, in itself, a problem but the sociotechnical regime, which, as has been shown above, was also altered in privatisation has not managed to find a way to correct this reverse salient. Following Railtrack's demise Network Rail, its successor, has moved some of these maintenance activities back inside the organisation, altering the problem to one of internal processes rather than inter-organisational relationships and contracts.

6.4.2 An abrupt change to system development: system knowledge and product approval

Examples such as a review of development projects (e.g. Railtrack, #82) and changes to the structures of development expertise (e.g. Railtrack's proposed integration of civil and signalling expertise #349) contained in the 1998 sample also show changes that are happening to the structure of the system's sociotechnical regime/system-building activities. These data do not permit the detailed study of changes in these developments or in their focus; that would be an area for further study. However, one sub-case featured in the reverse salient data and expanded on in the later interviews offers an insight into sociotechnical regime change that complements the reverse salient introduction findings above: the gap, that existed at privatisation, in knowledge about the infrastructure system.

[112]In his study of the electricity following its privatisation Künneke (2008) finds a similar 'critical transaction' does not function effectively and links it to a series of blackouts.

In addition to developments in track measurement and remote condition monitoring seen within the 1998 sample, there are also several *indirect* development activities from the 1998 sample that refer to changes in the acceptance process for new products introduced into the network: Changed structure of System Review Panels in the acceptance process (#312), Database for accepted products: Parts and Drawings System 2000 (PADS 2000) (#254) & Changes to Access Conditions & Group Standard to reflect new traction & rolling stock acceptance process (#20).

> *"Initially Railtrack did not have the information about the infrastructure or its requirements needed to make decisions about the safety of changes for incoming rolling stock."* (Interview record: F, appendix A)

Other interviewees involved in rolling stock introduction also highlight the difficulties with product introduction immediately after privatisation and reflect upon the problems caused for innovation that were created by the absence of information to allow demonstrations of compliance with the network. As well as process changes, there are references to measurement and visual recording technologies that have been developed and that Railtrack, and its successor Network Rail, have put to use. In 2008 and 2009 interviewees indicate that these problems were easing and clear, if still demanding processes, are described. There is evidence that expertise has also been built up by the procuring and consultant organisations to aid progress through the acceptance processes that have been developed.

The need to demonstrate new products' compliance in this way was created at privatisation. Several interviewees highlight that testing was easier under the integrated operator. There is also a change in connectedness; vehicles under British Rail were often designed by BR (and then built by a manufacturer) to run on a particular part of the network.

This case can be considered a new element introduced into system development as a result of the changes made to the installed system. These data indicate that learning and process changes have been occurring in the organisations involved to enable system development activity that can deal with these requirements.

From the 2008 and 2009 interviews a picture emerges of an industry that has been learning. Relationships have developed between organisations and there is evidence at this stage of collective/precompetitive technology development processes emerging. Research and technical integration organisations and committees have been created.

> *"Collaboration has become easier as the industry has settled down after privatisation."* (Interview record J, appendix A.)

These developments around product acceptance and the finding that relationships and organisational processes for system development took time and trust to reform following privatisation are consistent

with the view that privatisation provided a discontinuity in the sociotechnical regime without redesigning it. This fits with the findings of Markard & Truffer (2006) and the conceptualisation of privatisation discussed in chapter 3.

6.5 Discussion

These findings show that privatisation brought changes to the sociotechnical regime developing the railway system as well as the organisations operating it. This supports the findings of Markard & Truffer (2006) considering the liberalisation of European electricity systems. The example of the product acceptance process illustrates sociotechnical regime alteration, caused by the new organisational interfaces and altered regulatory regime introduced with privatisation. And evidence from interviews of further development work around this process and organisational interface and a 'settling down' in the system indicates the new element of a sociotechnical regime were demanded by the changes at privatisation but these have taken time to build.

Privatisation brought about changes in roles in system development. TOCs, and their service focus, came into development and local government organisations became much less active. The different motivations of these organisations also appear to show in the resulting development activity, these are not changes in system-builder in name alone. This analysis connects the changes in developers to, the expected, development trajectory shift. The role taken by government also changes but by the time of the 1998 sample a directing hand (the SRA)'s involvement in goal and budget setting is already being set up and afterwards this role goes back into government. System guidance from the DfT appears to be increasing further around 2007-2008.

Applying the model of system change, adjusted for established systems in chapter 3, changes in both blueprint and installed system change are seen. A change in system goal, brought about by financial penalties for delays, affects both types of development. There also appear to be changes in actors in both arenas, with the involvement of service-focused TOCs and a more varied supply industry. It is possible that some of, particularly supply industry development work, will have changed in character, from *specific* to *general* with the entrance of new suppliers for infrastructure and with the opening up of that market. More supply industry development activity is visible here but it is not possible to rule out changes in visibility[113] rather than activity in this analysis.

The evidence presented here indicates that both the operational organisations and the sociotechnical regime for the system were changed at privatisation, but their challenges might appear in different parts of the system, as shown in the two examples of introduced changes that came with privatisation. This loosening of the sociotechnical regime could lead to system transformation and some level of change in development trajectory is to be expected, however the direction and its benefits depend on the

[113]Also brought about by industry restructuring

sociotechnical regime that will be rebuilt in place of the old one. Relationships and processes need to be built up for both development and system operation. It is possible that these areas of development will interact, leading to correction of introduced reverse salient not being achieved. The delay, caused by a need to rebuild processes and relationships for development in the sociotechnical regime, might not be without cost for system operation.

Further examination of these types of system reconfiguration and resulting system development could provide new opportunities and useful warnings for policymakers looking to generate controlled transitions and seeking to avoid uncontrolled ones.

6.6 Conclusion

Viewing privatisation as an opening for transformation provides a series of case studies for MLP scholars where the case does not need to be identified by outcome. This study is the first, in what could become a set of cases for comparison.

Another challenge for the empirical testing and extension of the MLP framework addressed in this work is what to look for within system change stories. Hughes's (1983; 1987; 1992) LTS theory of infrastructure system development offers a model that underpins the concept of the sociotechnical regime used in the MLP. This has allowed the concept of sociotechnical regime to be broken down in a way that is generalizable across cases and for changes in these component parts to be sought in data from contemporary sources, that has been structured using LTS. The study finds goal change as well as changes in the system actors involved in development and the types of change being initiated.

Focusing on the phenomenon of system reconfiguration, this study also highlights changes in reverse salients caused as part of the restructuring at privatisation. The use of the LTS theory has made these events visible and this conceptual approach assists understanding of unexpected developments following privatisation. It could also assist an assessment of how system development might be affected if a given operational structure is introduced.

However, even with the application of this conceptual tool, it is unlikely that the problems associated with the product acceptance process would have been anticipated. These problems would not have been visible at the point of privatisation, it is only with the operation or testing of the sociotechnical regime that this kind of issue becomes clear. In future, planned reconfiguration processes with the combination of safety critical reverse salients being introduced into the structure and these uncertainties in the sociotechnical regime need to be considered with great care.

This study identifies a series of changes in the sociotechnical regime introduced across privatisation, however there is still work to be done to fully understand the processes involved in those changes. The application of the LTS model of system change, as demonstrated in this study, could be used to identify

a set of theoretically selected cases to further examine components of the sociotechnical regime and how they change. A useful development would be to apply the method developed in chapter 4 longitudinally to part of the system to consider how changes in the sociotechnical regime come about and interact with system development. Another approach would be to apply the method developed here longitudinally across the whole system but using only certain *types of action* codes; in particular the *indirect* code can provide insight into sociotechnical regime change.

7 Conclusion

Established infrastructure systems provide services such as telecommunications, energy and transportation; they play an important economic and social role in the societies they support. The research presented in this dissertation contributed to our understanding of how these systems change. Although mature infrastructure systems can appear unchanging, they do continue to develop. New technologies, ideas and organisational solutions are absorbed and developed and these systems need to continue to adapt to the needs and expectations of the society they serve. Over time, through knowledge development, professionalisation of their system-builders and installation of capital intensive networks, infrastructure systems develop the momentum that makes them appear fixed and that can lead to the impression that they cannot and will not change. However, as seen in the example studied in this research, LTS development includes both periods both of relative stability and of transformation; there can be periods of momentum reduction and system redirection in addition to system development that generates an expected trajectory.

The case study developed in this research examined an established and high-momentum infrastructure system over a restructuring that provides the potential for a period of relative instability and a change in the direction of system development. The privatisation and restructuring of British Rail led to new organisational boundaries and interorganisational relationships that affect both the way the system operates and the ways in which it develops. Knowledge and processes for operation need to be moved and reconfigured to fit within the new organisational structure, so do those for knowledge development and system change. This research used this setting both to consider system development processes that operate within the system for a mature LTS and to investigate the way system development processes changed across the privatisation that was initiated in the system's environment. The insights generated in this research can be applied across mature LTS and add to existing understanding of system response to trajectory redirection, particularly but not exclusively those generated by policy interventions such as system privatisation, nationalisation and reorganisation.

This work provides three contributions to existing research. First, the archive based method developed for this research, described in chapter 4, provides a systematic approach to studying established LTS across the broad scope and for the long periods necessary to capture change in these systems. It has the potential to facilitate cross-sector and cross-study comparisons. Second, the development of LTS theory discussed in chapters 3 and 5 extended its application to the cases of established infrastructure systems and enhanced our understanding of the way they change. Third, in considering the potential transformation of the system following privatisation, LTS theory was incorporated within the MLP framework. LTS theory was used to operationalise the socio-technical regime concept to address some of the limitations of the MLP framework.

The method developed using the LTS theory of system change provided a systematic approach to the study of mature LTS that can assist more rigorous empirical work that considers large systems over long periods of time. One benefit of a systematic approach is that it allows cross-system comparisons and a set of cases to be developed by different researchers, something that is particularly difficult to achieve in the study of such complex systems. The method has been in applied in this research. It would benefit from further development so that it can be applied longitudinally to the study of 20 or 30 year periods.

This research proposed an extension of the LTS theory to improve its explanation of change in mature systems. Two lines of reverse salients, which represent the performance of *installed* and *blueprint* forms of a system, were used. This allowed the role of the installed system, so important in established systems, to be considered in system change. This study also highlighted the idea that reverse salients might be introduced into system performance. Although this can occur as part of development within a trajectory, system reorganisation at privatisation presents a more dramatic illustration and, in this case, one such example has been linked to system failure. These ideas are demonstrated within the empirical work presented in chapters 5 and 6; the extended LTS model was used to assist analysis. This model would benefit from further testing and from development in other empirical settings. The extension of LTS proposed is applicable across mature infrastructure systems but it could also benefit understanding of system change in any setting where installed assets and processes influence decision-making. One interesting further extension to the application of the model proposed here would be to consider 'softer' infrastructure systems such as healthcare.

MLP and LTS frameworks are used together to examine the system's response to privatisation and restructuring. The reverse salient correction mechanism of change, from LTS theory, was used as a mechanism of internal system change within the MLP framework of system transformation. This theoretical step, the novel method developed here and the selection of the privatisation setting used together present the opportunity to address some of the weaknesses in the MLP framework, in particular the operationalisation problems that have led to success and retrospective biases within empirical studies. The empirical work presented in chapter 6 identified changes in the socio-technical regime that occurred across privatisation and it highlights critical points for system performance. The application of MLP and LTS frameworks together, in the study of system response to privatisation, also illustrated opportunities to break down the socio-technical regime concept to encourage new questions within transformation research and to allow comparison across times and sectors. The investigation of purposive transitions/transformation, such as sustainability transitions, first requires understanding of the mechanisms involved in socio-technical regime change; although commonly applied to infrastructure systems, LTS theory has the potential to be applied beyond these settings and this work could support further research of transitions and transformations outside network infrastructure systems.

Recent infrastructure privatisations and restructurings provide opportunities for improving our understanding of how change occurs in well-established mature systems. Some outcomes, including accidents and failures, accidents and failures, have taken system-builders and policy-makers alike by surprise. Studying movements between stability and change in these systems can provide opportunities to improve understanding and can, perhaps, open up paths to environmentally, economically and socially improved infrastructure systems.

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APPENDICES

Appendix A	Interview data
Appendix B	Data generation
Appendix C	Interdependencies between three major projects
Appendix D	Data description
Appendix E	Blueprint data
Appendix F	1998 *Local*; *Local/Private*; *Central/Local* & *Industry/Local*
Appendix G	Delay: finding its role throughout the 1998 sample
Appendix H	TOCs development activity
Appendix I	Permissions for re-use (figure 1-1): License agreement

Appendix A Interview data

Details of interviews conducted with system actors.

In order to find out about the practices of the privatised industry, particularly around technological innovation, a series of preliminary interviews has been conducted[114]. These in-depth discussions were conducted with a range of industry personnel, most of whom were senior engineers; the distribution of the interviews conducted is shown in A-1. The interviews focused on the roles of the different organisations in the industry, any innovation processes and how they interacted with other organisations within the industry. Most of the interviews were conducted between March 2007 and May 2008. This was a sensitive period for some parts of the industry, there was a Competition Commission (2009) investigation being conducted into the practice of the ROSCOs; as a result, interviews were recorded using hand written notes, rather than transcripts, and these were written up into interview records which were sent to the interviewees to give them the opportunity to have an input into their record. The records produced provide views of changes across the industry overtime as well as accounts of activities for innovation conducted within and between organisations and examples from individuals' experience.

These records provided guidance for commencing a more detailed study of this industry; they also offer additional source of data to complement the media analysis work in the form of a more detailed view of certain changes going on within organisations (as opposed to between them).

[114]Most of these interviews were conducted as part of a Rail Research UK funded project: Whole system cost model. (For more information on this project see Lovell et al. (2011))

Table A- 1 Interviews conducted

Reference	Date	Organisation (Numbers identify different organisations)	People in interview
A	15/11/07	ROSCO 1	1
B	15/11/07	Supply 1	1
C	20/11/07	Linked to a number of organisations since privatisation. Senior role within BR.	1
D	20/11/07	ROSCO 2	1
E	22/11/07	ROSCO 3	1
F	23/11/07	Vehicle Manufacturer 1 (and held a senior position in Railtrack)	1
G	26/11/07	University (also linked to other organisations in the industry)	1
H	03/12/07	Vehicle Manufacturer 2	1
I	06/12/07	Supply 2	1
J	19/12/07	TOC/ATOC 1	1
K	25/01/08	TOC/ATOC 1	1
L	30/01/08	Supply 3	1
M	12/02/08	Supply 4	1
N	20/02/08	Supply 5 (a young organisation seeking to supply the industry).	1
O	25/04/08	Vehicle Manufacturer 1	2
P	30/04/08	Department for Transport	1
Q	30/04/08	Supply 6	1
R	01/05/08	TOC/ATOC 2	1
S	07/05/08	Vehicle Manufacturer 3	1
T	09/03/09	Network Rail	3
U	10/03/09	Network Rail (R&D focused)	2
V	10/03/09	Network Rail (Modelling focused)	1
W	25/11/09	Network Rail (Product acceptance focused)	1

Appendix B Data generation

This is a record of the data extraction process, how it was developed and the borderline decisions made in defining the dataset.

Early exploratory work with the data source, the archive Modern Railways magazine, took the form of searching for instances of change and recording information of and about changes in word documents. Following the decision to use reverse salients as a way to structure system developments, data were extracted into spreadsheets. Each row was dedicated to a reverse salient or work to correct a reverse salient identified in the archive material; the creation of a new entry/datum could be triggered either by reference to a problem/area for improvement (the reverse salient) or by discussion of development work going on which would be adjusting system performance (and therefore altering reverse salients). To extract information on reverse salient identification and correction the following fields were created.

Table B-1 Fields in each datum record

1	Reverse Salient reference number	Identification number
2	Entry description	A reference title for the datum[115]
3	Reverse Salient	Issue being worked on as characterised in a news item or as the central topic of an article.
4	Project or Change	Project for change or change being implemented as described in a news item or as the central topic of an article.
5	Cost (£ millions)	Information found on proposed and/or actual costs.
6	Installation completion date	Information found on intended and/or final launch of the change.
7	Set up correction	Information found on the way the reverse salient has been identified and/or the project/change has been initiated.
8	Doing work for correction	Information on the process used for reverse salient correction. For example project structure or phases, information on the organisations involved in the project or innovation.
9	Sources	Each point entered in fields 2-7 is referenced here. 1) Month, year, page number, magazine section, information on the article's remit. e.g. In the Manchester Metrolink project: *2) March 1993 140 Newsfront (On figures for Greater Manchester transport)*
15	Links to other Reverse Salients	This is a reference column for the analyst; where there appear to be links to other projects these can be recorded here (e.g. track work to allow channel tunnel traffic, is linked to the creation of the Channel Tunnel)

[115]This field was added after data entry was complete, to aid comparison between the three samples.

The research design involves three samples of system development activity each 12 months in length; their definition and importance are discussed in chapter 4. The data extraction process for this work was developed during the creation of the sample of June 1992-May1993: that of privatisation. This is the most useful sample to start with because it deals with development under way in the existing governance system whilst encompassing the early developments of the new governance structure. Therefore this sample was constructed in several stages and care was taken to address reflectively decisions over what to include; the aim was to abstract those decisions away from specific events to form reasoned boundaries for dataset creation.

June 1992 – May 1993

Once the database structure had been determined the first phase of data extraction began, according to the principles set out in Chapter 4; however there were questions of scope and detail that still needed to be addressed and other issues which emerged. As a result data generation for this sample was an iterative process and it involved decision making on what to include and why. Several months of data were entered into the spreadsheet and then reviewed based on the accumulated decisions taken up to that point. Then another section of the archive was used and the full dataset up to that point was reviewed again, and so on. The first review was conducted after June-August 1992 had been considered, the second, which was an extension of the same principles, at the end of December 1992. There followed a period of research framing and theory and a break from data extraction; data were then added for January to May 1993 and a further full review was done and finally the data were also reviewed with initial coding.

An early decision was to limit data collection to certain sections of the magazine. The aim was to focus on news items or reviews of developments, rather than opinion/commentary pieces; this lead to the inclusion of NewsFront, Informed Sources, Modern Railfreight, Moving Wheels, (a Privatisation News section was also included when it was introduced) and the articles in each issue. Forum (the letters page) and Alan Williams's Column were excluded. There was also a need to work at a useful but manageable level of detail; this led to the exclusion of Trackwatch, as this details every element of infrastructure maintenance in the system without providing more than geographical context. Both of these concerns also led to decisions of what to record from within the sections being used, these are discussed below.

What changes should be recorded from the data source?

Avoiding commentary

In addition to reporting on 'news' from the railway system this publication contains sections for commentary, as referred to above, and it includes opinion pieces and a platform for campaigners. Although the voices of campaigners and individual opinions are often relevant to change, at source they are also indistinguishable from lobbying. For that reason, opinions of what needs to change (reverse salient identification) /what is being changed in a particular project (reverse salient definition) are only included where they are from an individual or organisation that is in a position to make these changes to the system directly (e.g. if the engineering director of Network South East talks about future plans to change signalling in a particular location within his network then this is included but if it is raised only by a local users group this would not be recorded). This also applies to the voice of the writer of an article where it appears to stray from the views of its sources (for example the Informed Sources section often includes analysis or assessment by its author, this is not used to initiate reverse salients recorded). For the inclusion of voices of system outsiders when they do lead to change, these data will rely on that being identified in the discussion of those changes when they occur.

Although the Transport Users Committees were a formal part of the railway system, they only had the power to recommend change, and not require it, therefore their decisions and reports are not included as actions for change in their own right. However if they were featured in articles about a change that has other parties involved, their influence would be recorded in the 'setting up correction' field for that change.

There is a further and related concern in the area of the identification of reverse salients which are not yet being acted upon. Where there is a realistic expectation or a forming plan to act on this change in the near future then these should be included, because if they are not pursued that is as interesting as if they are; in cases where plans are pursued it would be expected that they would feature in reports on industry change at a later time. However, unrealistic or long term wish lists (by which time priorities and mechanisms for change may have altered) should not feature. There is not a concrete way to distinguish between long and short term plans; sometimes this is signposted in the reporting or language quoted from articles' sources but a certain level of judgement from the researcher is required in this area. Where there is variation in the placing of this boundary it should be relatively minor, neither on a scale nor sufficiently central to the analysis to disrupt the findings.

Level of detail

The aim is to be true to the interpretation of reverse salients and corrections seen by industry practitioners and observers. This leads to some projects being subsumed into larger projects. So two

projects renewing an equivalent amount of track might appear differently in the data: one as an isolated project and one as part of a larger project. The original intention had been to enter all projects and then link them under umbrella projects where appropriate; however, once working with the data it became clear that a more faithful interpretation of system change would be to take the top level project (as referred to in the source material) and fill in information from there, which would include project structure and any subprojects discussed. This is because decisions over project initiation and scope (linked to reverse salient selection and definition) are present at the top level of a project, as seen by practitioners. So the two track renewal projects referred to above, although similar in content, will have different initiation processes which are linked to their contexts; and that is what needs to be captured in these data.

The appropriate level of detail to use was investigated through the expansion of two articles on infrastructure change to introduce new trains, Networkers. These appeared in the June and July issues in 1992 and described the infrastructure project within the project by Network South East to introduce a new type of vehicle on several parts of the network. The subordinate change events/projects as described in the article led to 29 reverse salients being identified within the infrastructure project and these were recorded in a separate spreadsheet. This experimental data extraction highlighted that an article like this can go into a much greater level of detail than would be expected in the news reports. This could be useful but it leads the data to be dependent on the interpretation of the structure of changes by the writer or their key sources and to bias being created in the data via the editorial selection of what is interesting enough to feature in an article. Discussion of projects across articles and news entries provides triangulation to help produce a more reliable interpretation of reverse salients/projects being addressed. It also allows a relatively consistent level of detail to be maintained. As a result of these considerations, it was decided that new data entries should only be generated from news sections, where they are the main topic of an article or from review articles (which discuss developments within a particular section of the industry (with an established identity, e.g. Network South East)) rather than those which discuss particular change projects.

The data for this research is pulled from a publication and one concern is that the publication (its format, mechanics of production, agenda of individual writers etc.) might direct the data/be the lens through which the system's behaviour is captured. However, an important element in dealing with reverse salient correction is the interpretation of those reverse salients used by the system's decision makers and developers at any given moment; the ability of industry press to communicate that and provide that lens to this analysis is crucial. This is present within both the information sources for the publication and in the way it shapes itself for its industry specialist consumers. As a result, care has been taken to try to eliminate the influence of the biases of individual reporters (with the exclusion of commentary and of exceptional levels of detail from single sources which might skew the analysis) whilst embracing the balance of reporting within the publication. If very important projects or developments were not

featured or if the balance of content was not representative of their interests (as industry members), the readers are likely abandon the magazine; therefore the magazine can be assumed to be attempting to reflect the developments, scope of interest and perspective (relevant for an understanding of system goal within the LTS theory) which are relevant for system actors.

An observation not anticipated in advance of data collection was the idea of interpretations of the decision making points/project definition/level of attention changing over time. This is most clearly demonstrated with major developments such as privatisation itself or megaprojects such as CTRL. Smaller scale changes fit within the processes the system developers would expect to deal with and so could be set up with system-builders already knowing what sort of form the projects will take as they progress; however, even these can join with other developments and become co-ordinated with/subsumed into another project and come to be viewed as one larger change. The privatisation example demonstrates this phenomenon clearly in these data: early discussion is around the privatisation bill and considers the full new structure, whereas at a later time actors and readers are sufficiently aware of the overall picture of privatisation for subsections, e.g. the role of the regulator, to become the focus of reporting in their own right. This reflects a sensible/logical shift in attention which is highlighted by these data. (This is also written up in Chapter 4.) As a result, although the priority should still be to make sure the highest level of project hierarchy featured is captured, where lower level projects/reverse salients appear to be referred to in isolation (i.e. have gained an identity as a change project), these too should be entered; then the higher level project is listed in the links field for its subproject.

Recording only changes to 'the system'

A further decision was taken to exclude articles that review fleet or freight developments. These articles focus on elements of the system which are not infrastructure. They do sometimes include reference to changes in the infrastructure but as these developments are on the periphery of the subject matter there is potential for distortion. In addition these articles are very detailed so they feature relatively minor depot/track configuration changes and they take a disproportionately long time to analyse.

One issue not anticipated prior to data collection was the distinction between changes to the railway system and changes to the projects which are changing it. This was identified in the first review with the example of delays occurring to the Cowlairs Chord project which meant certain changes needed to be made; project issues or decisions acting as instigators of changes to projects are to be treated as reverse salients of the project not of the railway system and therefore are not to be included in these data. In addition in this case, delays were caused by an issue from within the system, a shortage of signalling staff, this was recorded as a reverse salient in its own right.

The focus of these data is the networked infrastructure of the system. This includes track, signalling, power sources etc. It was decided that stations, depots and freight facilities are important infrastructural elements which affect the character of the network and therefore they are included. However, as well as forming part of the technical infrastructure with which operations work, they also encompass areas of change indirectly connected to the core infrastructure, such as information systems for passengers. Passenger and freight customer focussed changes are not central to the interest of this work and therefore have been excluded. In the case of stations this is operationalised into the inclusion of the addition, re-opening or closure of stations and to changes directly interacting with the networked infrastructure (e.g. platform alterations or reconfigurations of track or signals in the approach to a station). This allows the many references to, for example, footbridge additions, station renovation and additional parking facilities to be excluded from the data. In the case of freight and depots, changes to the operation of the facility are not included but changes to the rail infrastructure at this location are recorded. This leads to a boundary case where a facility closes, the intention is to include closures that affect network form or capacity, however it is not always clear whether a facility closure leads to a capacity change or only (leads to or results from) traffic changes. Although in some cases it might be safe to assume a network change, these instances are only included in these data if the railway element is discussed; it is possible that some small alterations to the network might be missed through this approach but major changes will be featured because the railway element will be discussed within the reporting. Most importantly, this approach ensures incorrect assumptions about changes not fully discussed are not included.

In addition to the main heavy rail network, the UK railway system includes light rail and tram systems. Where these are self-contained, development decisions do not need to interact with those of the main network and therefore these subsystems are excluded from this study. However, once data collection began it became clear that what is 'self-contained' is not as easily identified as would be expected. The decisions to create a new metro system do, to a certain extent, reflect and affect the aims and development of the full system. In addition, lines can be transferred from heavy to light use, for example in the case of the Sunderland Metro. As a result the establishment of new examples of these systems are included as infrastructure system reverse salients/correction projects. However, development activities of organisations such as London Underground are outside the scope of this work. The exception to this decision is where the main rail network is affected by developments (e.g. the transfer of lines to London Underground control from British Rail) and these reverse salients are considered from the point of view of the main network.

Post-data input check

The check of the full dataset, tracing information from the source and checking its representation in the spreadsheet, and checking as part of initial coding, generated a series of changes linked to the decisions

being made as the data were assembled. One major alteration was to include developing changes linked to privatisation within the same dataset, eight reverse salients were added because of this. Changes to the dataset included the addition of 33 reverse salients and the removal of 30; these are broken down in the tables below. A further 16 reverse salients had information added[116]. The resulting dataset includes 290 reverse salients.

Table B-2 Changes to data in review: additions

Nature of datum, includes both content and source characteristics	Number	
Captions (these are easily missed in the datasource and making sure these were included was part of the check)	8	
Within Newsfront articles (change to consciously including all information that could be extracted – the number includes reverse salients which were added from the same article)	11	
Described as 'abandoned plans' (Decided to include as potentially serious possibilities)	1	
Within Modern Railfreight	1	
Station information (changes over the course of data collection)	6	Shared with Caption: 3 Shared with Newsfront: 2
Depot/terminal information (changes over the course of data collection)	3	Shared with Caption: 2 Shared with 'Abandoned plans: 1
Privatisation developments (change in approach)	8	
Proposals for new subsystems	1	
Announcements linked to studies (adjusted decision to include)	2	
Total	(41 – 8 =) 33	

[116]Where information was added to reverse salient records; the breakdown of the sources for the information added is as follows: Captions (4), Newsfront (3), Main articles (4), Moving Wheels (1), Informed Sources (1), Modern Railfreight (1), Newsfront Box (2).

Table B-3 Changes to data in review: removals

Actions from actors other than those with the power to change the system directly (e.g. Recommendations from TUCC).	3	
Changes linked to the core infrastructure but to other part of the rail system (e.g. about vehicles for infrastructure maintenance: include changes in the nature of the maintenance vehicles used (such as introducing high output track laying machines) but not redeployment of standard equipment)	5	
Station projects which do not directly affect the core network (e.g. ticket barrier introduction) (2 of these removed entries are different aspects of the same project)	6	
Changes judged too far removed from direct and current changes to the system in terms of timing or planning (e.g. changes that do not form part of a plan but have been identified, for the future, by an informed individual)	5	
Project featured in more than one entry; reverse salient removed in rationalisation	5	
Changes not directly to the infrastructure or decision making for it but second order concerns; for example changes to infrastructure projects (to change them) (e.g. Railway Inspectorate delays following Newton).	6	
Total	30	

Following the completion of this and the following two datasets a further 4 data were added. These were studies of infrastructure linked to accidents. The decision had already been taken to exclude accidents but include resulting system changes; however, work on the later samples highlighted the relevance of these reports so these were added retrospectively. And in a review of the maintenance development to be included one entry was removed. The final dataset contains 293 data.

Initial data coding

In order to set up the dataset for comparison across samples, it was found that reference data field as well as content data fields would be useful. As a result the second field was added, this gives a project description to be linked across data samples. In the course of coding the following fields were added to the dataset.

Table B-4 Code categories

10	Geography	Used to allow the grouping of geographically adjacent projects for analysis and aids matching projects between samples. Network Rail's route plans (Dated 2010)[117] have been used to divide up the Network Rail owned infrastructure
11	Growth Code 1	This is a theory based set of codes to categorise the change made to the system. (*Scale*, *Scope*…etc.)
12	Growth Code 2	This is an inductive code to categorise reverse salient identification/project initiation
13	Types of action	This set of codes consider the type of activity (general, specific, indirect or study)
14	Notes on coding	This is a field to allow additional references used for coding to be recorded and to incorporate descriptions of any boundary/novel decisions made by the analyst in allocating codes.

The following 2 data samples

Many decisions and process refinements occurred during the iterative construction of the 92-93 dataset. It was expected, therefore, that most issues for data extraction principles had been considered and resolved in the course of the generation of this first dataset. With the majority of the principles for borderline data decisions set out, the inclusion mid-dataset reviews for consistency is no longer necessary. However, some decisions may remain to be made; to retain a systematic and reflective approach the measures were adopted for the construction to the remaining two datasets:

- The underlying principle of '*if in doubt include it*' was adopted. This means that checks can be conducted of only the dataset, with a view to removing material, and reviews of the source material to consider adding information are not necessary.

- An additional procedure of creating a document parallel to dataset generation, which documents decisions, and the reasoning behind them, made on data inclusion. Documenting these decision in the one place allows review checking for internal consistency within each dataset at the end of each dataset creation process; they can also be reviewed across datasets to check consistency throughout the case.

[117] http://www.networkrail.co.uk/aspx/4451.aspx

- Following dataset generation from source material, it was reviewed for duplication/over inclusion in parallel with data coding.

The documents for the 1990 and 1998-1999 datasets made a note of any decision made by the analyst in dataset generation that required extension of the above guidelines or involved operationalization of them that required some thought. The intention was to document any new areas of uncertainty and to provide a record of operationalization that could be checked within and across samples for consistency.[118] As each sample was completed the parallel document was reviewed and checked against the first part of this document; any inconsistencies in data generation could then be adjusted to match or to more faithfully extend the guidelines used previously. With the completion of the final sample the documents were also compared with each other to check that faithful extensions were consistent with each other. Additional issues raised in this process are outlined below.

The magazine's structure changed across the samples. Amongst the news sections being used as data sources the NewsFront, Informed Sources and Moving Wheels sections continued to exist and be used throughout the three datasets. The 1990 issues also used an Accident Report section sometimes and they included a News Briefing section at the back of the magazine; the Railfreight section was not used but freight news was still reported, just within the general news section and a privatisation news section was not yet relevant. The third sample featured Infrastructure News (in 1998 issues), Legal Lines (a column on legal issues that was sometimes included), and a Railtrack Safety Report section was added part way through 1999. In addition there was a Railfreight section throughout the issues that was included in the sample except for a column that had been added since 1993 entitled 'The Rail Group' this was more editorial than news or background and was written by a freight lobby group so it was not included as a source.

1990 sample

Points of clarification that have come from the 1990 sample. Changes to the level of performance targets should not be included in the sample, though changes to the nature of them should be recorded. Studies or reports that result from or respond to accidents (inquiry reports etc.) should be included, even though the accident itself is not, because they are a system development activity to help decisions on changes to be made. There was also a development that demands a re-examination of the nature of unpredictable contingencies not, in themselves, to be included; accidents and weather events such as lightening strikes are not included as developments themselves (work to correct a reverse salient formed or identified through the accident are included). Speed restrictions introduced as a result of buckling risk for rails

[118]Initially the documents also included additional information that was not going to feature in the data but was interesting for background/context; however these elements were removed into a separate document.

because of the sun are included as a local and short term reverse salient because this is not an unpredictable 'act of God' but an example of unusual conditions that could reasonably have been planned for, and might need to be in future (this line is of course a judgement call in each case). A useful exemplar of the distinction being made here is that a tunnel temporarily affected because of flash flooding would not be included in the data but a site where flooding happens frequently would be featured as a system reverse salient.

98-99 sample

This sample raised some new issues as privatisation brought with it changes in activities and changes in the level of detail being discussed. Reviewing the notes made alongside the data collection led to the following decisions:

- Changes to depots were sometimes raised. These are to be included where there is information that the facility (its physical set up or its procedures) has been changed to perform differently. So for example, the new wheel lathe at Tyseley that removes a need for a considerable round trip for vehicles is work that removes a reverse salient. However, where this deliberate change is not mentioned or when the depot's balance of use is what changes, this is to be treated as an operational change and is excluded; for example, were the lathe's use to be extended to a new fleet.
- Timetable changes have always been outside the scope of this study. In generating this sample, however, a change to timetable creation processes and the software to do it were noted. This is another change that borders between operations and infrastructure. This type of change is to be excluded as it affects the way the infrastructure is used rather than its form. The processes and software will become part of the constraints/facilities for operation but are not here considered part of the system infrastructure.
- Activity linking regulators and political actors into the railway system can be less straightforward to capture than, for example, new physical installations. Reports of legislative and governance changes that affect the whole industry are included (e.g. the creation of the Strategic Railway Authority (SRA)). Government documents (Green and White papers) and reports are included in these data where they are described in datasource; their influence in captured closer to impact with the recording of changes being made to accommodate/respond to them. There has been an attempt, however to exclude changes that do not influence the infrastructure part of the system, or only do so indirectly via other actors. This came into focus over an episode of changes to industry governance in Scotland that were highlighted in the October issue and reviewing the material the decision was made to include a separate entry to the governance changes, linking in with the introduction of the SRA, but actually brought about by the creation of the Scottish Parliament, and with it a Scottish Executive.

- As discussed above new self-contained systems, including new lines to existing systems, are included as developments because they are expected to interact either directly (taking over heavy rail lines) or indirectly (changing passenger movements) with the national system. (Modifications to these self-contained systems are excluded except where there is an explicit connection made in the reporting to the core rail network. An exception is made however for the London Underground and the Docklands Light Railway (DLR) in London; as they are part of an established alternative governance set up in London that was not part of British Rail in addition to being self-contained, by virtue of physical differences in the technology, none of these projects, including extension projects, are included in these data. London Overground, however, is treated as other self-contained systems (e.g. Tyne & Wear Metro).
- In this data sample mechanised infrastructure maintenance features in reporting, this includes purchase of new high output machinery as well as references to the more established sandite and weedkilling trains. This highlights a distinction needed between operational and development elements of infrastructure maintenance (and movement between them). Systematised (not necessarily automated but formally defined processes of infrastructure checking and adjustment) ongoing activities, such as the operation of weedkilling trains and the maintenance activities around that equipment, is not captured in these data. Where there are changes to the nature of the equipment or to the decision process through which it is applied those are development changes and they are included. This issue is brought into relief with the activity highlighted in this period around high-output maintenance equipment (e.g. mechanised track-laying machines and tamping machinery). In this study the introduction of new types of machinery or changes in the way it is used should be included, this includes for fleets being added for different organisations (not just the first vehicle of a certain type onto the network) but adding more of the same technology to an existing fleet would not automatically be included in the sample.[119]
- A reference to university research being reported at an industry conference (April 1999: p242) led to consideration of how this type of work should be treated. Where there is evidence that research work was either commissioned by, done with industry collaboration/input or has an implementation route into the system outlined, then this work should be included. These conditions are added because university research can include developments that the industry would never take on or work that is targeted a long way into the future and this is not to be included.

[119]This clarification lead to one further entry being removed from the 1992 dataset; this was on changes to the operation arrangements for sandite trains. The final data included: 293.

Datasets

The resulting datasets for the three samples take the following form:

Table B- 5 Summary of the datasets

Name	1990	1992	1998
Embedded Case	Pre-privatisation	Privatisation	Post-privatisation
Period	Jan 1990 - Dec1990	Jun 1992 - Jul 1993	Oct 1998 - Sept 1999
Pages in Source	668	748	920
Entries	228	293	377

Appendix C Interdependencies between three major projects

Table C- 1 Details of three interdependent major projects

	CTRL	King's Cross	Thameslink 2000	Other linked projects
Background	A proposed new line to provide a high-speed connection between the Channel Tunnel and London (also known as High Speed 1)	The redevelopment of King's Cross station in London. There were property development, capacity and station quality elements to the project. CTRL was intended to terminate at King's Cross.	A project to increase capacity on the thameslink route, running through King's Cross Thameslink, moving from 6 to 18 trains per hour.	
1990	Eurorail (a private sector consortium) was dissolved after the Government decided not to contribute funds to the BR/Eurorail CTRL scheme. Route changes and further consultations are in progress; BR is proceeding with assessment basing plans on a Kings Cross terminus and a proposed route from Cheriton through Kent.	The Commons committee considering the King's Cross Railways Bill wanted to be able to examine the interaction with CTRL plans, before provisional approval was given, but the plans had not been finalised by BR. These plans were then affected by the Government's decision not to fund CTRL; 'BR is pressing on with its bid to secure Parliamentary approval for the King's Cross Bill, saying that it is needed to replace the inadequate King's Cross Thameslink station.' The Thameslink route was then being considered as a way to get international trains to King's Cross without CTRL.	A Parliamentary Bill for the Thameslink Metro scheme had been expected by November 1989 but the project has 'been postponed because of its close interconnection' with the CTRL, 'with which it would share a new low-level station at King's Cross.' Scheme includes capacity increase through Snow Hill Tunnel by infrastructure improvements south of the Thames, if Channel Tunnel trains were to be added to the route as a way to get them to King's Cross without CTRL: 'a great deal more work would be necessary – hence the hold-up on the Metro proposals.'	• Channel Tunnel: Tunnelling breakthrough expected December 1990; to open June 1993. • Spur between Midland main line and the North London line: '...among plans included in a British Rail Bill for improvements to existing railways for Channel Tunnel traffic.' It would give access (underground) from the new King's Cross station joining the existing Thameslink route to the Midland line, and over the spur and the North London line to the WCML.

1992	BR team and Government working out requirements; a Parliamentary Bill was anticipated in late 1993. Cost estimates referred to Thameslink 2000 and King's Cross/St Pancras development work. Government decided St Pancras should be upgraded to be the terminus (rather than King's Cross). March 1993 BR provided adjusted proposals (the original route proposals were rejected by the Government October 1991); Government decisions to follow.	'King's Cross Railways Bill, promoted jointly by BR and London Underground has been before Parliament since 1988.' It is approved by the House of Lords Committee. And the EC 'dropped its objection over environmental assessment of the King's Cross terminal and rail link.' Government decision that 'St Pancras should be upgraded to take Eurostar trains' from CTRL rather than King's Cross.	This is a NSE project; BR is hoping to fit project in with proposed 1998 finishing date for King's Cross project. (The King's Cross project has been impacted by decision for CTRL to go into St Pancras.) NSE seeking planning permission for improvements to the Snow Hill line through the City of London - under the new Transport & Works Act. A Parliamentary Bill has not yet been generated for the project.	• Blue Circle has proposed a station on CTRL near Ebbsfleet

1998	Sod turning ceremony: 15 October (1998); First Phase due to open in 2003; Section 2 (taking trains into St Pancras) construction 2001-2007. CTRL was 'rescued' when the Treasury agreed to back the £3.7billion of bonds issued to get the project off the ground; Railtrack will acquire the new line, at cost, on lease until 2086 and it will enter an agreement to purchase Section 2 on similar terms.	Within the CTRL project there is a £160m scheme to redevelop King's Cross underground station as part of this project (it'll focus on reducing existing congestion and work recommended following the King's Cross fire - the second phase will be done as part of Section2 of CTRL - full cost of this subproject to be from the Government's contribution to CTRL). Otherwise this project does not feature in the 1998 data sample	The scheme's been delayed because of the delay to CTRL stage 2, probably until 2004-05; 'A new low-level' station box was to be provided at St Pancras', as part of its CTRL redevelopment, for Thameslink trains. There has been a Railtrack, DETR & OPRAF review of the project Railtrack's amended proposals for Thameslink were presented at local consultation roadshows in June and July Anglia Railways 'says capacity has now been reached in the morning peak into London and further service improvements can only be achieved with the implementation of the Thameslink 2000 project.'	• Link from CTRL to West Coast and North London lines. Including a new CTRL station at Stratford: the Deputy Prime Minister said he is minded to approve planning permission. • Two, of the 26, bottleneck locations identified in Railtrack's 1998 Network Management Statement (NMS) are dependent on Thameslink 2000 completion. • Railtrack considering freight options on routes south of London in response to CTRL work that's restricting capacity. • Modification of existing railways for junctions with CTRL • Study looking at easing congestion on North London line demands include for diversions, CTRL is
Outcome	Full system opened in 2007; its London terminus is the redeveloped St Pancras station.	A redeveloped King Cross station was formally opened in 2012, in time for the London Olympics.	This project did continue under both Railtrack and Network Rail. It is now known as the *Thameslink Programme* and is scheduled for completion in 2018.	

Appendix D Data description

This section contains descriptive tables of the data used in this dissertation. These data are not developed to be used in quantitative studies; these tables are intended to provide an overview of the qualitative data used and the frequency of codes applied and discussed in chapters 5 and 6[120].

Table D- 1 Types of action for development contained in the data

	Specific	General	Study	Indirect	Total		Specific	General	Study	Indirect
1990	184	12	21	11	228		81%	5%	9%	5%
1992	230	17	23	23	293		78%	6%	8%	8%
1992b[121]	230	17	23	16	286		80%	6%	8%	6%
1998	261	34	41	41	377		69%	9%	11%	11%
All	674	63	85	76	898		75%	7%	9%	8%

In the table above, the *action for development* data for the three samples reflecting pre privatisation development activity (1990, 1992 and 1992b) appear to be similar whilst the post-privatisation sample shows a different pattern. Using the percentage of *specific* codes, the probability of getting this difference in outcomes have been calculated[122] between both of the 1990 and 1992b samples and the 1998 sample. Z-values for the 1990/1998 and 1992b/1998 comparisons, with the null hypothesis that the percentages would be equal, are significant at p=0.01 whereas the 1990/1992b comparison is not significant at p=0.1 (p=0.93 to 2 d.p.).[123]

Table D- 2 1990 Sample: Coding Pattern

	Central	Local	BR/Local	BR	Private	Supply	NE	Reg. only	Total
Scale	2	20	5	8	4	0	10	0	49
Scope	0	2	0	1	0	0	2	0	5
Metro	2	18	2	0	0	0	4	0	26
Throughput	1	7	16	62	0	0	22	0	108
Other Core	0	0	0	4	0	0	0	0	5
NE	0	0	0	2	0	0	2	0	4
Indirect	5	0	0	6	0	0	0	0	11
Study	4	5	4	1	0	0	3	4	21
Total	14	52	27	85	4	0	43	4	228

[120]The percentages are generated using excel: although entries are rounded for display sums are done using the original numbers (this can lead to the appearance of inconsistencies in summing percentages).
[121]1992b gives the figures for the 1992 sample if the 7 entries coded *privatisation* are removed.
[122]A Z-value with p_1-p_2=0 as the null hypothesis is calculated (using a two-tailed Z-Test) and the p-value for each is found.
[123]Z-values are 3.1001 (1990/1998), 3.2553 (1992b/1998) and 0.03515 (1990/1992b) with p-values 0.0019, 0.0011 and 0.9362 respectively

Table D- 3 1990 Sample: Coding Pattern (Percentages)

	Central	Local	BR/Local	BR	Private	Supply	NE	Reg. only	Total
Scale	1%	9%	2%	4%	2%	0%	4%	0%	21%
Scope	0%	1%	0%	0%	0%	0%	1%	0%	2%
Metro	1%	8%	1%	0%	0%	0%	2%	0%	11%
Throughput	0%	3%	7%	27%	0%	0%	10%	0%	47%
Other Core	0%	0%	0%	2%	0%	0%	0%	0%	2%
NE	0%	0%	0%	1%	0%	0%	1%	0%	2%
Indirect	2%	0%	0%	3%	0%	0%	0%	0%	5%
Study	2%	2%	2%	0%	0%	0%	1%	2%	9%
Total	6%	23%	12%	37%	2%	0%	19%	2%	100%

Table D- 4 1992 Sample: Coding Pattern

	Central	Local	BR/Local	BR	Private	Supply	NE	Reg. only	Total
Scale	1	17	8	22	8	0	34	0	90
Scope	1	5	0	3	0	0	1	0	10
Metro	1	8	2	0	0	0	2	0	13
Throughput	2	8	19	67	0	0	32	0	128
Other Core	1	0	0	5	0	0	0	0	6
NE	0	0	0	0	0	0	0	0	0
Indirect	16	0	0	7	0	0	0	0	23
Study	0	9	4	5	1	0	0	4	23
Total	22	47	33	109	9	0	69	4	293

Table D- 5 1992 Sample: Coding Pattern (Percentages)

	Central	Local	BR/Local	BR	Private	Supply	NE	Reg. only	Total
Scale	0%	6%	3%	8%	3%	0%	12%	0%	31%
Scope	0%	2%	0%	1%	0%	0%	0%	0%	3%
Metro	0%	3%	1%	0%	0%	0%	1%	0%	4%
Throughput	1%	3%	6%	23%	0%	0%	11%	0%	44%
Other Core	0%	0%	0%	2%	0%	0%	0%	0%	2%
NE	0%	0%	0%	0%	0%	0%	0%	0%	0%
Indirect	5%	0%	0%	2%	0%	0%	0%	0%	8%
Study	0%	3%	1%	2%	0%	0%	0%	1%	8%
Total	8%	16%	11%	37%	3%	0%	24%	1%	100%

Table D- 6 1998 Sample: Coding Pattern

	Central	Local	Ind./Local	Industry	Private	Supply	NE	Reg. only	Total
Scale	2	17	6	32	3	0	23	0	83
Scope	1	0	0	9	0	0	3	0	13
Metro	1	11	0	1	0	0	1	0	14
Throughput	2	3	4	123	1	10	27	0	170
Other Core	1	0	0	12	0	0	0	0	13
NE	0	0	0	0	0	0	1	0	1
Indirect	11	0	0	26	0	1	2	2	42
Study	6	4	1	18	0	1	6	5	41
Total	24	35	11	221	4	12	63	7	377

Table D- 7 1998 Sample: Coding Pattern (Percentages)

	Central	Local	Ind./Local	Industry	Private	Supply	NE	Reg. only	Total
Scale	1%	5%	2%	8%	1%	0%	6%	0%	22%
Scope	0%	0%	0%	2%	0%	0%	1%	0%	3%
Metro	0%	3%	0%	0%	0%	0%	0%	0%	4%
Throughput	1%	1%	1%	33%	0%	3%	7%	0%	45%
Other Core	0%	0%	0%	3%	0%	0%	0%	0%	3%
NE	0%	0%	0%	0%	0%	0%	0%	0%	0%
Indirect	3%	0%	0%	7%	0%	0%	1%	1%	11%
Study	2%	1%	0%	5%	0%	0%	2%	1%	11%
Total	6%	9%	3%	59%	1%	3%	17%	2%	100%

Regulation activity involvement

Table D- 8 Frequency of regulating involvement (3 samples shown together: 1990, 1992 1998)

	Central			Local			Ind./Local			BR/Ind			Priv.	Sup.	NE			Reg. only			Total
Samples	90	92	98	90	92	98	90	92	98	90	92	98			90	92	98	90	92	98	
Scale	-			-			-			-	1	-	-	-	-			-			1
Scope	-	1	-	-			-			-			-	-	-			-			1
Metro	-			-			-			-			-	-	-			-			0
Throughput	-	-	1	-	1	-	-	1	-	4	11	7	-	-	-	1	-	-			26
Other Core	-			-			-			-			-	-	-			-			0
NE	-			-			-			1	-	-	-	-	-			-			1
Indirect	-	2	-	-			-			-	2	4	-	-	-			-	-	2	10
Study	-			-			-			-	-	1	-	-	-			4	4	5	14
Total	4			1			1			31			0	0	1			15			53

Appendix E Blueprint data

The table below gives some descriptive information on the *General* coded data across the three samples that are compared in section 6.3.3. As the 1990 and 1992 samples would be expected to show a similar sociotechnical regime in action and the two sample descriptions appear to be broadly consistent, the Pre-Privatisation column is the combined results for the 1990 and 1992 samples.

Table E- 1 Description of the blueprint development activity data

	1990	1992	Pre-Privatisation	1998	1998a[124]
Data	23	31	54	62	54
Percentage of original sample	10%	11%	10%	16%	14%
General	12	17	29	34	33
General/Specific	7	3	10	13	6
Study/General	4	11	15	15	15
BR/Industry[125]	17	19	36	53	45
Non-BR/Industry[126]	5	12	17	8	8
NE	1	0	1	1	1
Percentage of *General* sample with regulation or response	48%	52%	50%	11%	13%
Supply initiation	1 (4%)	0	1 (2%)	12 (19%)	11 (20%)

[124]This is an adjust sample for an alternative reverse salient representation considered in section 6.2.3; it groups all high output maintenance developments into one reverse salient coded as *general.*
[125]Includes *BR*, *Industry*, *Supply* and *Private* codes
[126]Includes *Central*, *Local*, *BR Local* and *Regulation* codes

Table E- 2 Changes to maintenance processes from the 1998 sample

	Changes to processes and co-ordination	**98/Ref**
1	Amey's proposed development of track recording train	94
2	Co-ordinating maintenance and renewal planning (Balfour Beatty & Railtrack)	102
3	New road/rail Land Rover (Balfour Beatty)	104
4	Simplification of written plans (Balfour Beatty)	106
5	Drive for increased safety (in track maintenance) (Balfour Beatty)	107
6	Inspection 2000: initiative aiming at automating track inspection (Balfour Beatty and Halcrow Transmark's Strategic Development Group)	146
7	Project simplifying crossings in use on network (using fewer models reduces lead times for replacing them)	148
8	Review of and changes to Ballast transport	152
9	Maintenance scheduling: 'Informed Traveller' initiative	153
10	Ultrasonic rail-flaw detection cart	179
11	Railtrack's track quality improvement programme	210
12	Trakat: vehicle for transporting maintenance crews with their equipment to site	341
13	GTRM's computer-based maintenance estimating system	365

Table E- 3 Changes to assets and operation aimed at reducing maintenance from 1998 sample

	Changes aimed at reducing maintenance	**98/Ref**
1	More reliable switches and track circuits	139
2	Steel sleepers to reduce in maintenance activities	141
3	Switch Actuating Mechanism (Balfour Beatty/FHL SAM): 'solution to meet railtrack's performance specifications for a new generation of low maintenance, high reliability switch and crossing systems'	147
4	New metallurgical make-up of crossings (to improve wear)	149
5	Approval for Swedish company's switch design: Ebiswitch (mechanised track maintenance can be done around it and uses a modular form for ease of maintenance)	212
6	Approval for Swedish company's interlocking design: Ebilock (involves remote trackside reporting and control)	213
7	Track-bed protection system (to increase life of the track, ballast and sleepers)	237
8	Ballast Bonding applied in Devon (to 'ensure greater longevity for the track formation…')	348

Appendix F 1998 *Local*; *Local/Private*; *Central/Local* & *Industry/Local*

In the figures in appendix D the *Central/Local* code is included in the *Central* Category. There is one *Central/Local* entry in this sample, accounting for the difference between the 47 entries here and the figures in appendix D. Table F- 1 shows a breakdown of the projects with local coding in the 1998 sample. Schemes found in the earlier samples and extensions to pre-existing light rail systems are filtered out first as they are continuations of developments initiated pre-privatisation. There are a series of entries that are funding bids; this appears to be a new feature of this sample and also to show a less concrete stage of project formation than had been represented before; so these too are removed.

Next, several projects that are relatively simple and often seen before developments are sorted out from the sample: new station projects; freight extension projects and regional strategy studies. The number of those projects that are in Scotland or Wales are given in brackets.

Table F- 1 Filtering out known types of development

Categories skimmed off (in order of the sections)	
Previously mentioned schemes & other Light Rail System extension schemes	16
Projects referred to in the form of funding bids	6
New stations	10 (8 projects in Scotland)
Freight facilities/Connections to them	3 (1 in Scotland)
Strategy studies	2 (1 in Scotland)
Remaining	10
Total	**47**

This leaves just 10 projects to investigate further; these are shown in Table F- 2, below. The developments in the three countries, England, Scotland and Wales, are shown separately because their Government-Railway interactions will have been different. Devolution is underway; there is evidence of Scottish Office and the Welsh Office involvement in the details of projects' initiation below.

These details on project set up also show a more complicated set of arrangements that tended to be seen in the earlier samples. Several of these projects have been initiated by the Industry but need local support; some of these, like Railtrack's looking for funding in two Welsh signalling upgrade projects, are relatively simple and are similar to BR's reaching out to local authorities; however, there are also complicated projects that need several players involved not just for funding but to get the project going.

Outside of Scotland and Wales there is very little evidence of railway system building activity from local authorities or PTEs in this sample (apart from through already initiated projects). It is possible that this is because of a change in reporting rather than in activity; however, there is no reason to believe

that is the case and former projects reported came from a variety of organisations (so one council's change in PR policy would not explain this change). Some points in the 1992 data, highlighted in chapter 5, also show disruption being noted by the incumbent local government actors. So, at least temporarily, the local system building part of railway system development has been cut back following privatisation and restructuring.

Table F- 2 Details of the remaining local projects (separated by Country: Wales, Scotland and England)

Project/Reverse Salient	Setting up the work	Code
Wales		
Feasibility Study into the re-opening of Ebbw Valley railway (#10)	Funded by Railtrack, the Welsh Development Agency, local authorities and an EU grant. Halcrow Transmark and Gwent Consultancy have been commissioned by local authorities.	Local
Signalling remodelling of Radyr & Pontypridd areas (#192)	Scheme was promoted by a local borough council and funding sources included local authorities, the Welsh Office, the EU and Railtrack.	Local
Signalling upgrade for Rymney Valley (#193)	Railtrack is considering this scheme; they say go-ahead would depend on partnership funding.	Ind/Local
Signalling upgrade for Vale of Glamorgan (#194)	Railtrack is considering this scheme; they say go-ahead would depend on partnership funding.	Ind/Local
Scotland		
Resignalling the approaches to Glasgow Queen Street (#37)	The work is Railtrack's response to ambitious plans being explored by ScotRail and Strathclyde Passenger Transport Executive	Ind/Local
Edinburgh Crossrail project (#287)	On 11 March the Scottish office announced a grant of £8million to the City of Edinburgh Council for the Crossrail project…; part of a £50m package for public transport services from the Scottish office…	Central/Local

England		
Proposed East-West Railway between Oxford & Cambridge (#45)	A TOC is working with the Franchising Director to evaluate the route; a consortium of local authorities is examining it in conjunction with consultants Steer Davies Gleave, Government regional offices, Railtrack and train operators; Transport Minister's officials and OPRAF are also discussing a business case with the LAs.	Industry/Local
Study of possible electrification Newark-Lincoln (#66)	Lincolnshire County Council has commissioned Steer Davies Gleave to make further studies of possible electrification between Newark & Lincoln; separate from Railtrack's studies on ECML capacity.	Local
Proposed re-opening of the old Grand Central route (#83)	Central Railway has launched a formal consultation process with local authorities on the old Great Central route with a view to resuscitating plans for reviving the line.	Ind/Local
Study on proposed reopening of Matlock-Buxton line (#271)	Railtrack, with Derbyshire County Council and its partners, is examining options to reopen the Matlock-Buxton line	Ind/Local

Appendix G Delay: finding its role throughout the 1998 sample

There is an entry in the 1998 data entitled 'train delay figures' (1998, #255); these are produced by Railtrack and are referred to several times throughout the sample. Table G- 1, below, shows references to the delay measures or to the influence of the performance attribute it represents (punctuality) within system development projects in the 1998 sample.

Table G- 1 References to delay and punctuality in development projects in the 1998 sample

Ref	Project	Influence of delay/measures of delay
25	Work to improve punctuality on ScotRail	Improvements to the punctuality performance of ScotRail are referred to as "a real team effort with Railtrack".
33	Work to reduce delays on the Midland mainline	Project to address delay performance in part of the network
119	RS: Punctuality problems – 'minutes attributable' to Railtrack	Work in Railtrack focused on this measure is referred to and the measure's reduction over the last few years is noted and further improvement anticipated.
180	RS: infrastructure reliability Great Western Zone	Refers to delay minutes as a performance measure demonstrating the effects of reliability problems.
192	Signalling remodelling of Radyr & Pontypridd areas	Intended improvements from the project include reliability and punctuality.
229	Woking resignalling project	Refers to a section causing delays to be altered
231	Remodelling at Euston	One of the project aims is to reduce delay.
241	Removal of permissive working at Cardiff Queen Street station	Dissenting voices consider the adverse effect of this change upon delay recovery.
309	Remodelling at Proof House Junction in Birmingham (WCML)	One of the project aims is to reduce train delays (by ~50%).

By way of control the same search was conducted within the 1992 data sample; the findings are shown in the table, below. It should be noted that punctuality was measured and was of importance under BR[127] however, these findings indicate that the explicit influence of this aspect of performance upon system development changed considerably between the 1992 and 1998 samples.

Table G- 2 References to delay and punctuality in development projects in the 1992 sample

Ref	Project	Influence of delay/measures of delay
50	Repair and track lowering for Arley Tunnel	Describes the work as improving journey times and punctuality because trains will no longer need to slow down for the tunnel.

[127]Published quality measures, including punctuality, are referred to throughout Gourvish's (2002) second history of BR.

Appendix H TOCs development activity

TOC initiated developments[128] from the 1998 sample are shown in the table below. The development activities have been sorted into four different types of infrastructure change: New stations/lines; Adjustments to allow service patterns; Adjustments to allow particular vehicles to use the infrastructure and changes to improve service performance.

Table H- 1 TOC initiated developments1 in 1998 sample

	TOC initiated developments[128] in 1998 sample
New stations/lines	• Proposed East-West Railway between Oxford & Cambridge (#45) (TOC and FD actively involved in collective project) • Proposed re-opening of the old Grand Central route. (#83) (Development proposed by an operator seeking to run open access services) • Proposed New Parkway stations near Edinburgh, Doncaster & the M25 Orbital on ECML (#222) • Feasibility study into the reinstatement of the full Edinburgh-Carlisle 'Waverley' route (#289) • Proposed reopening of Moor Street station (#352)
Adjustments to services[129]	• New depot at Soho, Birmingham (#26) • Line-speed improvements: Aberdeen-Inverness (#38) • Line-speed improvements: Inverness to Wick (#39) • Capacity upgrade of West London line (#47) • New Depot: Hoole Road in Chester (#161) • (Proposed) Kent link capacity project (including platform lengthening & strengthening of the electricity supply (#264) • East coast capacity: upgrading low-speed junctions (#266) • New servicing depot: Eastcroft (allows a new service) (#293) • RS: power supply restricting capacity on ECML at peak times (#318) • Infrastructure changes to support the Cross Country franchise (#328) • (Proposed) linespeed improvements between Barking and Upminster (#350) • Linespeed reduction Shenfield-Liverpools St (#366)

[128]Includes joint work with Railtrack but excludes the unusual cross industry project: Proposed East-West Railway between Oxford & Cambridge (1998, #45).

[129]These changes allow certain service patterns to be introduced; advances include reducing journey times,

Adjustments for vehicles	• Study of Victoria approaches to adjust for 23m trains (#63) • Negotiation over structure gauge and new trains (#298) (Problems due to mismatch between vehicle and infrastructure kinetic envelope) • Getting Juniper Trains into service on South West Trains services. (e.g. signal adjustments at Reading station) (#315)
Development focused on performance	• Chiltern Railways joint programme with Railtrack & LU to improve infrastructure reliability (#19) • RS Ride quality (on Midland Mainline) (#24) • Work to improve punctuality on ScotRail (#25) • Speed review for some rural routes of Central Trains (#32) • Work to reduce delays on Midland Mainline (#33)

enabling additional services.

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