Managing engineering design in complex supply chains

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MANAGING ENGINEERING DESIGN IN COMPLEX SUPPLY CHAINS

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Abstract

The trend towards organising design, development and manufacture via supply chains, rather than predominantly in-house, poses major challenges for design management. Procurement methods based on adversarial competitive tendering are generally unsuited to complex engineering products requiring strong design and development coordination.

Literature on 'supplier partnerships' has largely overlooked the implications for managing design and development. This paper reports the results of a major project that focuses upon this issue, concentrating on practical case studies – from British Rail, Netherlands Railways, Rolls Royce and British Coal – that involve the management of 'devolved' engineering design by large business organisations.

A spectrum of approaches from in-house to fully devolved design is described. It is concluded that there does not appear to be a single best approach for managing devolved design, but that appropriate approaches for an organisation depend on its location in the supply chain and its ability to manage organisational change.

Keywords

Engineering, Design and Development, Buyer-Supplier, Procurement, Purchasing, Supply Chain, Railways

Biographical notes

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In 1979 he founded the Design Innovation Group to act as a focus for research on the management of product design and technological innovation. He has held several major research grants and published many books and papers in this field.

Dr Stephen Potter is a Research Fellow in Design in the Faculty of Technology at the Open University with a background in economics, geography, transport and urban studies. He joined the Open University in 1974, initially working in the Social Sciences Faculty on research and course production. He joined the Technology Faculty in 1987 to work on a variety of research projects in the Design Innovation Group. His research work, as well as the project described in this paper, includes a study of 'green' product development, a rail technology 'foresight' study and research into transport and environmental issues.

INTRODUCTION

The externalisation of design

During the past fifteen years there has been a significant trend for firms and public organisations, especially large ones, to externalise a wide range of functions that formerly might have been carried out in-house. Increasingly business organisations are concentrating on 'core' activities and 'contracting out' or 'outsourcing' other functions to external suppliers. This ranges from major manufacturers increasing the proportion of components and sub-assemblies designed by suppliers to the contracting out of functions such as R&D and accountancy.

There are a number of reasons for this trend, including rising global competition, more rapid technical change and the need for the faster development of products of ever higher quality and reliability. This means that, increasingly, organisations have to focus on their core competencies (i.e what they can do best) and for other activities to draw on the best expertise available worldwide. Thus the old pattern of the large, vertically integrated business which did almost everything, is being replaced by one consisting of complex 'networks' of collaborating organisations, both large and small, and 'chains' of buyers and suppliers[1,2].

In this new industrial structure, the design and development of complex engineering products is one of the functions that is being devolved back along the supply chain. The extent to which this occurs varies. Some service operators, such as railways, that previously had major in-house design and manufacturing facilities, now devolve most engineering design and development work to external suppliers. Among large manufacturers, for example in the motor industry, there is often a mixed situation, in which the design of some sub-assemblies and components are devolved to suppliers, or where in-house designers work closely with their suppliers to ensure that components of the required performance and quality are developed.

These changes, of course, have major implications for engineering design management. In the integrated firm, the key participants in research, design and development were located within the company. The major management challenge was ensuring coordination between different individuals and departments, so that all aspects of a product's design – function, styling, manufacture, marketing, servicing, and so on – were taken into account, without slowing the development process too much. As a result there is a large design management literature on multi-functional teams and concurrent engineering [e.g 3,4,5,6] and over the past decade considerable efforts have been made by many major companies to introduce these organisational innovations.

But in the new structure, design and development not only has to be managed within one large organisation, it also involves managing relationships between many companies of different types and sizes in an extensive chain of buyers and suppliers. The co-ordination and other problems that team-based, concurrent engineering approaches are intended to overcome can be considerably more severe and, not surprisingly, much less is known about how to manage engineering design and product development in this new situation.

From adversarial relationships to buyer-supplier partnerships

Business organisations have, of course, always obtained certain products and components from external suppliers and a whole purchasing profession has built up around this function. Traditionally, however, the culture of this profession tends to be adversarial, in that a particular item could be purchased from a number of suppliers who are obliged to compete with each other for the contract to supply that item to the buyer.

Shapiro [7] summarises the key aspects of traditional adversarial 'competitive tendering' as involving: i) multiple sourcing to ensure supply continuity and to increase buyer leverage, while limiting the power of each supplier; ii) frequently shifting orders between suppliers, often to 'discipline' them; iii) 'arms-length' relationships and formal, often short-term, contracts chosen largely on the basis of price.

One consequence of this approach is that product quality, reliability and delivery often suffered badly as suppliers try to compete for contracts on price. Recent management literature on buyer-supplier relationships has recognised this problem. For example, Burt [8] cites the well-known quality authority, Joseph M. Juran, who commented on supplier incentives in a typical competitive tendering situation. In the case of the US automobile industry, Juran notes: 'The automakers turn the screws to the point where it's almost impossible to make money selling to the auto companies. So the vendors have to make it on spare parts in the aftermarket. That gives them a vested interest in failure, a miserable arrangement.'

Progressive organisations have therefore increasingly moved away from the traditional adversarial approach of competitive tendering towards developing long-term 'partnership' relationships with a limited number of 'preferred' suppliers. This new cooperative approach has been given various names, including 'relational contracting' [9], 'supplier partnerships' or 'partnership sourcing'. Partnership sourcing has been defined as, 'where the customer and supplier develop such a close and long term relationship that the two work together as partners.'[10]

Long-term partnerships between customer firms and their suppliers is one of the notable features of Japanese industry and is now recognised as a key factor in the success of the Japanese economy [9]. Partnership sourcing, often introduced into Europe and the USA via the overseas subsidiaries of Japanese companies [11], is becoming much more widespread.

Xerox, for example, reduced their supplier base from 5,000 companies in 1982 to just 400 in 1985. Between 1982 and 1987, in a move to relational contracting, Rover Group reduced its supplier base from 1,200 firms to just 700 and plans still further reductions to 300 suppliers [12]. British Aerospace used to have 44,000 suppliers, but by 1994 had reduced this to 56 'collaborative' suppliers, 760 'acceptable' suppliers and 6,000 'restricted' suppliers[13]. More generally, one survey conducted in 1993 showed that 63% of UK engineering companies planned to enter into partnership agreements with preferred suppliers in the next three years [14].

Partnership sourcing does not mean the elimination of competition between suppliers, but involves a range of procurement techniques that involve long-term contracts, with extensive information exchange and co-operation on many issues, especially product design and development. Sefton [15] points out the one of the key advantages: 'In contrast with an adversarial approach, the supplier becomes a strategic resource and extension of the buying firm, thus enabling the customer to capitalise upon the supplier's design expertise and capacity for innovation'.

Although there seems to be widespread agreement that buyer-supplier partnerships are desirable, the implications for the management of design and development work are often overlooked. With a few exceptions [e.g 16,17,18], including a small literature on relationships between client companies and design consultancies [19,20] relatively little has been written on the design management implications of such partnerships. Additionally, there are difficulties in achieving the transition from in-house design and development coupled with formal adversarial relationships with suppliers, to one of shared design and development involving a partnership relationship with suppliers. Managing this transition is in itself a considerable challenge and typically is achieved in stages over a considerable period of time [21].

THE EXTERNALISATION OF DESIGN IN BRITISH RAIL

The interest of the authors of this paper in the management of engineering design in the context of changing buyer-supplier relationships arose from a research project commissioned in 1992 by the British Railways Board, through their Director of Technical Strategy. This project was concerned with identifying effective practices for procuring and introducing new trains – given the transition of British Rail from being a

designer and manufacturer of rail vehicles to concentrating on being an operator of railway services and devolving design, development and manufacture to the railway supply industry. This process, which has taken place over the past fifteen years, has produced significant benefits, but is also believed to be an important factor behind a number of problems arising in the design and development of new trains and other rail equipment.

Earlier research by the authors had compared the management of two high speed train projects at the time when British Rail (BR) had its own internal engineering departments and facilities for research, design and development, and also owned a manufacturing wing, British Rail Engineering Ltd., which manufactured rail vehicles and components. This work showed that, although BR's in-house system was capable of managing the development of an evolutionary design, the InterCity 125 train, it took so long to develop the technologically innovative Advanced Passenger Train (APT) that the APT was eventually abandoned before entering full service [22,23].

Even before the APT project was abandoned in the mid 1980s British Rail had decided to concentrate on the core function of operating railway services. After reorganisation into business sectors, BR withdrew totally from manufacturing trains, which were to be procured from external suppliers with open competitive tendering on a project by project basis. Organisational change has been taken even further under the UK Government's rail privatisation programme, with the creation in 1994 of separate companies for the provision of track and infrastructure, passenger and freight rail services, the procurement and leasing of trains, and maintenance.

Despite some success stories, such as the electric locomotive developed by GEC for BR's InterCity 225 high speed train [20], the experience of devolving design and development to suppliers under this model has not been good. The introduction of new trains generally takes longer than before (especially where technical innovation is involved), development is rushed and virtually all recent projects have been late and have ended up taking many months of in-service development work for reliability and other technical problems to be rectified [24,25].

Having recognised the limitations of the competitive tendering approach to procurement, in 1992 British Rail began a programme of developing partnerships with a limited number of accredited suppliers for the design, development and manufacture of trains and other rail equipment [26]. BR's Supplier Development programme was underway when we began our research and continues under the restructuring for privatisation.

Our research project involved studies of the process of procurement and introduction of new trains in British Rail and other railways, and also in 'parallel' organisations which manufacture or use complex engineering products. The research was based on a literature review plus a series of case studies of engineering projects involving large organisations which had made the transition from in-house to partially or fully devolved design and development. Six case studies have been developed, four involving the development of rail vehicles and two of engineering products in other industries.

BUYER-SUPPLIER RELATIONSHIPS IN ENGINEERING DESIGN

It soon became clear from the case studies and the literature that there was no one model for effective procurement in supply chains. In fact there existed a spectrum of approaches to developing complex engineering products where a chain of buyers and suppliers are involved.

Figure 1 Spectrum of buyer-supplier relationships in design and development

At one extreme we find traditional in-house design and development. For example, British Rail's signalling engineers, until recently, designed most signalling equipment in-house with external suppliers providing standard or specialised components and manufacturing the equipment. In this approach design and development is clearly under the control of the buying organisation and hence is labelled 'Buyer-driven' in Figure 1.

At the other extreme there is fully devolved design. Our case study example was British Coal (before its recent privatisation), in which equipment suppliers have taken total responsibility for design and development of new underground mining machinery with minimum interference from the buying organisation. In this approach the suppliers are controlling the development process, hence it is labelled as 'Supplier-driven' in Figure 1.

In between are the cases in which the buying organisation is attempting in different ways to devolve design and development work to suppliers, but retain some degree of involvement and managerial control. Conventionally buyers have done this by providing detailed specifications for competition between suppliers to win the contract. In British Rail specifications of up to 4,000 pages have been known. Secondly there has often been a large 'scrutiny' function by in-house engineers which involves checking the tenders and the successful contractor's design. More recently, as mentioned earlier, progressive buyers are trying to enter into various forms of partnership relationship with selected suppliers for design and development.

Most of our case studies are examples either of adversarial competitive tendering or of attempts by organisations to introduce partnership sourcing for product development, because it is in this middle part of the spectrum that the greatest problems of design management occur. In both these approaches it is the buyer, as the organisation that commissions the design and development work, that is driving the process . Hence both competitive tendering and partnership sourcing are classified as 'Buyer-driven' in Figure 1.

Recently another approach has emerged, which might be called 'Supplier Interactive' design. This is where the supplier designs and develops a new product in close consultation with its main customers. This is often found in the computer industry, where the main computer suppliers will develop new systems in collaboration with their main customers, such as banks [27]. Another example is Boeing's development of its new 777 airliner in which the company's main customer airlines were represented on the design team [28]. The difference between this approach and Partnership Sourcing is that it is the supplier rather than the buyer that is initiating the product development process - hence it is classified as 'Supplier-driven' in Figure 1.

CASE STUDIES OF PRACTICAL EXPERIENCE

In this section four of our case studies are summarised [29]. These outline how two railway operators and two other business organisations successfully work with their main suppliers in the specification, design, development and introduction of major new engineering products and equipment.

The case studies show that the approach to procurement and design management taken by these organisations depends on several factors. These factors include the history, ownership and nature of the business concerned (in particular whether it is primarily a manufacturer of engineering products or a service operator which uses such equipment). In addition the management approach will depend on the technical strength of the supply industry and degree of technical innovation involved in particular design and development projects.

Given the variety of possible circumstances, the four cases below represent only a few points along the spectrum in Figure 1 of the ways that a buying organisation might effectively work with its suppliers in the management of major engineering design and development projects.

'Developing cooperation': British Rail's 'Stoneblower'

This case study was undertaken when British Rail was still responsible for rail infrastructure and concerns the development of an highly innovative machine for

railway track maintenance called the ‘Stoneblower’. This machine, which measures track irregularities, then raises and blows small stone chippings under railway sleepers in order to maintain track geometry, was originally invented in British Rail’s Research Department. It has been developed via two contracts with British Rail's suppliers; firstly to build a prototype and and another to manufacture the production version. Deliveries of the first production Stoneblower are due to commence in late 1995.

The project was technically difficult and developing the prototype taxed both British Rail’s and the external contractor’s engineers. However, a root cause was the difficulty in managing the relationship with the external contractor. Following a review, a full-time project manager and a new supplier were appointed and since then Stoneblower project has progressed well.

British Rail's internal research department designed and built an experimental Stoneblower machine, but then chose to use traditional, price-oriented, competitive tendering to obtain an external supplier to develop a prototype. The Stoneblower represented a considerable advance on existing track maintenance vehicles and several companies submitted low tenders in an attempt to get hold of the technology. This reaction illustrates how inappropriate adversarial competitive tendering is for such development contracts.

British Rail (BR) intended to go to tender to select a supplier with whom to collaborate on the development of a prototype machine. However, the nature of the collaboration was never specified and there was nothing in the contract to ensure cooperation took place. In practice, the successful bidder took the opportunity to obtain almost total technical and managerial control of the project. There was very little interaction with BR engineers and many lessons from the experimental machine failed to be fed into the prototype’s design. When delivered, the prototype Stoneblower failed to perform as well as the experimental machine and was highly unreliable. A protracted and costly development period thus became necessary.

This unsatisfactory outcome led BR to conduct a thorough review of the project. The review concluded that the Stoneblower concept was technically sound and that developing the prototype into a reliable production design was financially justified. However, to do this required a stronger project management system.

Although BR had a Stoneblower project team, including two project engineers, project management was weak; managing the Stoneblower was one task among the general responsibilities of the Permanent Way Engineer. He only had a limited amount of time to devote to the Stoneblower and the rest of the project team did not have the authority to act without his consent. This very much limited the project team and

manager's abilities to cope with what had become a complex and difficult task. The BR review concluded that a full-time BR project manager was needed together with appropriate backing from the organisation.

Under this new structure, the Stoneblower project progressed successfully. Although BR retained competitive tendering to procure the initial production batch of Stoneblower machines, they developed innovative features in their tender specifications to detail the reliability standards required. This had not previously been done for track maintenance machinery in Britain. In addition, suppliers were thoroughly evaluated via visits and references from their existing customers to evaluate, among other aspects, their ability to work cooperatively with their customers.

The contract was awarded to an American subsidiary of a British group on the basis not only of price, but also technical capability and approach to project management. This succeeded in producing an open and cooperative partnership approach within the confines of a legal contract. An example of this open and cooperative manner of working was the flexibility involved in reaching the reliability specifications. This was a difficult process, requiring considerable improvements over the industry standard. BR and the contractor had to study closely the elements in the design that determine reliability and sometimes trade off one aspect against another in order to hit the overall desired target. The end result was that not only were the reliability targets met, but through this contract, the supplier strengthened its reliability engineering capability. By being a good customer, BR helped its supplier to improve.

Overall, the well-supported cooperative management approach by both BR and its supplier worked well. It is this attitude that makes the Stoneblower project manager optimistic that the Stoneblower will ultimately turn out to be a successful innovation.

Several lessons and issues arise from the Stoneblower example:

• For a development of this scale and novelty, sufficient human resources need to be dedicated to project management by the buying organisation: normally this will involve a full-time ‘heavyweight’ project manager [4] who has full backing of the organisation.

• Cooperative partnerships are a way to enhance the engineering capabilities of suppliers.

• The cooperation needed for innovative engineering design and development projects can in some cases be generated within a framework of competitive tendering, which is normally associated with adversarial buyer-supplier relationships.

‘Cosy partners’: Netherlands Railway’s ‘Railhopper’

The next case study concerns the development of a new design of suburban electric train the SM’90 ‘Railhopper’ for Netherlands Railways (Nederlandse Spoorwegen or NS). In this example we see how a national railway works closely with a few favoured suppliers in the specification, design and development of a prototype new train and how it intends to maintain a close relationship with its suppliers in the context of new European legislation on competition.

The strategy of NS is to introduce a new design of passenger train about every twenty years and then to incrementally improve that core design in subsequent orders until studies of life cycle costs indicate that investment in another new design is worthwhile. The Railhopper was such a new design planned in the early 1980s to replace an existing fleet of suburban electric trains. Although the Railhopper was of the same basic type as the trains it was planned to replace, it incorporated several technical innovations including three-phase electric drive and lightweight construction. Its development to date has followed a typical pattern adopted by NS.

At an early stage an in-house multidisciplinary group was established to draw up a ‘functional specification’ of the proposed new train. This specified the vehicle’s performance requirements, provided some basic technical choices (informed by preliminary discussions with NS’s favoured suppliers) and outlined a development programme. Together with other information, this specification provided the case needed by the NS Board to approve the design, development and construction of prototype trains. A multidisciplinary project team under a dedicated project manager was then established to develop the technical specification and manage the project through to completion. Developing this technical specification was a two-stage process with close involvement at the second stage by NS’s preferred suppliers, including the train manufacturers Waggonfabrik Talbot and the traction system company Holec. A preliminary technical specification was sent to the few suppliers with which NS has long-term relationships and, from the responses received, the technical specification and preliminary designs were developed further with the various suppliers through to the final technical specification, which was then agreed before the order was placed.

NS also maintains direct contact with the suppliers of all major systems in its vehicles in order to be able to influence the concept development of such systems.

Once the technical specification was agreed, responsibility for developing the design and manufacturing the prototypes to satisfy the technical specification, including agreed reliability targets, lay with the suppliers, particularly the main contractor.

However, NS rolling stock engineers were available to help tackle any technical problems on the understanding that contractual responsibility was with the supplier. For example, some of design ideas for the Railhopper's lightweight body came from NS engineers. The buyer's engineers therefore had a continuing role in developing the prototypes, as well as being responsible for checking that the design was satisfactory. The general aim is cooperation in design and development between NS and its suppliers with penalty clauses, for example over reliability, being viewed as a last resort. This partnership approach contrasts with the more adversarial position taken by British Rail, both in terms of the procurement process and the 'fault-finding' engineering scrutiny function.

NS's close relationships with a few suppliers has, in the past, been driven by official policies to protect the local rail industry. Although such protectionism is now not permitted under recent European Union legislation, NS's close cooperation with certain suppliers contains lessons that are of more general relevance. NS still intend to achieve a high level of cooperation under the new EU rules by continuing to work closely with a few pre-selected suppliers on the specification, design and development of new trains rather than changing to a system of open competitive tendering. However, as NS is currently being split into several business units, each of which will be responsible for its own fleet, procurement policy is under review.

Some of the lessons of the Railhopper example include:

• Long-term relationships built up over many years with particular suppliers can facilitate cooperative working in the specification, design and development of new products. However, there are dangers of such sole supplier relationships becoming too 'cosy' without the stimulus of competition.

• A multidisciplinary project team in the buying organisation under a dedicated project manager is needed to provide and manage the technical, commercial and other inputs required for such cooperative working.

• A two stage procedure, in which a preferred supplier is involved at the second stage to help develop a preliminary specification into the final technical specification for a new design before the contract is agreed, may be a useful model for other organisations, including those operating in a more open competitive situation than NS.

• A strategy based on developing major new designs only infrequently allows time to be devoted to careful specification and the development and testing of prototypes within limited technical resources available in the buyer and supplier organisations.

‘Becoming cooperative’: Rolls Royce aeroengines

The third example concerns Rolls Royce, a world-class manufacturer of high-thrust civil and military aeroengines. This company is in the process of transition from an approach in which most research, design and development was carried out in-house towards an increasing reliance on cooperative partnerships with its suppliers for these functions. This is driven by the need to maintain a high level of product quality and innovation, reduce costs, and speed product development. The company currently designs in-house around 60%-75% of its aeroengine parts and components by value, compared to nearly 100% twenty-five years ago. The key issue, as Rolls Royce managers see it, is not the administrative arrangements for making the transition, but implementing these in an effective way, often against the grain of the old culture.

While there has been relatively little design devolution in Rolls Royce’s core engine technology, such devolution has been particularly strong in the design and development of control systems and accessories. But whether designed in-house or not, the purchasing of parts and components has been by competitive tender. However, it is increasingly becoming clear to the company that this approach was not achieving the required results, particularly on parts where the design responsibility was vested with the vendors. Non-compliance with specifications, poor reliability and increased life cycle costs have been significant customer irritants. In Rolls Royce’s experience, therefore, a move towards a supplier partnership philosophy is essential.

Managing the transition is involving a major effort for the company. In 1991 a task force was established to examine ways of improving the purchasing process for engine parts designed in-house but manufactured externally. This was followed by another task force to improve the process for parts and components where both design and manufacture were devolved to suppliers.

For the purchasing of engine controls and accessories new procedures have been established for managing the relationship with suppliers for both in-house and devolved design. In both situations all possible suppliers world-wide are identified and then narrowed down to a few contenders for the particular contract. In the in-house design process, Rolls Royce engineers do the conceptual design work before asking two short-listed suppliers to quote for the work. One chosen supplier then collaborates with Rolls Royce in producing a satisfactory detail design and/or prototype before the contract is awarded. For devolved design, an original shortlist of at least five suppliers is reduced to two or three, based on their technical and commercial response to a Rolls Royce’s performance specification plus replies to a supplier evaluation questionnaire.

Rolls Royce then collaborates with one or two selected suppliers to develop the component concerned to the detail design and/or prototype stage. The contract is only awarded to one supplier after a satisfactory design review. As in NS, there is a two-stage process with close buyer-supplier collaboration in design at the second stage.

In this way selected suppliers collaborate with Rolls Royce engineers on the building of the specification and/or development of the design before the award of the contract. The supplier who gets the contract is thus committed to playing its part in achieving key design objectives.

However, the change in terms of new administrative policies and procedures has proved to be only a minor part of the effort. Implementing the change appears to be a relatively long term, highly culture-responsive, adaptive process. This requires consistent (and sometimes even courageous) management commitment, acting quickly to counter threats to delicate emerging relationships with suppliers. Rolls Royce managers have had to take a number of measures to overcome implementation problems and help designers and engineers learn new skills and ways of working. For example, ‘facilitators’ have been appointed to ensure that the partnership processes are actually being adopted and purchasing managers are being used to train engineers in ‘supplier management’ skills such as ensuring that suppliers keep to development schedules.

The lessons from this example include:

• Making the transition from in-house research, design and development plus competitive tendering, to working in partnership with suppliers involves a major change in culture and methods of working. Implementing the change therefore takes time and needs significant management commitment and effort in order to succeed.

• By collaboration on design and development before the award of a contract for the manufacture of a component, suppliers are encouraged to bear their full share of risk and responsibility for producing a design that is fit for purpose.

• There appear to be clear benefits from partnership sourcing. For example, design changes can be identified early in the development process, thus reducing costs and greatly improving lead times; many suppliers are more in touch with new developments than in-house engineers; and involving suppliers in design reduces design-for-production problems.

Fully devolved design: British Coal's underground mining machinery

The final example is concerned with the procurement and introduction of new underground mining machinery by British Coal prior to its privatisation in early 1995. The machines concerned are: power loaders (for cutting coal in longwall mining used in Britain) and armoured face conveyors (for transporting cut coal from the coal face).

British Coal (previously the National Coal Board - NCB) had undergone a radical shift in its approach to the introduction of new mining machinery. In the 1950s and early 1960s, NCB engineers designed, developed and tested underground mining machinery and the equipment supply industry refined and manufactured it. From the mid 1960s to the mid 1980s there was a gradual shift away from in-house design and development towards joint ventures with the supply industry and the industry developing its own machinery for sale to the mines. In the mid 1980s–given a greatly reduced resource base–top management decided that British Coal's business was mining and selling coal, not developing mining equipment and, from then, all major underground mining machinery was designed, developed, tested and manufactured by the equipment suppliers. Many of British Coal's engineers and in-house testing expertise moved to the supply industry, which is dominated by a few world manufacturers and is now technically strong. In the past NCB engineers created much of the innovative machinery used in the longwall mining system [30] and the supply industry developed it. Recent technical development is mainly evolutionary and has largely taken place in machinery suppliers outside Britain.

The relationships between British Coal and the manufacturers of mining machinery had always been close, involving much informal contact between the two. Where supply of an item of new or modified mining machinery was involved, manufacturers would discuss concepts with British Coal engineers to establish whether there was likely to be a need for the machinery for a particular operational application. The risk involved in designing and developing the machinery to the production version was entirely with the supplier and British Coal was under no obligation to purchase. These manufacturers were prepared to take all the risk because of the high value of the equipment concerned and prospects of further sales on the world market. During development British Coal engineers monitored the design work and approved the equipment for compliance with various safety acceptance schemes while the manufacturer would keep them informed of test results on the machinery. If the tests were satisfactory British Coal usually gave the machinery a field trial under operational conditions (normally of 6 months duration). Only when the machinery had proved itself in the field trial in terms of performance, reliability and cost would British Coal

decide whether or not to purchase the equipment. An exception could be made if the machinery has proved itself safe, reliable and effective in overseas mines, but even then British Coal often required a field trial to prove the machinery under specific local conditions.

The lessons of this example include:

• British Coal successfully made the transition from an organisation which designed and developed its own mining machinery to one which obtained this equipment entirely from the mining machinery suppliers operating in the world market. The main role of the small complement of in-house technical staff was to ensure that the equipment was safe and performed satisfactorily and reliably before being given general approval for purchase and use.

• Making this transition has taken time and could not have been accomplished without full commitment from top management and a champion of change at Board level.

CONCLUSIONS AND ISSUES

As was shown earlier in Figure 1, there are many possible approaches to managing engineering design and development where chains of buyers and suppliers are involved. Our case studies have identified several factors that determine the extent to which it is appropriate to devolve design and development to suppliers. These factors include the type of industry, firm and product, and our studies indicate that it could also vary according to the level of innovation concerned – evolutionary designs may be more amenable to procurement by competitive tendering than innovative technological developments, which are more likely to require stronger partnership relationships between buyers and suppliers.

One of the key factors identified earlier is whether the buying organisation is primarily a manufacturer or a service operator. This indicates that the most appropriate approach to engineering design management varies according to where a particular organisation is located in the chain of buyers and suppliers (see Figure 2).

Figure 2 Appropriate buyer-supplier relationships for product development at different levels in the supply chain

The evidence from the literature [16, [31]] suggests that for a service operator, such as an airline or railway, a fully devolved, or a supplier interactive, approach to the design and development of major engineering products is most likely to produce the best results. In other words, for such organisations the ‘Supplier-driven’ approaches in Figure 1 are likely to be more effective than the ‘Buyer-driven’ approaches.

Historically-established approaches of in-house design and development by service operators, such as railways, is usually no longer appropriate for obtaining major new equipment. Today, in-house design and development is probably only justified if there are no suitable external suppliers willing to provide the equipment required.

For service operators or equipment end-users, fully devolved design can be a highly effective option. We have shown the successful shift to this approach by British Coal. This is also the approach of the airlines, who buy the aircraft they need from the world's aircraft manufacturers. The manufacturers obviously consult the airlines about what they need, but the airlines do not normally commission the development of new aircraft nor do any design or development work themselves. It is an approach that has resulted in highly reliable, technically advanced and efficient products [16].

However, this 'airline model' of fully devolved design is not appropriate in all cases. If the supply industry is not technically strong, the buying organisation's engineers may have to become involved in helping the supplier with design and development. This has been the argument used by the railways to justify their drawing up of very detailed specifications for competing suppliers and then closely monitoring the design and development work of the chosen contractor. However, as was noted earlier, this competitive tendering approach has not been very successful, often resulting in delayed and unreliable products. In our case studies, British Rail's prototype Stoneblower railway track maintenance machine suffered from these problems.

It is to overcome such problems that many organisations, including British Rail, are moving towards a partnership sourcing approach to design and development. In BR's case it remains to be seen how successfully this change is implemented following the restructuring for privatisation, but the experience of other service operators suggests that such buyer-supplier partnerships can be effective. We have described how Dutch Railways, for example, has traditionally worked closely with a few local suppliers to develop its trains. After the early problems, a similar partnership approach was adopted to develop the Stoneblower, which now looks as if it is going to be a successful product.

So far we have discussed service operators moving towards the 'airline model' of fully devolved design. This approach is, of course, not suited to manufacturing organisations further down the supply chain, whose main function is the design and development of products and components. For such manufacturers – both main systems suppliers and their major subcontractors – a mix of in-house design and partnerships with key suppliers seems to offer the best combination (Figure 2). The

precise mix will depend on where the greater design competence lies, in the manufacturing company itself or with its suppliers.

For manufacturers attempting to introduce partnership sourcing, the main problem is making the cultural changes necessary to create real partnerships with suppliers. In particular, the Rolls Royce case study shows that establishing a culture of cooperation, openness and trust between buyers and suppliers may require special provisions to stop engineers and others 'reverting' to the old adversarial culture.

Another very promising approach, relevant to both service operators and their main suppliers, is the 'supplier interactive' model. It arose as a result of drawbacks in the fully devolved approach to procurement, such as delays in product development due to late design changes being demanded of suppliers by their customers. Boeing's development of its new 777 airliner has already been mentioned as a good example of this approach. For the first time a major aircraft manufacturer directly involved its main customers – the airlines – in the design and development of a new civil aircraft, not just its specification. Although in this approach the supplier remains in control, the buyers' representatives become full members of the design team and can influence design decisions from the beginning of a project. For instance, on the 777 project, the representatives of three launch airlines were involved in Boeing's 'design-build' teams and suggested, for example, that the aircraft's interior should be flexible to allow different mixes of first, business and economy class passengers to be carried [32].

The value of the supplier-interactive model has been demonstrated in other industries too. Studies of the machine tool and textile machinery industries have shown that the suppliers which actively involved their customers in research, design and development were more likely to produce successful new products than the suppliers which only involved customers when the product was ready for delivery [1].

Recently a number of hybrid approaches have emerged involving new relationships between buyers and suppliers of engineering equipment. These include approaches in which manufacturers are not only designing and making equipment for service operators such as railways, but also taking on many of the former functions of those operators. New supplier responsibilities range from maintenance of the equipment they have developed, through to financing of projects and even operating the service itself [33]. For example, the new trains being supplied to London Underground's Northern Line involve the supplying, on lease, of sufficient rolling stock to operate a particular level of service—with the design, building and maintenance of this fleet being the supplier's responsibility.

Our case studies and the literature have shown that choosing an appropriate model for managing design and development in a complex supply chain is important. However, making the transition from one approach to another, in terms of the detailed implementation of new procedures plus the associated changes in organisational culture, is equally important and is usually more difficult. Buyers and suppliers in some industries, such as airlines and aircraft manufacturing, have built up considerable experience in managing devolved engineering design whereas others, such as railways, still have much to learn.

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