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DESIGN FOR MAINTAINABILITY: THE INNOVATION PROCESS IN LONG TERM ENGINEERING PROJECTS

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Introduction

In this paper we are concerned with design and innovation in the context of long-term service driven engineering projects. These are defined as capital projects which involve, not just the manufacture or construction, delivery and/or commissioning of a capital facility, but also *the long term operation and/or maintenance* of that facility for the client. We argue that long-term projects create a particularly complex context for the management of innovation. The introduction of additional stakeholders and interest groups, in the form of an expanding project consortium, present particular difficulties of coordination for project managers and those concerned with managing design and innovation. The requirement for the facility provider to operate and maintain it throughout its life places a premium on technical and organisational innovations that reduce through-life cost rather than first cost. As such this may be regarded as a subtly new design paradigm. However, we also find that there are many barriers to the diffusion of this objective across all of the project actors; in particular, the design process(es) underpinning capital goods project are observed to be contextualised in different business, cultural and strategic environments. The case studies demonstrate the complexities inherent in the coordination of design and innovation in such projects and the multiple and sometimes conflicting objectives which designers are presented with. Nevertheless, the cases reveal a number of ways in which new organisational arrangements have emerged from attempts to deal with these difficulties and also some of the mechanisms that have helped companies to identify the design implications of future maintenance requirements.

This paper is based upon research relating to two long-term engineering projects from the capital goods industry. They were firstly, ALSTOM Transport's project to supply and maintain a fleet of high-speed tilting trains for Virgin Trains on the West Coast Main Line (WCML) and Clarke Chapman's contract for the refurbishment, upgrading, operation and maintenance of wharf-side materials handling facilities on behalf of a newly privatised steelworks in Argentina.

Background

Service led, long-term capital goods projects

Like many other enterprises, low volume capital goods firms in recent years have faced increasing internationalisation of markets and production and increasing competitive pressures. In addition, and due in part to the nature of the product or service they provide, many of them have been affected directly by changing regulation (e.g. environmental regulation) and/or deregulation (e.g. privatisation). These drivers have brought about fundamental changes in the sources and nature of demand, the character of projects and the sources of revenue within them. In addition these changes have also influenced significantly the configuration of the value systems/networks that surround capital projects. While some of these changes are perhaps expressed most strongly in the UK and in the old public sector (e.g. rail, road, water, health) many of the features of the new arrangements are being experienced elsewhere (for examples see Davies and Brady, 2000).

A characterisation of the 'traditional' capital project would involve a customer, from its own resources, drawing up a detailed specification for equipment and commissioning a capital goods supplier to construct the facility under their, or their agent's, supervision. The project would probably be financed on the customer's balance sheet. The equipment is then delivered to the customer and after a short period of warranty the supplier withdraws. What one UK minister referred to, with respect to the construction industry, as the BAD old days – 'Build And Disappear' (cited in Winch, 2000). It is the customer's responsibility to integrate the equipment with other physical or service features and to maintain and operate the equipment over its lifetime upgrading and replacing as necessary. The customer also remains responsible for the provision of the service to its own customers.

Projects are now moving increasingly towards turn-key contracts – in which the end customer does none of the interfacing between the different parts of the system, but deals with a single supplier in the provision of the entire system (Maylor, 1999). The project will increasingly be financed off the customer's balance sheet requiring the finance house to take a greater interest in the performance of the project. Moreover, in many cases the customer now demands a service over a given period from the capital goods supplier (which may be subject to extension with or without the original supplier) articulated to reflect the service rather than the capital good (e.g. kilowatt hours, passenger miles, tonnes per hour). Contracts are negotiated to establish responsibilities, payments and penalties across the life of the contract, during which the supplier is encouraged to make suggestions as to the forms the equipment and services may take and how they will be delivered. The skills which the client has, in engineering terms, to comprehend what is being delivered, may be limited (Newcombe, 2000). Clearly, in this type of contract, demand has shifted from equipment supply-only with time limited responsibilities (i.e. a warranty period) to the supply of a package of goods and services over extended periods (e.g. rail franchise agreements). Thus, a capital goods supplier may now be responsible for the conceptual and detailed design of the project and equipment, its manufacture, assembly, installation, testing and setting to work. In addition it may be responsible for the maintenance and operation of the equipment, its service over an extended period and may even be responsible for dismantling and removing the project facilities at the end of their expected life. Severe penalties in the form of liquidated damages are imposed by some clients for failure to deliver the agreed service level in compensation for lost availability.

Critically, we find that the range of competencies necessary for delivering service, operational and maintenance functions in one capital goods 'package' are unlikely to be within the scope of any one capital goods supplier. The tendency is thus toward the development of project consortia entering into supply chain and/or joint venture relationships with organisations able to fill gaps in their own management, operational or technical capabilities. Projects, therefore, become underpinned by multiple interfaces and multiple actors (often including both public and private sector organisations) in a project delivery network (often referred to as a consortium). These types of arrangement engender high levels of complexity and risk as the capital goods supplier may have to generate, seek out, manage and integrate into the project technologies and knowledges with which they are unfamiliar. There has been a consequent need to rethink the form of the contracting process and the contracts themselves.

Historically, the owners of capital goods products have shouldered the burdens of high running costs and poor reliability, this burden is clearly now beginning to shift upstream to capital goods providers. Consequently, for capital goods firms, the main sources of revenue and risk have also moved from equipment supply to long term reliability and high standard service performance. In past capital goods projects the price of the equipment could approach 100% of the total project value. In service led long-term capital goods projects the equipment can form as low as 10% of the total project value with the major revenue earning and risk sources concentrated down stream in service provision. Thus, it is a further critical feature of these projects that they serve a number of customers – not only the client who initiated the project (and its service users), but also the internal customers and users residing within the capital goods supplier, and associated consortia, who will depend upon the revenue stream once the project is up and running. Again, the finance house may be the contractual customer and will therefore make its own demands (e.g. for residual value). Traditional capital goods projects are viewed as having a definite client in mind. From the client's perspective, the project is a purposeful undertaking stemming from the perceived needs of that client. In long-term projects, however, capital goods suppliers are delivering the *product* to themselves (i.e. they are their own customer) and the *service* to the traditional customer. This shift highlights the need to ensure low through-life costs rather than focusing only on first costs. As Winch (2000) has argued with respect to Private Finance Initiative (PFI) projects, innovation that will reduce running costs and / or increase reliability is essential to make projects affordable, and in these cases, to protect the consortia's revenue stream.

Thus, the key element in these emerging long term capital goods / service projects is to minimise overall project costs over the lifetime of an agreed contract. In this context, capital equipment costs can be seen as the flow of costs associated with the service provided by the equipment over time and not solely of the first cost of the equipment. One route to achieving an efficient, effective, low cost, profitable and desirable service is to explicitly incorporate maintainability and maintenance into the design of the service provision through equipment and service design. It is claimed that 60 to 75 per cent of large equipment or systems lifecycle costs can be incurred through maintenance and support costs (Dhillon, 1999).

Issues in 'design for maintainability'

'Design for maintainability' requires not just the resolution of *maintainability* issues but also the resolution of *maintenance* issues. *Maintainability* can be defined as: *"…the measures taken during development, design, and installation of a manufactured product that reduce required maintenance, man-hours, tools, logistic cost, skill levels, and facilities,…"* (Dhillon, 1999, p.1). Emphasis here is placed on the use of proven long-life component parts, accessible and interchangeable modules and units, ease of inspectability and maintenance features and the use of sophisticated built-in diagnostic systems. *Maintenance*, on the other hand, *"…deals with the specific procedures, tasks, instructions, personnel qualifications, equipment and resources needed to satisfy the system maintainability requirement within an actual use environment."* (Anderson and Neri 1990, p 2).

Thus, both the organisation of work, as well as the organisation of technology, must be the concern of long-term service driven projects if they are to operate effectively and protect their revenue streams. Dhillon (1999) suggests that in both project and design terms, there is a need to fully recognise the importance of maintainability and so systematically incorporate it into the overall project and design processes.

Dhillon (1999) maintains that although there is an increasing interest in maintainability there are still only a few texts on the subject. Moreover, authors tend to take an engineering and very detailed view of 'design for maintainability' which tends to model or provide mathematical aids to problem solving in parts of the process and only a passing mention of the management of maintainability and maintenance (see Bentley 1993, Dhillon and Singh 1981). Some areas of design education have developed models of the design process that are more cognisant of long term design issues and the importance of interaction over time (e.g. Pahl and Beitz, 1984; Pugh, 1990 and Cross, 1989).

We suggest that a detailed incorporation of maintainability in design is essential but in long term capital goods projects it is equally about ensuring that the process is in line with the *overall* as well as the *detailed* project aims. In long term capital goods projects there is a need for an ongoing interaction between project design and management and the conceptual and detailed design of equipment (see also Blanchard et al 1995).

The design process in 'new' capital goods projects

Birmingham et al (1997) suggest that design is now so complex that it usually requires a team of designers or the co-ordination of groups of designers to bring a project to fruition. The available design models appear to have their limitations with respect to complex projects. Birmingham et al (1997, p.90) suggest that the majority of design models:"*…usually address what is required to be done as distinct from how it should be done."* What is required, they claim, is that the design be: *"given a framework within which to work by those further up the hierarchy, and make decisions which act as a framework for those lower down"* (Birmingham *et al.* 1997, p.18).

We suggest it is necessary to go further even than this. We suggest that successful 'design for maintainability' emerges not from the imposition of a 'top down' frame work upon a homogeneous activity (i.e. 'design'), but from attempts to co-ordinate often disparate design actors in a multitude of different business settings. We outline a more sophisticated model of the design process below.

Social shaping in projects

Our conception of the design process in the capital goods sector is drawn from social constructivist approaches to innovation. Social constructivism is a broad term covering: the Social Construction of Technology (SCOT), Social Studies of Technology (SST) and Actor Network Theory (ANT). These approaches share a view of the design process which sees it as open, flexible and shaped by multiple actors and agencies. These theorists reject the notion that particular solutions (e.g. existing technologies and design choices) are in any way natural or inevitable or that technologies emerge from the imposition (top down or otherwise) of a single rationale.

The exemplar of this approach, what has come to be known as the SCOT approach, is applied by Pinch and Bijker (1987) to the development of the safety bicycle. Here, Pinch and Bijker identify not rational technical choices but the influence of a range of 'relevant social groups' – different categories of bicycle user (e.g. women, racers general leisure users) other stake holders and others affected by its early use – in bringing about, over a number of years, a degree of 'closure' in the design – i.e. the hegemony of the safety bicycle configuration. Thus, technology is seen to proceed by the interaction of different social and technical elements in *"constant mutual tension"* (Williamson and Edge, 1992. P. 19) while *"Social interaction amongst particular occupational groups within and between firms, their cultures and orientation, all influence product design and choice"* (ibid, p. 21).

Thus, social constructivism sees design choices and technology solutions as emerging from the combined actions of multiple organisations and as given to often highly political social processes (i.e. multiple objectives). Technical choices are seen as malleable - they are not fixed by a trajectory toward an 'ideal' solution, nor are they solely determined by their own histories (Bijker, 1995). Designs change direction, stall and even reverse (Law and Callon, 1992).

From this perspective it is possible to make two critical observations of the design process in capital goods projects:

Firstly, projects tend to involve large numbers of varied 'stake holders' (in as much as projects often require multiple skills, external investments and draw the attention of regulators and other 'affected' parties). Consequently, they provide an abundance of actors with differing levels of power, objectives and perceptions that have, potentially at least, leverage over the design process. Although ideally these differing objectives are resolved to reflect the goals of the end client (Winch, forthcoming), in reality we acknowledge that the design and delivery of capital goods is shaped by the potentially conflicting end goals of numerous stake-holders in the project.

Secondly, projects also, by their very nature, create periods of uncertainty and, therefore, flexibility ('interperative flexibility'). Midler (1995), for instance, argues that at the outset, project partners have very low levels of information - an exact understanding of what is required and how best to deliver it is lacking. Initially, project partners may thus be involved in a very broad search for solutions – many dead ends may be encountered before an agreed solution is reached. Towards the end of the design phase information levels increase. However, as projects progress it becomes increasingly difficult to re-design without troublesome, unintended and expensive knock-on effects elsewhere. This declining flexibility matches exactly Pinch and Bijker's concept of 'interperative flexibility'. Commentators in the project management field have also pointed to the susceptibility of projects to changes of direction. Drawing on Wheelwright and Clarke (1992), for example, Winch (forthcoming) argues that projects flow across time though major decision making 'screens'. At these screens projects can halt, change direction and even stall. This suggests that the very nature of project management (with its reliance on reviews and meetings) invites flexibility.

We build on the observations of these authors by considering the conduits through which *particular* aspects of the design, such as 'design for maintainability', are managed and controlled in projects. While we accept that design choices and technical innovations are shaped by multiple stake holders, we do not accept the notion that the design process within capital goods projects is entirely malleable. The project management literature is clear that projects are purposeful undertakings with specific functionality and profit in mind. The project environment, for example, has been described as comprising: *"A unique set of co-ordinated activities, with definite starting and finishing points, undertaken by an individual or organisation to meet specific objectives within defined schedule, cost and performance parameters."* (Lester, 2000 p1 quoting from BS 6079). Thus, while flexibility in the search for solutions exits it is also constrained (or at least *should* be) by the perceived end-goals of the project.

The issue of control

Our concern lies with the middle ground between an acceptance of multiple shaping influences and the reality, of needing to 'control' the project (i.e. so that what is delivered in terms of customer value provides some sort of return to the vendor). However, control is itself far from an unproblematic issue in project management. Indeed, it is possible to conceive of control in ever more complex ways.

For Morris (1997), based on an extensive survey of major projects over the last thirty years, *the* key element in the control of successful projects is good 'leadership'. Morris harks back to the 'great' project leaders of the last century stressing their role in creating vision, confidence and focus within the project. Newcombe (2000) supports this position also stressing the need for a single individual to lead the project - the function of this individual being one of: *"…directing, co-ordinating, communicating and controlling the project components and of liaison with, and manipulation of, the project's environment"* (p.195). Bowen *et al.*, (1994) offers further support, suggesting that 'heavy weight' management is usually the most effective form of project management. Winch (forthcoming) makes a similar point, arguing that diffused responsibility for the project can lead to difficulties in allocating responsibility and so to sub-optimal decision making. This very 'top down' model of control in projects is mirrored by Birmingham's top down conception of the design process. It is one, which we feel ought to be rejected as being inadequate.

An alternative view of control in projects is offered by Boddy and Buchanan (1992), in the context of organisational change projects. They argue that projects, rather than be viewed in terms of project tools and top-down control, should be viewed in terms of a 'front stage and a back stage'. There is, they argue, a 'public performance' of the project (meetings, reviews and so on) but that this is only part of the process by which projects are managed. They argue that projects must also be supported through simultaneous 'back-staging'. This back-staging is the messier work of political negotiation and of selling and promoting concepts and ideas and of strategic 'managing meaning' for different stake holders. Rational decision making (i.e.

"directing, coordinating, communicating and controlling") although accepted as occurring, is nevertheless seen as emergent. Buchanan and Boddy argue that project co-ordination (and in particular the buy-in of the project team and other stake holders) emerges, in part, through the work of deploying the idea that projects *are* 'linear and rational'; that the 'right' project *can* be rolled out unproblematically.

If management and control is an emergent phenomenon then a genuine control (in the narrow sense) of projects may be impossible. Indeed, as has been observed, because projects must function to hold together temporary alliances of stake holders, they are in fact best served by close and relatively informal relationships (Bryman, 1987). If so, what does 'control' constitute? One clue lies in a particularly useful collection of work examining the broader context of technological development, from a social shaping perspective, by Alfonso Molina (1989, 1993).

Molina's (1989) work examines pan European attempts to collaborate over the development of a European computer system. His work examines the way in which potentially divergent interests may be made to work together to follow complimentary goals. For instance, critical to the success of the European Strategic Programme for Research and Development (ESPRIT) project, Supernode, argues Molina, was the common goal of obtaining, and continuing to obtain, 'Commission money'. This common objective created the right balance between a *"what's-in-it-for-me attitude and an if-the-project-grows-I-grow"* (p. 11) - an attitude that was critical to successful conflict resolution within the project. This implies that project design may best be conceived in true Machiavellian mould – it is easy to rule (i.e. control) when those who are ruled perceive their interests are being served.

Law and Callon's (1992) work, a detailed case study of the failure of the UK governments TSR2 military jet project in the 1960s, details the antithesis, and shows what happens when the project coalition does not perceive their interest's to be served. Although Law and Callon's (1992) work stresses the heterogeneity and complexity of project organisatation their conclusion about the project's failure points ultimately to the failure of the main contractor to control dialogue between actors in the project network and across its immediate boundaries. They describe the project as a socio-technical[1] network comprising two aspects – a global network (the technological resources base, finance, political support, government client, societal stake holders) and the project network (the project supply side). The project failed, they argue, because the lead contractor was unable to make itself an 'obligatory point of passage' between the two networks. Their case study shows that the collapse of the project occurred because the main contractor failed to control the dialogue between the two networks. Effectively other contractors in the network began talking directly to government departments to address their own interests within the project. As a result, there was a loss of leadership and focus, without which it became impossible to continue to justify the public resources the project needed to continue. Note that in this story, while a loss of leadership is a critical event in the project's downfall, loss of leadership is it is itself an 'outcome' of the 'back-staging' being enacted by other players in the project and the failure of the main contractor to control it. This lack of ability, one might argue, is tied to the structuring of the project network and the failure, therein, to align and satisfy the interests within it.

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[1] Comprising interwoven social and technical actors.

With respect to the control of projects, it may be reasonable to surmise that that control over the projects direction is rooted less in the charisma of its leaders and more in the design of the project network itself. Thus, we contend that that control over specific areas of the design (e.g. 'design for maintainability') lies in the way in which the relationships between the various actors are configured from the outset. The case studies, in our view, bear out this assertion.

Method

The research was conducted by a multidisciplinary team involving researchers from engineering and the social sciences (including management and sociology). The research approach followed was to map out the project network and identify the key actors in each project. This approach commenced with initial interviews with the principal contact within each collaborating company and snowballed out to cover the collaborator's project team and subsequently the supply chain organisations associated with the project, including where possible the client.

The second principal method of obtaining information was through a series of workshops held with the collaborating companies. The workshop discussions focussed on key themes that the initial investigations had suggested were critical in long term engineering projects. Participants were drawn from the collaborating and their supply chain companies appropriate to the topics under discussion and included representatives at Director level.

Interpretation of findings adopted a multidisciplinary approach involving all of the research team. Project away days were held regularly to bring the research team of six together to brainstorm and discuss the findings and to develop an appropriate framework for analysis and interpretation.

The case studies

The case studies highlight some of the main means by which project managers attempt to control what is delivered by projects. We find little evidence of 'leadership' in the traditional sense, but much in the way of vehicles and fora for generating and exchanging information in the pursuit of broad project goals. We also find evidence, however, of losses of control and of sub-optimum design outcomes.

Cases 1 - Clarke Chapman, Siderar

Introduction

Clarke Chapman Ltd (CCL), at the time of the research reported here, was part of Rolls Royce Materials Handling (RRMH) but has recently been subject to a transfer of ownership. CCL/RRMH have long term experience in the manufacture and supply of materials handling equipment to ports and terminals, shipping and offshore operations, the rail industry, etc and at the beginning of project under study (1995) were the largest crane-makers in Europe. At that time the CCL group of companies tended to see their business principally in terms of equipment and spares supply where low cost and price of equipment were key market parameters in achieving commercial success. CCL has built up experience of organising and undertaking equipment supply and maintenance arrangements for dock facilities in the UK.

The SIDERAR Project.

In the 1990s the markets for materials handling equipment became increasingly competitive and CCL were looking to place their products and services in new ways in new market areas. An opportunity arose when the steel industry in Argentina was privatised leading to the outsourcing of wharf management and operations handling the import of bulk raw materials and the export of finished goods by the SIDERAR steel works on the Parana River, Argentina. In partnership with Portia, a subsidiary of Mersey Docks and Harbour Company (whose expertise lay in the area of port operations management), CCL successfully bid to supply a new unloader, a new stacker and two new conveyers to SIDERAR, to refurbish other existing equipment and to modernise the port infrastructure. The contract with SIDERAR also called for CCL/Portia to maintain and operate the port, including the employment and management of staff, over a twelve year period with a possible extension to twenty years. This was the first contract of this nature undertaken by CCL and perhaps the first in the world in the port industry. The majority of equipment was designed, built and refurbished by CCL companies or under their supervision - including an innovative motion control system for the unloader. By the end of the year 2000 the new and refurbished equipment and facilities were in place and the contract moved into its full operational phase.

Contract details

A key feature of the concession-winning bid was the innovative financial package put together by CCL/Portia to finance the venture. This package included staged SIDERAR payments to CCL/Portia for the new equipment and refurbishment together with a monthly payment for raw materials and finished materials determined by volume passed over the wharf. SIDERAR guaranteed minimum volume transfers over the wharf while CCL/Portia guaranteed availability of equipment, manpower and transfer of agreed volumes at prices (i.e. price per tonne) fixed in advance. Failure to meet the terms of the agreement led to the imposition of severe penalties on CCL/Portia. For example, demurrage charges if the loading or unloading of ships was delayed, the financing of alternative supply if the equipment failed, substantial losses if the negotiated fixed prices did not cover costs. The value of the contract over the 12 year period was approximately £100m with 90% of payments to CCL/Portia determined by operational performance and 10% allocated to equipment and refurbishment.

The ability to satisfy the terms of the contract and earn profits (and avoid penalties and losses) was, therefore, inextricably linked to the design, organisation and conduct of maintenance to ensure equipment availability and to help control operational costs. Questions such as robustness of equipment, accessibility for maintenance, elimination of maintenance, modularisation, standardisation etc needed to be addressed from the outset of the project. However, there is frequently an additional cost to be borne in designing for maintainability, which in CCL's experience can be as much as ten per cent of equipment cost. There is obviously, therefore, a trade off here between first cost and whole-life operational costs.

CCL/Portia's competitive edge.

CCL/Portia held an edge over many would be competitors in the field of long term projects of this nature because of their experience. Portia were experts in port and man-management issues and had worked together with CCL over many years (18years) in the development and operation of Liverpool docks. CCL supplied equipment to Liverpool but also provided the maintenance function. There has therefore been evolving experience of maintenance in Liverpool that has led to significant developments for maintenance and maintainability including the construction of maintenance schedules and the multi-skilling of maintenance staff. These skills have been passed on to other workers and other projects, including the SIDERAR project, through job descriptions and training packages. In addition CCL have systematically constructed a computer-based record of maintenance by item of equipment over many years. This allows CCL to estimate such things as wear rates for components, maximum life of equipment and to some degree life-cycle costs of equipment. Such knowledge is extremely valuable in preparing bids, running long-term projects and negotiating long term spares agreements with suppliers. It also has the potential to have a significant input into the technical and organisational design processes. There has been less exploration of the implications of maintenance systems for equipment and organisational designers.

Design for maintainability and maintenance.

At the highest levels within CCL it was recognised that the realisation of the full potential of 'design for maintainability' frequently requires a re-conceptualisation of the total project and its sub-components. A conceptualisation of the project that recognises the importance of integrating 'maintainability' in to all aspects of the project: strategic, planning and operational.

The directors and project leaders of the SIDERAR project were familiar with this approach to design and the importance to the SIDERAR project of maintenance issues. The directors of CCL have held a number of meetings to disseminate knowledge of business objectives and recent company reorganisation has led to the formation of a business unit focussed on facilities management projects. At the outset of the SIDERAR project CCL was organised around a head office and a number of profit centred subsidiary companies. A separate and joint CCL/Portia company, SOM SA was set up in the Argentine with a remit to ensure the delivery of the project with a focus on operations and maintenance. CCL and Portia had also passed on to SOM SA their experience in operations, maintenance and quality assurance in the form of job descriptions, training and software packages.

The alignment of design to maintainabilty and maintenance concepts.

Even with cognisance of maintenance requirements CCL found that the transfer of knowledge across projects and between experienced and less experienced staff proved difficult. Formal transfer mechanisms are difficult to develop in the areas where tacit knowledge transfer is critical. Capturing tacit learning from maintenance operatives (such as where to look for a wiring fault on a crane) has proven particularly difficult (not least because some repair activities are not repeated for months or perhaps years at a time). In addition project teams in the capital goods industries are often in a continual state of change with individual members joining and leaving teams as the project progresses.

Operational realities of 'design for maintainability'.

It was also apparent from the case study that management, engineering and design staff had found it difficult to fully align themselves with the needs of the overall project (with respect to 'design for maintainability'). As we were told:*"Historically there has not been any feedback from the experiences of the maintenance system back into design."* Moreover, the focus of initial investigation of the site was primarily upon the replacement and refurbishment of existing equipment in respect of meeting throughput targets, and rather less with maintainability issues. Subsequently, designers had failed to recognise the implications for maintenance of the operation of the equipment by a non-English speaking workforce. Also overlooked were the high levels of dust in the local environment as a potential source of maintenance problems. In the event, dust from a local sinter plant was found to be clogging air intake filters. This approach to design, in which long feasibility, scoping and planning studies tend to be short and to focus upon determining the equipment demanded to 'do the job', is perhaps more in keeping with traditional project execution, in which down stream operating problems are seen as the client's concern.

Internal interfaces

While the need to incorporate maintainability into design was appreciated at company and core project team levels the equipment itself was supplied from a number of internal and extra-corporate sources. The detailed design and supply of equipment was, therefore, to some degree fragmented with some suppliers able to follow their own design strategies. As a result attention to long term operational (maintenance) and integration (maintenance system) issues were not always fully addressed. Key to this problem were difficulties associated with aligning all of the internal and external suppliers around the 'long term' project vision. It was, in other words, this vision which CCL/Portia needed to enforce as an 'obligatory point of passage'. As one respondent involved with the project stated: *"The way we operated was cellular, certainly we were not integrated into a common purpose."*

The key to this issue lay in the corporate structures through which CCL (as distinct from the project team) managed its constituent companies. In CCL, management of internal companies was achieved via a quasi-market – such that the performance of each business unit was measured by profitability. While this may have been conducive to cost performance it was less conducive to long term planning based on short-term profit sacrifices. Internal suppliers, for obvious reasons, were ill-disposed to see their own margins eroded in order to safeguard revenues they would be unlikely to benefit from (in business unit or career terms). The structuring of roles within CCL thus posed a barrier to the uptake of a 'design for maintainability' vision.

Conflicting organisational objectives

Project organisations must pursue not only objectives related to projects, but also those related to the overall competitive development of the organisation over the long term. In CCL's case the development of a motion control system during the Siderar project was seen as a means to develop long-term technological competencies. Problematically, the needs of technological innovation are not necessarily congruent with the execution of a project. In this case the control system was perhaps more complicated than necessary and with non-standard components that had to be sourced from the UK, it was difficult to maintain at a distance (in Argentina) from CCL's base in the UK. The example serves to remind that even in the core-project team there may be conflicting objectives able to impinge upon the direct needs of the project.

Summary

Clearly, at the outset of the SIDERAR project, CCL/Portia had considerable experience of designing, building, operating and maintaining mechanical handling equipment under port conditions. They passed on much of this knowledge to those involved in the maintenance and operation of the SIDERAR port in the Argentine. Moreover, the project team at CCL realised that this type of contract required a reorientation of the company, its philosophy and culture to meet the challenges the project presented. Many lessons were learnt that led to a more positive approach to facilities management projects. Nevertheless, the case also demonstrates the importance of particular organisational configurations in structuring the possibilities for developing a 'design for maintainability' vision. Clearly, it is essential to spend time analysing the nature of the motivations in the project and to act, as far as the organisation allows, to re-design them to suit before the project begins. However, getting this right is a learning process and CCL has had to cope with operating in a new and poorly defined project paradigm. As the rules of the game become clearer, however, CCL will no doubt find itself some way up the learning curve.

Case 2 – ALSTOM Transport, West Coast Main Line

Introduction

The case of ALSTOM Transport's West Coast Main Line demonstrates clearly the influence of new demand, through privatisation, upon the organisation of projects. In this case there is clear evidence of an active re-distribution of risks and responsibilities. The case demonstrates some of the strategies that are available to both clients and main contractors in their struggles to create new project structures – i.e. to re-configure the motivations of different stakeholders in the project and to make 'design for maintainability' a key driver in the design and innovation processes.

ALSTOM Transport

ALSTOM Transport has a 12-year contract with Virgin Trains worth £1.2bn (1.8bn Euros) to supply tilting trains to the West Coast Main Line (WCML). Of this figure £592 million was accounted for by the rolling stock while the remainder was taken up by the service provision. ALSTOM Transport is the main contractor developing the revolutionary Pendolino for the West Coast Main Line, the UK's first 140-mph tilting train.

New customer demand under privatisation

Historically maintenance issues have not been at the heart of thinking in train design. As we were told: *"The railway has suffered from being engineering led. BR had big engineering operations to be fed. Manufacturing was never involved in maintenance and so there was no feedback into design"*. Although some 'systems level' innovative steps forward have been taken (through for example, the development of Train Management Systems through which train problems are recorded and transmitted ahead to maintenance depots), the incremental 'learning by doing' from actual maintenance activity has been less active. Arguably, in part this is due to the 'technology push' engineering led culture of the 'old' industry[2].

Since privatisation new customers, such as Virgin Trains, have entered the industry to take up the franchises made available by government and have pushed 'design for maintainability' to the fore. Virgin Trains, for instance, no longer wants to buy trains, rather they want to buy 'seat miles'. In other words, they wish to buy the service not the product. Key to the WCML contract is the fact that Virgin Trains expect ALSTOM Transport to deliver the requisite number trains to the platform each morning to allow them to fulfil their obligation to the Office of Passenger Rail Franchising for the number of daily diagrams agreed in the WCML franchise. In order to ensure that the level of service availability is maintained (this includes aspects such as the catering services) Virgin Trains insisted that ALSTOM Transport accept liquidated damages on service availability. It is these expectations and Virgin Trains' power as a customer, that are creating new incentives and motivations through a re-distribution of the responsibilities and risks associated with train manufacture and operation.

Contract details

The initial contract for WCML included 53 Pendolino tilting trains to run 42 diagrams at 125 mph (prior to 2005) and 47 diagrams at the higher speed of 140 mph after 2005. Train reliability is expected to equate to 50,000 miles between failures, ride quality is expected to be 30% better than a (specific) loco-hauled train and interior noise levels are expected to be low (at a maximum of 65dBA). At the outset of the project Fiat Ferroviaria was 45% joint venture partner, providing the body shell, bogies and doors. ALSTOM Transport has since acquired a majority share in the company. ALSTOM Transport are responsible for the interior design, assembly and remaining integration.

The development of a service provision

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[2] That maintainability has failed to be central design heuristic in train building is evidenced by numerous features on existing trains. On the class 91, for instance, removing the cab air conditioning packs for servicing necessitates the removal of the entire roof. Similarly, checking the rear brake stack over-heat thermostat (this shuts down and vents the brake if it over-heats), though in itself *"…a two minute job"*, necessitates removing the whole brake stack. In another instance, designers placed a compressor laterally across the under-frame of the train. Mounting it this way makes it impossible to remove using a fork lift truck.

WEST Coast Train Care (WCTC) is the lynch pin of ALSTOM Transport's maintenance of the Virgin Trains WCML fleet. WCTC is also the signatory on the contract with Virgin Trains for the Pendolino train sets. Thus, WCTC, rather than Fiat Ferroviaria or ALSTOM Transport, is perceived by Virgin to be the service provider and it is from WCTC that it takes delivery of the trains (and to whom it will apply liquidated damages if they prove unreliable).

WCTC has introduced a number of improvements to the way it manages the maintenance of the WCML fleet. At the heart of the change process for WCTC is cultural change. WCTC found its train care centres (originally owned and run by British Rail to maintain their own fleets) lacking in a common sense of the company's overall goals[3]. In order to encourage ownership of maintenance problems, the way in which information about failures is disseminated to the maintenance workforce has been improved. The WCTC's contract with Virgin Trains stipulates penalties for 'discrete' failures while Virgin Trains' own performance is measured in 'minutes delay'. These minutes include those lost by trains held up by the failures of trains in front of them. It has now been agreed with Virgin Trains that WCTC will receive information on delays in impact minutes. These figures are passed to the depots each morning so that teams can grasp the 'real' impacts of failures.

The way in which maintenance is actually carried out has also been re-thought. WCTC have created, for instance, a 'balanced exam' approach. This approach breaks down each train's major overhaul and spreads it over a number of (night shift) sessions and centres. This increases the availability of rolling stock by no longer taking it out of service for major overhauls. WCTC has also increased its staff (680 new staff).

Re-configuring inter-organisational interfaces

Post privatisation, service capability has tended to be seen by manufacturers as a new area of business - rather than as a part of a co-ordinated product offering. Consequently, the question for manufacturers as to how to inject their maintenance experience into their design remained largely un-tackled. Both Virgin Trains and ALSTOM Transport view the resolution of this as a key for business success.

A key feature of the new forms of contracts outlined here is that maintenance staff are in effect becoming vocal internal customers of the capital good produced. User groups like drivers and assemblers have long been recognised by designers in the design process, and attempts have been made for some time to reflect their needs in design. However, it is more recent that maintenance has emerged as a distinct voice in design – in part because their activities, rather than being *sold* as a service, now have direct bearing upon profitability. On the Northern Line, a similar style of contract,

[3] Although WCTC has made great strides toward providing comprehensive and effective maintenance service for the WCML, it has had to do so 'in spite' the disrepair underpinning the poor performance of the WCML. These problems stem from chronic under investment in the past. As we were told, some maintenance centres have been allowed to become a *"black holes"* into which trains *"go and never come out"*. One shed still had cobbled stone floors and no doors making it *"freezing"* in winter.

maintenance staff were brought into the design studio while the design process was on-going. The success of this was limited, due in part to the late involvement of maintenance staff, but also because engineers regarded the presence of maintenance staff as 'big-brotherish'. Again, one might suspect that this reflects the engineering design led-led culture of the industry.

From WCML's perspective the problem remains one of distance between the design process and the processes and problems that accompany the 'doing' of maintenance. As was clearly recognised within WCTC, reliability can be specified in a contract and can be responded to in design, but: *"'Maintainable' - what does that mean to someone who has never been in a maintenance depot"*. The battery box on the Pendolino, furnishes an illuminating example. The battery was designed to be removed by a fork-lift truck at the maintenance depot. However, it has became apparent that there is not enough space in the maintenance shed for a folk lift to do so.

In an effort to improve learning, WCTC centre team leaders from around the country have been made responsible for different aspects of the train design (e.g. traction at Manchester and toilets in Glasgow) – this makes a focussed interaction with the design process easier. Team leaders can build up expertise in their own areas and form a point of contact for designers. Designers are also now expected to spend time in these train care centres developing an awareness of maintenance problems. WCTC has implemented, for example, a programme of two-week visits, including time on the night shift, for designers.

Attempts have also been made to re-design the interfaces between maintenance (WCML) and manufacturing (ALSTOM Transport) to improve their co-ordination. It has been recognised that *"…one team was policing the other"*. A solution to this has been to create a 'Fleet Development Director' responsible for the outputs of both teams. Under him there is a 'New Trains Build Manager' who looks at 'design for maintainability' and reliability and the production of manuals and other materials.

The role of suppliers

ALSTOM Transport is dependent upon external suppliers for long term parts supply. This is not a new problem (trains have always lasted for 35 years or longer) but the nature of the relationship is changing. Contracts with suppliers now extend beyond a set warranty period and include rewards for good performance and penalties for poor performance. Like ALSTOM Transport, industry suppliers no longer expect to supply spares at a profit unless their equipment has performed as agreed and this is increasingly being reflected in contract agreements. Where possible, the liquidated damages agreed with Virgin Trains are rolled out to suppliers.

ALSTOM Transport procurement has also been careful to ensure that 'maintainability' has been clearly specified to suppliers. Suppliers to the WCML contract must state the life-cycle costs of all equipment on a standard pro-forma. For maintainability, ALSTOM Transport also state fixed times within which individual items must be accessible for maintenance. To change a light inverter, for example, must take no more than 6 minutes. Suppliers have had to prove this accessibility in 'type-tests' observed by ALSTOM Transport.

It was also recognised by WCTC and ALSTOM Transport that suppliers should also be involved earlier in the project. *Reliability conferences* were set up to encourage their input. There have also been changes in the deployment of finance. Money, once set-aside for penalty payments, is now re-deployed to help improve train life-costs by being used to fund technology solutions developed though reliability conferences[4].

In general, ALSTOM Transport has encouraged suppliers to become more pro-active in making changes post design - a position that is beginning to yield results. Westinghouse has, for example, improved their contribution to a similar contract on the Northern Line by suggesting a screw compressor in place of the existing reciprocating compressor. Although more expensive it is more reliable - something which ALSTOM Transport has shown a growing willingness to pay for. This has required an evolution away from the traditional 'buying department' toward design team focussed procurement.

Summary

In terms of motivation ALSTOM Transport has been put in the position of an operator. Virgin Trains has re-designed the distribution of risk, responsibility and motivation in its supply chain in such a way as to re-focus ALSTOM Transport's commercial motivations. In short, they must now ensure that the trains are reliable, not overly costly to maintain and that they *are* effectively maintained. Performance penalties are heavy and, accordingly, keep ALSTOM Transport *"focussed"* on 'design for maintainability'. This has also raised the profile of train service provision in the company to the point were it is no longer seen as simply a *"…necessary evil"*.

The broadening of WCTC's role, to encompass holding the contract with Virgin Trains is a clear signal to the rest of the project consortium that 'design for maintainability' is a central feature of the contract. This is ALSTOM Transport's own attempt to re-design its internal interfaces and so to alter the motivations across its own organisation. In this way, ALSTOM Transport has WCTC as its customer. It is WCTC, who will maintain the trains and so WCTC that ensures 'design for maintainability' is a central part of the design. The way in which ALSTOM Transport interfaces with its suppliers has also been considerably re-thought. ALSTOM Transport has ensured that the 'design for maintainability' message has been rolled out to its suppliers. This message has been reinforced by being bundled up with financial penalties and rewards associated with reliability performance.

It is now generally recognised at board level that the imperative for trains to be delivered on-time and to cost must now be balanced against a longer-term view of maintainability and reliability. However, *"…engineers find the adjustment difficult"* and although the needs of maintainability have made some in-roads into the design process, the industry essentially remains 'product performance' led one. *"Big and strong"* has historically been the key heuristic in train design. While there are good reasons for this – arguably the train is perhaps one of the worst environments in which

[4] It is important for these events to be held at an early stage in the design process. Changes made after the design has been stabilised serve merely to increase the costs and difficulties of making changes.

to operate sophisticated equipment – it remains that new customer demands are forcing a broadening of the focus of train design. Now that the structures which determine the distribution of risk and reward have begun to emerge it remains to be seen how resistant these ‘old’ cultures will prove.

Conclusion

This paper has stressed the role of new forms of demand in creating a new design paradigm within the capital goods industry. A key characteristic of these ‘new’ projects, it has been argued, is that the revenue and risk foci of projects have moved downstream into areas of service provision leading to new demands on value-earning and cost reducing capacity. Project managers are finding that it is not enough simply to ‘tie together’ the various packages of goods and services to form a physical product, but that is necessary to fully integrate service and physical elements into a unified ‘service led’ product offering. Project managers thus are under pressure to find ways to ensure that the design of equipment, and the organisational structures left behind after the delivery of the capital good, reflect the need to maintain the equipment for maximum availability over the long term.

This context creates a need for ongoing demand for feedback of information from operations and maintenance to technical and organisational designers and a need to develop and promote a ‘design for maintainability’ approach to design across the project.

The research suggested that performance data was being systematically collected and mechanisms used (or sought) to feed this back through the project network to those who could take action. What was proving more difficult was the capture and transfer of experiential and tacit knowledge and the difficulty of articulating maintenance issues within the highly technology focussed world of the engineering designer. This is of particular significance in capital goods projects where staff tend to move between projects quite rapidly and repeatability is relatively low. While in some instances the managed exchange of design and maintenance personnel was being undertaken, in others the influence of operations and maintenance staff on project and equipment design was less obvious. Moreover, responding to problems is one thing but being able to look downstream to anticipate maintainability or maintenance difficulties or requirements is challenging when the long running operational phases of the project have not yet begun. Ideally, all parties engaged in a project, whether internal or external up and down the project hierarchy, would have a common framework for action linking customer requirements, design, production assembly and operation. However, our research suggests that design management involves the co-ordination of often disparate design actors in a multitude of different business settings. Control over the design process, we find, is negotiated and often partial in its view. Arguably, the further devolution of design to suppliers, partners and sister companies, in order to cope with the delivery of combined service and capital good ‘one stop shop’ services, implies a further loosening of control over the ‘design for maintainability’ process. As the range of actors delivering designed products proliferates, so do the contexts in which design is done.

It was clear from the cases that cross cutting design 'visions' in projects, such as 'design for maintainability', must be actively promoted within the project and built in to the project's organisational architecture. Programme directors and managers must, in other words, attempt to manage from the outset the motivations and incentives of the organisations which comprise the project. As the case studies show, this is possible when dealing with a supply chain but infinitely more difficult when dealing with project partners, internal suppliers and departments. Thus, although the alignment of interests may be critical to project control, 'top down' management may be something that emerges *out of* well-designed or serendipitous project organisation. It follows that systematic project design, one which tries to account for the likely motivations of the different players in relation to one another and the project, is a critical task for project and programme managers.

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