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Technology and Organisation: finding 'fit' in a mature system

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Abstract

This paper considers the role of technology in enabling and constraining the organisational forms that interact with it. It focuses on the setting of Large Technical Systems and introduces a case of a mature system which had its organisational structure transformed. In research on complex/hierarchical systems, the link between organisation and technology has centred around the 'mirroring hypothesis'. This paper characterises this connection as 'design fit' and considers it alongside the 'operational fit' introduced by Joan Woodward (1958). It is argued that in the case of Large Technical Systems there is a connection between these two types of fit which is more complex than the output of the design network being the source of technology change of the operating system; this is linked to the issue of legacy which is identified as an important distinction between an isolated system and one which forms an adjustment to a system of systems. The industry case illustrates the complexity of both the adjustments made around introduced organisational interfaces and the link between the two types of fit considered in this paper.

Technology and Organisation: finding 'fit' in a mature system

Introduction

Different industrial structures suit different industries at different times (Jacobides & Winter, 2005; Robertson & Langlois, 1995). In considering why a particular industry should take one form while other industries look very different, this paper considers the role of technology in shaping or constraining an industry's structure. A systems view, following research on Large Technical Systems (Hughes, 1987) and Complex Products and Systems (Hobday, 1998; Rosenberg, 1982b) of an industry/value network is taken.

In research on complex/hierarchical systems, the link between organisation and technology has centred around the 'mirroring hypothesis'. Although later work has retained these ideas (Baldwin, 2008) there has also been research which suggests that this relationship between technology and organisation is more complicated and, in particular, that organisational knowledge does not always adhere to this mirroring (Brusoni, Prencipe, & Pavitt, 2001; Hoetker, 2006). This paper considers mirroring in LTS and highlights the importance of legacy in this relationship. The idea of mirroring in the modularity literature is characterised as 'design fit' and considered alongside 'operational fit' introduced by Joan Woodward (1958). It is argued that in the case of Large Technical Systems legacy creates a connection between these two types of fit which is more complex than the output of the design network being the source of technology change of the operating system.

A case study is introduced of the UK railway industry following reorganisation; this is an industry characterised by a mature complex technological system. The transformation of its organisational system is described and it is studied in the years immediately following this reform. Archival data from industry press has been used to identify developments around operational and design fit following the industry's privatisation. These show the complexity of the adjustments made around introduced organisational interfaces; there are simultaneous organisational and technological changes. The case also illustrates the complexity of the link between the two types of fit considered in this paper.

Background

The 'fit' between organisation and technology has long been a theme of interest for academics in the management field. A key piece of work in this vein, which considers organisation and technology fit at the level of the firm, is Joan Woodward's 1958 report. This work finds a manufacturing organisation's structure reflects the flows of information and the decisions needed to interact with its production system. It considers the co-ordination and information flow requirements for the human elements of operating a technological system.

Moving beyond the level of the firm, and thus towards a systems view, the mirroring hypothesis from modularity theory uses a similar view of the link between organisation (or group of organisations) and product. It proposes a reflection between the structure of a product and the organisational system that develops it because of the relationship between the complexity of connections between subsystems and the amount (and nature) of communication needed in the designing organisation. Notably this moves the link between organisation and physical object to the second order consideration of 'design fit', as opposed to the 'operating fit' studied by Woodward (1958).

In the case introduced in this paper, the UK railway system, the organisations of the industry deal with both the operation of the system and the design of the system; the nationalised organisation, British Rail, carried out both functions. We propose that in Large Technical Systems (Hughes, 1983) both design and operation interactions with the physical system are relevant. In addition, because design is being used to adapt an existing system, there are times when they need to be considered together.

Within this notion of 'fit', the organisational element includes the location and nature of organisational boundaries. There is a stream of research which follows Coase's (1937) question of why do firms exist and what drives the location of their boundaries¹. This literature has developed to combine the Transaction Cost Economics and Knowledge Based theories of the firm. Although it has been noted that organisations sometimes change their boundaries without significant technology changes within the processes/products they deal with (Jacobides, 2005), there is work within this tradition which considers the connections between the content of the value chain/production network (the form being produced and the methods of production) and the locations of transactions between organisations. Modularity theory has been used as a basis for considering the emergence of transactions within the production networks for complex products or systems (e.g. Baldwin, 2008; Langlois, 2006). A key point of connection between modularity and this broader stream of literature is the mirroring hypothesis (Henderson & Clark, 1990; Sanchez & Mahoney, 1996; Colfer, 2007). This is discussed further below and this is the theoretical stream that we start with in this paper in order to consider fit and the behaviour of a mature system transformed.

This paper follows Langlois (2003) in expecting organisations and technology to co-evolve and although this work will focus on the role of technology in this relationship it seeks to avoid either a technology deterministic view or ideas that technology is completely manipulable. We take the view that

¹ Langlois (2006) argues that Williamson's work on Transaction Costs, which also follows Coase (1937) takes a different view of transactions (focusing on opportunism rather than what Baldwin (2008) and Langlois (2006) refer to as mundane transaction costs).

organisation and technology can reinforce or constrain each other and seek to examine what happens when one of these is released from their mutual adaptation/fit.

Modularity and mirroring

The tradition of modularity theory, built on ideas of hierarchy (Simon, 1962) and information hiding, (Parnas, 1972), focuses on the advantages to organisations of dividing complex systems so that they have low, and clearly defined, dependencies between subsystems. Baldwin and Clark (2000) identify the basis of modularity as: modules being units that work together within a larger system despite being structurally independent of one another. This field of research focuses on the level of the firm and/or that of the system. In this discussion we focus principally upon work that takes a systems view. It is important to note that the empirical case to be studied in this paper is more likely to be categorised as a system of systems; although simply another point within the hierarchy, there are some important differences between these settings that have been reflected in the theory discussed below.

The idea of mirroring between developing organisation and product designed was introduced in Henderson and Clark's (1990) work on architectural innovation. Henderson and Clark argue that where there is an established product architecture the definitions of workgroups, the communication channels and information filters as well as the set of problems solving routines commonly drawn upon in design are focused for efficient design of the existing architecture; this means that redundant communication channels, information inputs and problem solving approaches are removed. This represents certain interdependencies between components that need to be addressed in the design process as embedded in the organisational routines over time.

Later work uses ideas from modularity literature to address this mirroring and highlights the need to make interdependencies between components/modules explicit as a way of managing the co-ordination of the development of hierarchical systems. Sanchez and Mahoney (1996) introduced the idea of a mirroring between organisational and product structures being extended across organisational boundaries (Colfer, 2007). Sanchez and Mahoney (1996) suggest that, "... although organizations ostensibly design products, it can also be argued that *products design organizations*, because the coordination tasks implicit in specific product designs largely determine the feasible organization designs for developing and producing those products." (Sanchez & Mahoney, 1996; p64). So they highlight that the design of an organisation is constrained by the options it has for the shape of the product it develops, because of patterns of co-ordination, and, as a result, they promote *modularity in product designs* as "an important strategy for achieving *modularity in organization designs*" (Sanchez & Mahoney, 1996; p64).

In their theory work setting up the introduction of ideas of modularity to aid the co-ordination of design, Baldwin and Clark (2000) operationalise the mirroring between developing organisation and product form using a detailed examination of the design process. Relevant design parameters, to the market (and environment), are selected; in order to create a design (a description of the artefact) from these parameters a task structure is worked out: a list of tasks required, precedence relationships between tasks and assignment of tasks to those (people, machines or both) that will conduct the task. It is argued that to be effective the task structure should be an image of the design structure. The co-ordination

required within the designing organisational form, it is assumed, will need to fit the microstructure of the design tasks it needs to carry out. And so the form of artefact is linked to the organisational structure that develops it.

The argument that comes through in the literature is that module boundaries provide points of simplified co-ordination within the production (and development) network of a product/system. It is a 'natural' place for transactions to divide labour (of production and/or of design) between organisations and for the market to co-ordinate developments: the invisible hand. Modularity has been characterised as an alternative to complex interfirm interactions where opportunistic transaction costs are kept at bay by relational interactions/contracting (see for example Sturgeon, 2002; Powell, 1990); Sturgeon (2002) even goes so far as to identify the Modular Production Network as a governance transformation spreading through the economic system.

Focusing on mundane transaction costs Baldwin (2008) identifies three basic elements of a transfer which are needed to make 'common ground' to support a transaction: definition, counting and compensation. There are costs to carrying out these activities and Baldwin argues that costs will vary at different points in the task network. She argues that at the thin crossing points present at module boundaries, created by information hiding, where lower levels of transfer of material, energy and information are required will be points of lower mundane transaction costs. Following Jacobides & Winter (2005), who emphasise the ability of firms to adjust their capabilities and the transaction costs they work with, Baldwin (2008) makes a key step in the understanding of the product/organisation relationship in an industry's task network. She highlights the potential to move beyond fitting the appropriate transaction set up to the 'natural' dependencies at a given location of organisational interface and for firms to alter the location of thin-crossing points within the task network, by rearranging interdependencies using 'the method of design rules' (p177).

Within this work 'knowledge' and 'technology' are often not clearly placed. A knowledge base is present within ideas of design and co-ordination of knowledge and information within the design process is what is to be managed by information hiding in order to allow the division of labour. A distinction between division of labour and division of knowledge is an important element within this discussion; Colfer (2007) describes these two layers as 'how the work gets done' (p6) and characterises them as responding to the technical dependencies among development tasks and among the information/skill sets required to perform those tasks, respectively.

As highlighted by Baldwin (2008) and Colfer (2007), empirically ideas on mirroring between organisation and product have received mixed support (see for example Hoetker, 2006; Brusoni, Prencipe & Pavitt, 2001). As demonstrated by Brusoni, Prencipe and Pavitt (2001) this distinction between division of labour and division of knowledge is significant to these mixed findings. In a study of aircraft engine control systems Brusoni, Prencipe and Pavitt (2001) find that organisations often 'know more than they make'. They argue that mirroring between division of knowledge and the division of labour and product structure breaks down where a product has unknown interdependencies and/or where the interdependencies within a product are changing quickly. In order to cope with either one of these circumstances, they argue, a production network will be overseen by a systems integrator organisation

which will hold knowledge on the architecture of the product even though it may subcontract manufacture and design of subsystems. To cope with both circumstances vertically integrated development will be required. Baldwin (2008) and Baldwin & Clark (2000) also specify the need for interdependencies to be known for modularisation to take place.

The system of systems this paper will go on to study can be characterised as a large technical system (LTS) (Hughes, 1983; 1987). This view of a technological system can cope with both known and unknown interdependencies. Hughes (1987) defines the scope of a system as those elements under the control of the system builders and where an element does not interact with the system but is only influenced by or influences the system then it is considered part of the environment. Both human operations (Joerges, 1988) and organisations (Hughes, 1987) can be included within the system this is something we draw upon in the next section where we build our definition of technology.

Model of Technology

The literature on changes in organisational interfaces and governance structures of production networks introduces ideas on modularity as a way of considering the technology a value chain deals with. However, in both streams, what is meant by ‘technology’ is often left undiscussed.

Responding to a broader stream of literature which deals with technology as knowledge (see for example Dosi, 1982²); this paper begins with a working definition of the technology of a product or process as the means by which it achieves its output: how something is delivered.³ For a manufacturing process it is the means of shaping the relevant material; in theory two different process technologies could produce identical components. By considering the mirroring hypothesis we focus on the technology of products and attempt to hold to the same definition. Baldwin and Clark’s (2000) view of a design includes both its structure and its function; it is the structure of the design, how functions (deliberate and otherwise) are to be met, that we take as the product’s technology.⁴ We acknowledge the close relationship between product technology and function but consider them analytically distinct.

Clearly, the working definition discussed above encompasses more than, the sometimes used definition of, technology as ‘hardware’ (Rosenberg, 1982a; see for example Orlikowski, 1994). In this paper we divide this broad definition of technology into three elements involved in meeting function: knowledge base, physical system and human processes.

² Dosi (1982) defines technology as “a set of pieces of knowledge, both directly “practical” and “theoretical” know-how, methods, procedures, experience of successes and failures and also, of course, physical devices and equipment” (Dosi, 1982). Technology as the knowledge allowing the use of material or a new production process allows experience and experimentally derived knowledge to be included in the technological base used by designers. It is also possible to include non-explicit knowledge present in the skill of working with the potter’s wheel, for example (Baldwin & Clark, 2000).

³ This view of technology is compatible with that taken by Hughes (1987) of technology as problem-solving; he goes on to include the idea that the solution may emerge prior to problem identification.

⁴ This engineering definition fits well with the approach taken by Baldwin and Clark (2000), however it does have its disadvantages; not least the complicated and institutional nature of the notion of ‘function’. We recognise that the definition of function, as an engineer sees it, and ideas of value within and beyond that are complex issues in their own right. The institutional basis of ‘function’ is something we chose not to unpack here; however we do take the view that value is not only felt within how well a product meets its ‘function’.

We note that the process of how something is achieved is not all present within the physical elements of a system. Often an artefact can only enact its function through interaction with our human system. However, we consider the qualitative distinction between human/organisational processes interacting with a physical system and that hardware itself as an important one for technology and organisational fit. The skill of folding pieces of paper manually is just as much a technology of producing folded paper as is an alternative physical machine for folding paper, and even the latter approach is likely to involve human processes for loading the machine with paper and plugging it in.

Another element within the broad definition of technology, is the knowledge which allows a physical product to be created. As mentioned above, the view of technology as knowledge is common as the full definition for technology within the evolutionary tradition present in the innovation literature (see for example, Dosi, 1982). This view would identify knowledge as the important organisational factor behind a physical system and would depict both that physical system and the organisational routines employed to operate it as an embodiment of selected pieces of knowledge held and/or generated at the organisational level. To a great degree the author holds to this view of technology as knowledge; however it is worth noting that Dosi's work (1982) is concerned with the advance of the technological frontier whereas this paper is focused on a more local and product centric frontier where designers take developed technological ideas and fit them together to meet the functions anticipated as important (or perhaps demanded by a customer). There may be several alternative ways of accomplishing a desired outcome but only one can be placed into the product; and it is this structure⁵ and the distinction between knowledge base and knowledge embodied in a physical system that is highlighted as significant in this paper.

The use of this more product-centric view is important here as time becomes a factor in dealing with these systems; the knowledge base employed in designing a product is unlikely to be the same as that being used to operate it or to update it several decades later. Therefore it needs to be acknowledged that the knowledge present/represented in a technological system is not all of the same nature and different sections of this knowledge will need to be dealt with in different ways.

This leaves us with a view of the technology of a product being formed from a body of knowledge which is drawn on to achieve a design/blueprint for a physical system (an embodiment of a selected knowledge base) and the human processes that interact with that product to allow it to meet a function. This model of technology is represented in Table 1.

⁵ The knowledge it was based on may also be useful and is likely to be held onto by an organisation but it is not held by the product, this only gives us the signposts. If the understanding of a section of a system is revisited by different people at a later date the knowledge used may take a different form (even if it is only in the personal skill of the operator).

Table 1 Representation of 'Technology' and 'Function' as modelled in this paper.

Technology			Function
Knowledge base	Physical 'hardware'	Human processes	
The abstract, explicit knowledge and the tacit know-how used to arrive at a product design	The form of a physical product /system; it is the embodiment of knowledge which was held by organisations and /or individuals	The routines/processes in place for human elements of a system to interact with a physical product. These also draw on knowledge held by organisations and/or individuals.	The 'what' that is achieved. It is not unexpected that precise function will change with its matching technology between generations of products ⁶

Technology and operationalisation of mirroring

Baldwin & Clark (2000) develop a model of the design process in order to operationalise the mirroring between a designing organisation and the product it develops⁷. This section discusses how the view of technology introduced in the previous section of this paper fits with this operationalisation.

In this model the designer(s) match together a knowledge base to a function for the product through a design (complete description) of an artefact. Baldwin and Clark's (2000) representation of the design process shows the selection and use of relevant knowledge as the definition of a point (the design) within a landscape (or N dimensional space). In their formalisation of the design process, a list of parameters of interest are generated, different values can be selected for each parameter (e.g. colour: red, height:22cm). These parameters (and the bounds of values possible) define the search space for the design; a complete description of an artefact will have values for all these parameters and will therefore be a point within the search space. A designer needs to navigate the connections between parameter value (and definition) and product functionality and between that and value (defined as to society rather than market valuation). In order to visualise this process Baldwin and Clark (2000) use the idea of a landscape to show interdependencies between the values of design parameters and their combined effect on value⁸.

Knowledge base and physical 'hardware'

The distinction between knowledge base and physical product made in the view of technology presented above is reflected in this operationalisation of the mirroring hypothesis. The knowledge base resides within the organisational sphere and its structure (as held within the organisation) is a reflection of the knowledge embodied in the design developed. Although in any pairing of product at launch with designing organisation one would expect their structures to match, the operationalisation developed by Baldwin and Clark (2000) indicates that these are separate sets of knowledge. This implies that there is a

⁶ This draws on a point clearly articulated by Rosenberg (1982a, p3) that the role of technological progress is not solely about producing the same effects at lower cost but also encompasses the production of better effects.

⁷ It is important to note that this is a theoretical base developed without considering the ideas of modularity which are later introduced.

⁸ This is a representation used elsewhere, see for example Levinthal (1997) for its use with organisational attributes or Flemming & Sorenson (2004) for a technology based use.

potential for this match to be removed over time, the embodied knowledge in the product, becoming a frozen snapshot of reflecting the structure of knowledge in the organisation at the point of product launch; one would expect a knowledge base of an organisation to change from product generation to generation or, indeed, simply over time so that even if it were to adapt its own product years later the match may no longer exist.

Highlighting this distinction between technology available, the knowledge base drawn on by an organisation to develop a product, and that imprinted into the product should aid our understanding of the role the division of knowledge layer within views of mirroring. As discussed in the literature review the mirroring of knowledge as well as organisation and product has proved an area of contention in recent years. The view emphasised here, separating knowledge held by the organisation and that embodied in the product within the term 'technology', fits with the work of Brusoni, Prencipe and Pavitt (2001).

Human processes and function

Baldwin & Clark's (2000) model places the human processes element of the view of technology developed above into the function of a product. If one focuses on the level of the system, as modularity theory does, this is a sensible placement. However, this assumes that the use of a product can be separated from the decision process about that product's form, something that is often done using a specification to encompass how a product will be used or it could be done by building the human processes for how a product is to be used only after the physical object is produced. In the case that this paper goes on to consider, a large technical system, these assumptions are less likely to hold.

System of Systems

As discussed above, research on modularity and the mirroring hypothesis takes a systems level (or lower level) view rather than the system of systems view that is needed to consider the kind of empirical setting this paper introduces. There are two key factors of difference between these two levels analysis. The first of these is complexity. The author takes the view that this does not provide a qualitative difference between the two settings and that the vertical relationship between system and system of systems is not qualitatively different from that of subsystem to system it is simply at a different vertical connection within the hierarchy (Simon, 1962). In the context of design, this means that we expect the model developed by Baldwin & Clark (2000) to hold in both settings, it is simply that the task matrix will be larger and the expected connections to be addressed by the designers more numerous; more resources will be required for developing a system of systems than a lone system.

The second factor is legacy; this is expected to have an effect. The analysis conducted above helps consider this in more detail; the inclusion of human processes within technology rather than function is important here. As a result of the lifetime of large technical systems, the role of design is often to update part of the existing system. This means that, even though the designer's role is unchanged and will work in the same way as described by Baldwin & Clark (2000), there is an additional constraint on the process in the form of the influence of the existing system. If we focus upon the development of a new/replacement physical part of the system, this influence can take two forms: the fit between existing

and new elements of the physical system and the fit between the human processes of the existing system and the new physical part.

Dealing with legacy

If we treat the section of the large technical system being redesigned as a hierarchical system within the system of systems, there are two options for separating the new system from its setting. The first uses time: the new system could be designed and then the larger system will adapt to it. This is easily imagined for fitting design and practice (particularly the latter) held within the broader system to the new physical product. For example, this is common in the world of consumer products. However in the case of a system, where routinised interaction with a physical element of it is required, this approach is unlikely to provide easy solutions in both physical and human technology.

The second approach to dealing with the interaction between new and existing system is that used in the production of hierarchical products (e.g. Baldwin & Clark, 2000): the articulation of the requirements of human processes and existing physical structure's interaction with the new system through specification. This involves trying to isolate the new physical element from the existing physical system and from the existing human processes; it requires the large technical system to be divided into separate elements for which the characteristics of their interaction at the interfaces can be articulated: i.e. the introduction of modularity and the deliberate introduction of design rules at the system of systems level (Baldwin & Clark, 2000; Brusoni & Prencipe, 2006). If these separations cannot be achieved the design would need to be prepared to alter everything at once and so we enter the world of integrated solutions (Davies, 2004).

These two different kinds of separation, through time and through specification, can be elaborated through models of system development, Hughes's (1987) concept of reverse salient and Rosenberg's (1969) of focusing device. The use of time described above is the method expected in these models of an advancing frontier; one thing changes its performance and another element has to be adjusted to meet it (the close interaction between these elements is represented by the idea of a continuous line; this is expected to be a trial and error development. The modularisation of a system represents a discretisation of the frontier, with the points of interaction between segments clearly articulated in design rules; perhaps this enables more determined changes in performance within each module at one time.

Neither of these options appear entirely satisfactory for significant modifications to an existing integrated system. The literature does provide an alternative option, that of a systems integration approach which is closely linked to integrated solutions briefly introduced above. A good example of this integration in practice is Rosenberg's (1982b) learning by using example of the design of an aeroplane's fuselage. Here it is anticipated that the maintenance practice will adapt after the introduction of a new aircraft; scientific/articulable understanding of the relationship between design and maintenance requirements do not exist and so a trial and error development process in maintenance practice is required. These improvements in maintenance should in turn allow product adaptations, specifically the introduction of longer fuselage allowing better functionality (in terms of cost of operation per passenger) from the aeroplane. Rosenberg (1982b) tells of this relationship being anticipated and

fuselage extension was incorporated into the design of the original product to enable this transition without full redesign. However there is a downside to this approach for the industry we are about to consider: it is expected to require integration of knowledge within a systems integrator organisation, even if the labour of designing and producing the different elements is separated between supplier organisations; this umbrella organisation was not present in the organisational system produced at privatisation.

These considerations indicate a connection between operational system and the technology developed for the system which is more complicated than simply the output of the design work being an input to the technology of the operational system.

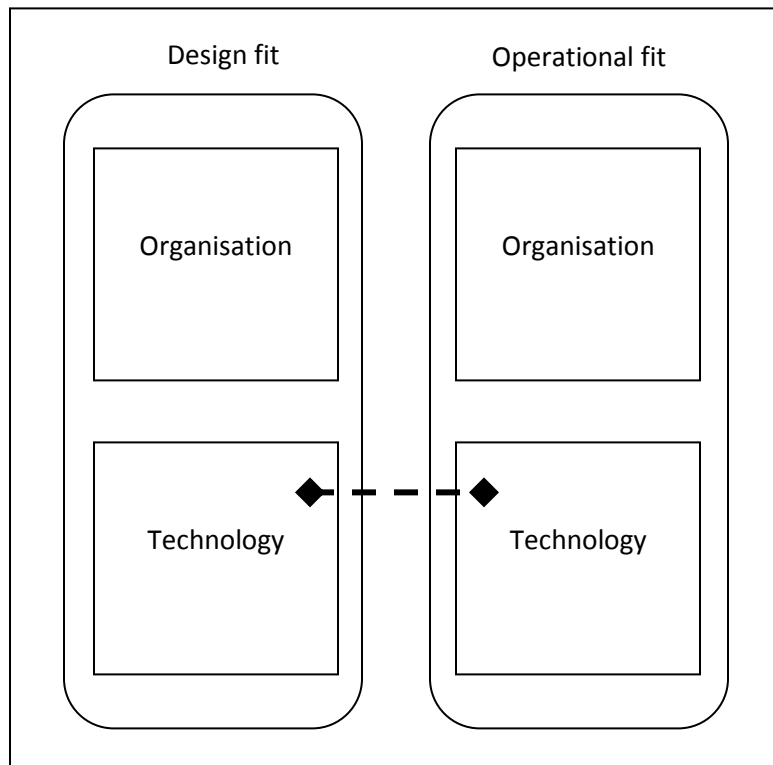


Figure 1 'Design fit' and 'Operational fit' connected by legacy in LTS

Figure 1 builds a representation of the issues discussed on fit between organisation and technology. It shows a distinction between the 'design fit' (discussed by the mirroring hypothesis) and 'operational fit' introduced by Woodward (1958) and it then divides changes towards fit from organisation and from technology. A connection between the technology of the two systems is also represented; as discussed above, for the case of adapting LTS this link becomes difficult to articulate/specify and the issue of legacy creates a more complex connection between technology output from the design world to that of the operational world. Both this framework and the model of technology set out above (Table 1) are used in the analysis of the case in the next section.

The case: the UK railway system

In this section we introduce a case study of a system which has seen major organisational change whilst retaining its physical system. We argue that transformation of the organisational structure operating the physical system will alter the function expected from the system which in turn will drive changes in the technology of the system. In addition the transformation of the organisational structure which develops the physical system alters the locations and forms of the knowledge bases interacting with the physical system through design.

The railway system was built by engineers and entrepreneurs through trial and error. Like the photolithography machine producers studied by Henderson and Clark (1990), the operation and development of the railway system has long been based on experience, rules of thumb and organisational procedures of inspection. Although it is clearly a multicomponent hierarchical system, many of its system and subsystem interfaces are not compliant with modularity as Baldwin and Clark (2000) define it; interdependencies are not always known and understood and design rules have not always been consciously constructed. The restructuring of the industry at privatisation (1993-1997) divided the integrated developer/operator, British Rail, into a disintegrated network with activities newly divided by market transactions. This study draws on industry specialist media from the time to follow changes in organisation and technology immediately after the completion of privatisation in 1997 ; it discusses the loss of 'fit' and examples of change which correspond to connections shown in Figure 1.

Background

In 1948 the UK railway industry was brought into public ownership (p182, Allen, 1982) with British Rail being formed in 1962 (p2, Gourvish 2002). British Rail presided over considerable technological development of the railway network as well as its rationalisation (particularly the Beeching cuts, 1963) (Allen, 1982).

Between 1993 and 1997 (Gourvish, 2008) British Rail was restructured and privatised to form a competitive market for the provision of railway services and, therefore, the development of the railway system. The Government's motivation for introducing competition has been linked to anticipated European legislation (Nash, 2008), reducing state subsidy of the industry (p63-64, Harris & Godward) and a political commitment to the power of the markets and transactions (Glaister 2004; Tyrrall, 2004). The operation and production network was reconfigured, with attention paid to existing technological architecture; it has been vertically, and in places horizontally, disintegrated to provide a new structure for the industry. Since privatisation there have been further changes in the industry's structure, both organic and imposed.

Privatisation

Between 1962 and 1989 British Rail owned the full physical system of the railway: infrastructure, vehicles, workshops - the lot. However, although overall ownership was consistent, the internal structure of British Rail was rearranged within its 30 year tenure, in some cases dramatically⁹. In 1989 British Rail Engineering Limited (BREL), which manufactured and conducted the heavy maintenance of passenger railway vehicles, was sold in 1989 to a conglomerate of private organisations forming BREL Ltd (p246, Gourvish, 2002); it is now owned by Bombardier. This meant a major component of the development of the physical system became organisationally separate from the system, day to day maintenance of the system and its operation. Between 1994 and 1997 the rest of British Rail was divided up.

The Railways Act introduced the privatisation process in 1993 but the privatisation of the organisational units that make up the industry was only completed in 1997 (p1-3, Gourvish 2008). 25 regional vehicle franchises were created for the operation of rail services¹⁰ to be run by Train Operating Companies (TOCs). Three Rolling Stock Companies (ROSCOs) were established as entities to own and lease the rolling stock. Railway infrastructure management was also privatised, although into a single supervising organisation, Railtrack; it began trading in April of 1994 (p84, Harris & Godward 1997). These organisations form the core of owners and users of the new railway industry but they are supported by a range of regulators and suppliers. A representation of the organisation of the Rail Industry immediately after privatisation is shown in Figure 2.

⁹ After Dr Beeching's 1963 reshaping plan, 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 (Gourvish, 1990); weakening of the regional structure followed and the functional structure remained in place. In the early 1990s another reorganisation was initiated, it came to be known as 'Organising for Quality' (p374-383, Gourvish, 2002). This involved the final elimination of the regional level structure, an alteration in the sector/functional structure and the ownership of operational of assets by the sector level businesses (p374-383, Gourvish 2002). Gourvish (p390, 2002) also highlights that this move reinforced the vertical integration between infrastructure and operations which was about to be threatened.

¹⁰ Several open access operators (those operating without a franchise) were also created e.g. Heathrow Express (p83, Harris & Godward, 1997).

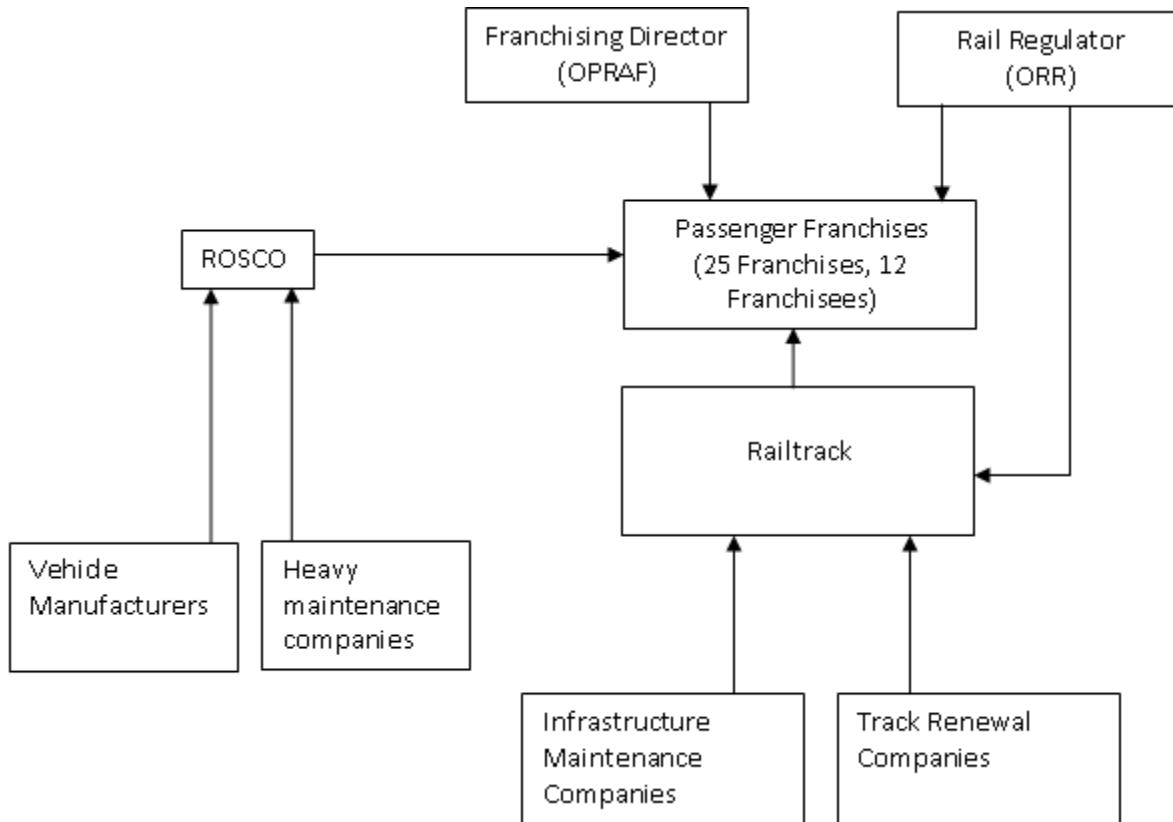


Figure 2 Industry structure in 1997¹¹

The disintegration of British Rail creates two streams of alteration to the technology and function of the system. There are changes in the network of organisations that operates the railway system, this has an effect on the function this system is to serve; at the very least this function has been segmented to include the profit generated for each type of organisation within operating network. In addition there is a separation of organisations involved in the development of the physical system; this alters the location and form of the knowledge bases which will interact with the physical system through design. This means that the organisational transformation of this industry will affect both the ‘design fit’ for the development organisations and the ‘operational fit’ for the operating organisations. Figure 3 illustrates this view of the transformation of the industry, in terms of the model of technology and function discussed earlier in the paper.

Figure 2 shows clearly a series of changes in the operational side of the industry. However the changes in the design side of the industry are less well developed here. Knowledge bases which were all held within British Rail become divided into a series of different organisations. Not shown in Figure 2 are the Technical Service Companies (TESCOs), formed from British Rail’s engineering divisions; these are railway specialised engineering consultants. At its creation Railtrack was envisaged as an engineering

¹¹ Adapted from Figure 1.1, p2, Gourvish (2008).

free organisation (p402, Gourvish 2002). This means projects, including R&D, need to be specified and purchased.

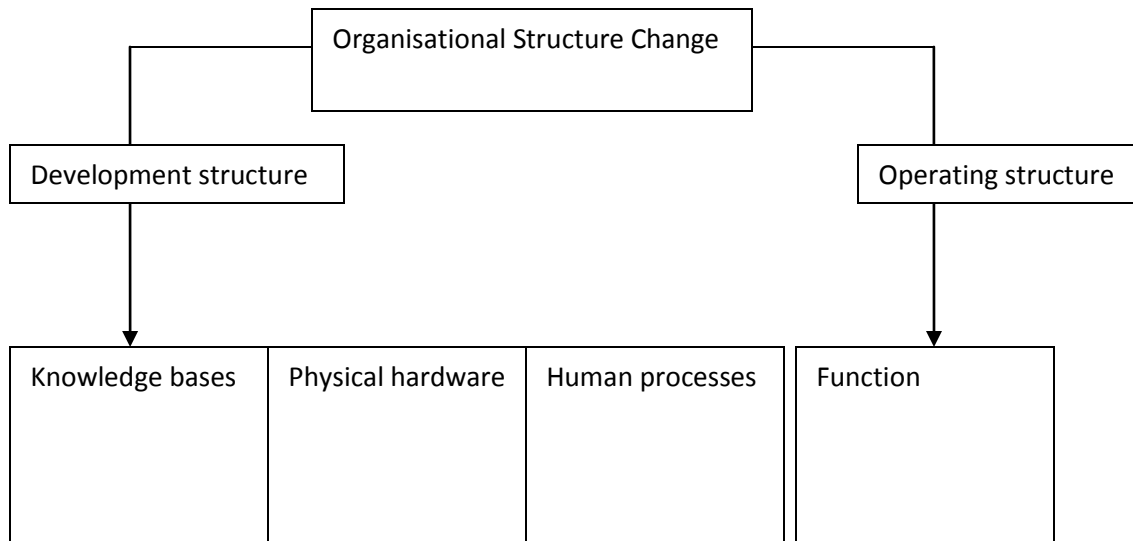


Figure 3 Organisational transformation: link to technology

The procurement of rail vehicles also became a more complicated process. The TOCs and ROSCOs cooperate for the procurement of new trains, they specify a vehicle from a vehicle manufacturer¹². The vehicle manufacturers are systems integrator firms that produce key components in house and manage a substantial supply network for more standard components; these organisations have changed their capabilities significantly since the sale of BREL and they have become increasingly international in outlook. In development, the interaction of the vehicle’s parameters with existing infrastructure, the intended operation requirements and the desired service regime, not to mention a certain degree of future proofing, are required by the asset owners.

What happened next: 1997-1999

Methodology

We have used media analysis to examine events following the completion of privatisation in 1997 to the end of 1999, when a new railways bill was introduced to further adjust the governance arrangement¹³. An industry specialist publication, “Modern Railways”, was used to identify changes in organisational structure¹⁴ and publicised technological developments¹⁵. The publication has a report on industry news and a specialist engineering column which were the core points of search, however main articles were

¹² Selected through a tendering process based on principal requirements.

¹³ It is also of note in this period that there was a new Government elected at the start of May, 1997; they had been very critical of the privatisation process and they introduced the white paper in 1999.

¹⁴ This was constrained to changes in organisational boundaries (acquisitions, mergers etc.) that were publicised and any mention of changes in operating procedure that were novel (For example, changes such as moving maintenance from depot A to depot B were excluded, not just for reasons of sanity, but reconfigurations of maintenance procedures featured were recorded.)

¹⁵ This was defined as new artefacts or systems being introduced that could be applied across the rail network (i.e. excluding one off civil-engineering projects but not where something was highlighted as being applicable elsewhere or the spread of existing approaches; this was for purposes of simplicity and repeatability).

also checked where the title fitted subject requirements. Changes in physical technology and changes in organisational arrangements which were featured in the publication were recorded¹⁶.

From this series of organisational and technological changes the author has selected several series of events around themes of interest for the framework shown in Figure 1; these are presented below. These data on industry changes are supplemented by a series of interviews conducted with industry technology managers and engineers in 2007 and 2008. The focus of these interviews was to understand how the many types of organisation created in privatisation operated and interacted with one another. The records¹⁷ of several interviews feature explanations of events and how the industry has developed over time. They provide both verification of events and views from inside organisations.¹⁸

Three sets of developments are identified; the first two focus on changes relevant to fit on the operational and development sides of the industry. The third focuses on a connection between these two sides of the system.

Operational fit

We focus our attention first upon developments in the operational system. Developments around Railtrack's contracting with the BRIS appear to show points of both organisational adaptation and technological change in order to create a functioning interface between these newly vertically separated parts of the value chain.

Reference is made to Railtrack introducing a series of extended 'arms length' contracts and to it replacing its original contracting arrangement with former BRIS maintenance units, which were in place when they were sold. These new contracts reflect Railtrack's intention to pass on as greater responsibility for infrastructure maintenance as possible.¹⁹ When the preferred bidder for the Scotland area, announced later that year, a spokesperson refers to the new type of contract as a strategic alliance and indicates that their introduction was to avoid adversarial relationships and incentive clash in contracts. This remark indicates that there are differences in the ideas of function for Railtrack and its suppliers and that this leads to a change in organisational boundary in order to provide a consistent view of function.

It is worth noting that in broader institutional developments over this period, Railtrack began to be criticised for its monitoring of contractor performance, the privatisation left the infrastructure owner with the role of guarantor of safety. This is raised in the publication and is referred to by Gourvish (2002) in the context of a new Government's comments on the new system and movements by their

¹⁶ This approach is not dissimilar to that using product announcements (see for example, Fixson & Park, 2008) however it is anticipated that significant changes even those not purposely publicised by their developers or users will be captured by using the press.

¹⁷ Notes were taken by hand to encourage interviewees to speak freely, as it was a period of turbulence in the industry, and copies of typed up records were sent to interviewees for comment and correction.

¹⁸ The interview data come with the narratives constructed over time by individuals, however, it is intended the media data, which is not affected by this qualification, will highlight any discrepancies.

¹⁹ In the process Railtrack redefines the boundary between maintenance and renewal having found the inherited British Rail distinction to be 'arbitrary, mechanistic and a source of dispute'.

proponents of reform. This indicates that a reason for the movement of the organisational interface might have been a lack of 'common ground' amongst the parties participating in the transaction making defining, counting and compensating difficult (Baldwin, 2008): this leads to a movement of the organisational interface to a location where it better fits with the knowledge flow needed to interact with the railway system.

Changes in the technology of the system that appear to be linked to this organisational interface were also observed in this period. A series of machines for assessing and maintaining asset condition feature, including more than one vehicle to search for track faults. These new introductions to the physical system remove human processes and replace them with a combination of physical 'hardware' and new human processes accompany it. There is an argument to say these systems provide more straight forward means of definition, counting (/assessment) and remuneration for a service provision transaction between Railtrack and BRIS organisations. It also might be argued that this creation of a physical product is a process of systematising knowledge now only represented in Railtrack inspection routines.

This development fits with a move towards non-destructive testing and condition monitoring which is discussed by several interviewees and this, in later years, became a core area for academic research for the railway and developed into the 'Intelligent Infrastructure' initiative which Railtrack's successor organisation had a major role in developing. So Physical 'hardware' change does appear to have had a learning impact and has contributed to/responded to active knowledge bases in this industry. Notably this is a knowledge base which spans both design and operational worlds.

Design fit

An interesting example in the data which appears to correspond to ideas of organisational and technology mirroring in design is the involvement of vehicle manufacturers in vehicle maintenance.

The renewable part of the physical system, passenger trains, saw dramatic developments. The first TOCs launched operations in February 1996, before the BRIS units went onto the market²⁰. Following a well documented²¹ 'hiatus' in passenger vehicle orders over the privatisation period, the first order of new trains was featured in the October, 1996 issue of modern railways. After this the orders came thick and fast; the vehicle manufacturers had designs they considered suitable for leasing ready to go. A related significant development in this sphere was the vehicle maintenance arrangements arising with the new train procurements and for the interim period before delivery. Most new vehicles were to be maintained (at least for the heavy maintenance) by the manufacturer. There is a capabilities argument for this change as during the procurement 'hiatus' manufacturers had developed their presence in the

²⁰ It is also relevant here that BR's manufacturing was sold in the late 1980s and so manufacturers had started to establish themselves in a fully detached market. So when the privatisation announcement came they could start working on their products for sale to this new system. Interestingly, modular products and a family of vehicles began to emerge through this process. Based on the way this is presented in the press this seems to have been about providing economies of scope to the production network whilst offering variety to customers (Langlois & Robertson, 1992).

²¹ In Modern Railways of the time.

major overhaul market in order to keep a work flow and right from the first order in 1996 Adtranz was announced as the supplier on a build and maintain package. However, it is clear from an interview conducted with a former member of British Rail Board, who was involved with the ROSCO privatisation, that this model was not expected for vehicle maintenance; it was thought that maintenance would sit between TOC and ROSCO with perhaps strategic alliances forming between ROSCOs and manufacturers.

He also describes a process of migration of British Rail Maintenance Depots to manufacturers since their initial sale. This is a process we can see the early stages of in the publication data. Following the initial sale of depots, the purchase of an electronic repair centre from its management-buy-out by Alstom is featured in 1997.

In terms of the organisational and technological changes to achieve 'design fit'²², this represents an acquisition of important human processes which interact with the physical system, so that they are being brought back together into one organisation, and with it a move towards integrated solutions (Davies, 2004). However the human processes transferred into the development organisations have been removed from the operational organisations. This highlights a link between the technology developed and the technology of the operating system which is more complicated than the simple insertion of a replacement system. There appears to be a difficulty in separating human processes held by the operating organisations and the production of physical systems by the designing organisations. This distinguishes the situation of a part of a LTS from an easily separable hierarchical product which were the artefacts of interest for the existing literature around the mirroring hypothesis (see for example Brusoni, Prencipe & Pavitt, 2001; Baldwin & Clark, 2000; Sanchez & Mahoney, 1996).

This situation leads us to ask why product and service have been reunited and why did they link in the design side rather than the operational part of the industry? Interviews conducted with senior engineers in the manufacturing organisations, and in one instance their service organisation, show that ten years on product delivery and service projects are still being delivered separately. There are processes in place to link back from the service team to the design team where any issues they encounter can be used, providing intra organisational co-ordination. There are issues of assessing the performance of a vehicle over the long term being linked to its servicing regime; an interview with a ROSCO engineer highlighted the different guarantees that can be offered with a vehicle if the manufacturer is also to have the maintenance contract. There is also the question of access to information about vehicle performance which is important for design but does not necessarily require joint delivery of vehicle and maintenance. Both of these issues are about the problem of separating the physical hardware of the vehicle and the human processes around it; knowledge does not appear to be sufficiently transparent/explicit to make it sensible to place these activities either side of a market transaction.

²² Note that alternatively or simultaneously this design fit situation simultaneously be driven from the requirements of operational fit – a need to remove human processes from function. It is assumed here that the need to recombine elements of technology more than a need to separate is relevant to the organisational structures interlinking with it. This is a point that could do with further investigation.

Design-operation connection

A further feature raised in the publication data is the launch of a process for the approvals of safety cases as part of the vehicle acceptance process²³ by Railtrack, featured in the March 1997 issue. Discontent with the process from equipment producers had featured in 1996 issues. In order for vehicles to be accepted for operation on Railtrack's infrastructure they had to meet certain standards set by Railtrack. In an interview conducted with a senior industry member who was involved with this process, he referred to some of the difficulties being faced by the organisation at the time. Key amongst these was a lack of information about the infrastructure or its requirements needed to make decisions about incoming rolling stock. This led to organisations that wanted to introduce a new train on a certain route having to pay for any extra data gathering required for Railtrack to assess and approve that vehicle; 'on the basis of the regulatory principle that he who wants the change must pay for it' (From the interview record). He acknowledges that this led to relational difficulties with the organisations dealing with the vehicles.

This is an example of the operational side of the industry assessing the input from the design side of the industry to change the technology of the operational system; it is an attempt to manage the legacy of the system and its interface with the new element. There were problems with identifying the characteristics of the existing system and in ensuring that new and old would fit together. And, in turn, the processes for checking these interactions will come to influence the design side of the industry's practice; they will add to the contents of the task structure matrix. And as we see from interviews, once again technological solutions also begin to be developed to help cope with the need for information on the state of the system; an example is the work of Laser Rail which develops a vehicle and system for gauge measurement.

Discussion: the role of technology

This case offers the unusual situation of the introduction of organisational interfaces. The examples presented show processes in both organisation and technology to allow transactions at these interfaces to function. Co-ordination of interactions across organisational interfaces is often complicated and both organisational and technological adjustments are made to address this complexity and adjust the points of interaction. There are also examples of system integration occurring where it was not first implemented.

In the case of Railtrack's interface with its maintenance suppliers we see a mismatch between the location/nature of a transaction and the co-ordination required by the technology of this system. There are adjustments in the transaction location (more of the process and decisions about it move to the BRIS units). Technological solutions to adjust the process of infrastructure management which alter both the process and the co-ordination of information are also being implemented. These technological and organisational adaptations appear to have emerged simultaneously; however more detailed examination of this example is needed to establish the processes of emergence.

²³ The technical requirements for acceptance remained unchanged

The case of vehicle manufacturers taking on maintenance contracts appears to be a case of organisations using capabilities built up through necessity; their existence is matched with a change in the product-service offering. However this example highlights a complex link between train and its operation and actually this acquisition of capabilities for the design side of the industry is also its transfer from the organisations central to operating the system.

The complexity of the connection between development and operation sections of the system is further demonstrated by the development of safety approvals. The beginning of the wheel/rail interface problems the industry would suffer following privatisation show a very blunt, temporary use of design rules: in the attitude taken by Railtrack that no change in artefact was to be allowed on a route (and to rescind this vehicle organisations had to pay to help get the information to identify interface characteristics between subsystems). Later attempts to deal with the infrastructure-vehicle interface have included the creation and consolidation of articulated limits and new methods for measuring infrastructure have been developed for gathering information on existing assets; these are means of attempting to direct and of identifying the characteristics of the interdependencies present in the system.

The case shows the complexity of the developments to adjust transactions and reduce the thickness of the crossing points for them (Baldwin, 2008); in particular we see organisation and technology adjusting simultaneously, but in some cases independently. It also demonstrates the difficulty, in a set up that has been built as a system, to separate a physical system from its operation and this is highlighted by complex interactions between the operational system and the designing system.

Conclusion

This paper considers the role of technology in enabling and constraining the organisational forms that interact with it. It focuses on the setting of Large Technical Systems and introduces a case of a mature system which had its organisational structure transformed.

Responding to ideas around the mirroring hypothesis, this paper argues that the issue of legacy, not addressed in existing research on mirroring, is important in the relationship between technology and organisation in systems industries. We make a distinction between the idea of fit discussed by Woodward (1958) and that developed by the mirroring hypothesis. It is argued both of these types of fit are important to the role of technology in Large Technical Systems and that the issue of legacy creates a complex connection between the two that is not of concern for the development of more conventional hierarchical products.

These arguments are illustrated by the case presented. The examples discussed illustrate the complexity of changes to allow introduced organisational interfaces to function, showing simultaneous movements in organisational and technological spheres. They also demonstrate a complex connection between design and operation: in some instances they prove difficult to separate in technology development.

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