Chapter 6

Finding a Lever to Move the World: the design paradigm and its value

The foundation of the current form of globalisation is a technical system designed in a social context. This chapter introduces a framework derived from design research and design management. This is developed in the following chapters and can be used to analyse strategies and alliances intended to diffuse innovation in design and development practice across regional and organisational boundaries.

The stresses inherent in the emerging global system described in Part I were highlighted by the difficulties of the East Asian economies following a period of unprecedented growth through the nineteen-eighties and into the early nineteen-nineties. The tight coupling of the emerging system propagated the diverse problems of these individual nation states across much of the globe while the failure of a number of states in Africa and elsewhere emphasised the problems of exclusion from the system.

A design perspective is critical to the consideration of opportunities and obstacles for effective participation in a globalising system and the achievement of meaningful development. Local initiatives aimed at entering the global production system can be mapped on to a generic model of the design process. This model accounts for the distinctive intellectual and physical resource requirements of the invention and initial innovation stages and the very different requirements of the mature manufacturing phases of the product life cycle. This gives a means of gauging the effectiveness of participation in the global nexus of production and consumption by both newer entrants and established players. A design framework offers a means of evaluating potential technology transfer and the developmental value of the participation on offer from inward investors.

The design and development of a range of advanced technologies are discussed in this chapter and the following chapters of this section. These technologies have been determined by the priorities of advanced economies. They in turn determine the prospects for less developed economies of either joining or abstaining from a growing global system.

Crisis and Continuity

At the close of the twentieth century events in the East Asian economies undermined the idea of a rapid and unproblematic process of globalisation, driven by “miracle economies”. As noted in Part I, Krugman (1996) criticised the acceptance of high growth rates over relatively short periods from very low base levels as evidence of such miracles. Unfortunately the immediate impact in the West has been the rejection of the development strategies which had delivered genuine growth. It was argued earlier that at least part of the current crisis in East Asia reflected the difference between the problems of technological leadership and those of catching-up with leading economies. The very different forms of crisis across the affected economies and the different responses at national level reflected the diversity of approaches within the region. Chapter 2 noted the work of Orru, Biggart and Hamilton (1991) which revealed strikingly different forms of intra-societal isomorphism among the relatively new industries of Japan, Taiwan and South Korea, despite their close historical associations.

Part III will return to the cultural and institutional dimensions of development, this Chapter considers the consequences of the success of the strategies of the growing economies described by Orru et al (1991). Eventually a paradigm shift is required from catch-up strategies which involve identification and adoption of best practices to the sustained innovation of new technologies and associated practices.

Economies such as South Korea which have been highly successful during the catch-up phase of development show that different socio-economic paradigms are needed to sustain growth in the conditions of lower absolute growth encountered in relatively mature markets. Korean companies have invested in the developing markets of the candidate states due to join the European Union in 2004, while accessing the intellectual capital of developed economies through the acquisition of research and development resources, as noted in Part I.

Participation in the development of the intellectual resources necessary for the next stage of development requires even more direct integration into the emerging world system and a greater institutional alignment within and between regions. Japan’s failure to build a new policy consensus following the collapse of the bubble economy has led to the term “lost decade” being used to describe the apparent hiatus of the last decade of twentieth century Japan (e.g. Hayashi &. Prescott, 2002). Key institutional arrangements, such as the readily available long-term finance sourced from within the Japanese *keiretsu*, are increasingly recognised as a liability not an asset both within and beyond Japan itself. The resulting accumulated bad debt is a major component of the current economic and political impasse.

China, as East Asia's largest economy has continued with high growth policies. However, this size also increases the problems of regional differentials in development. The successful business networks of Hong Kong can only be developed so far into the wider hinterland of the Special Administrative Region before cultural and linguistic differences impede their further extension (Yu & Robertson, 2000). As noted in Chapter 2, the Chinese government now acknowledges the problem of differential growth and the difficulties of matching the rapid advances in favoured coastal regions in the interior provinces (Information Office of the State Council of the P.R.C., 2001).

European and North American companies have sought to emulate aspects of Asian strategies for some time and comparative advantage has been eroded as Asian methods, building on the Western industrial model have been re-exported to the original industrial core of Europe and North America. Nuki (1998) shows that this in turn has engendered a response based on accelerating the product life cycle through the application of ICTs at all stages of development and production. This aspect of direct engagement with the timeframes of technical development is taken up in the next chapter.

Repositioning across a Global Production Web

Mature, developed economies are committed to remaining at the cutting edge of technology in a maturing global market. The opening chapter argued that many companies are directing their attention to the end of the production chain where product differentiation and customer support can maintain demand for goods and services. As a consequence, the distinction between products and services becomes less obvious. The high value end of the chain requires closer adjustment to cultural variation among users and customers and gives high cost regions some prospect of retaining these activities. James and Howell (2001) suggest that access to both broader intellectual capital for technical development and local knowledge for precise market adjustments are the objectives of East Asian inward investment in European research and development. The encouragement of both the British government and the European Commission to companies seeking alliances and opportunities in the opposite direction was noted in

Part I. This reflects both aggressive movement into potential markets and defensive development of low cost offshore manufacturing resources to support home and export markets.

The repositioning of ICL (International Computers Limited), from computer hardware manufacturing to information services provider was mentioned in Chapter 1. Further evidence of a "value chain" approach (Porter 1990) can be seen in a very different industry. Two EU-based trans national corporations, Imperial Chemical Industries (ICI) and Unilever have been engaged in shifting their assets along the production chain, to the area of higher added value. Unilever passed its specialist chemical division to ICI in 1997 in order to concentrate on the delivery of differentiated brands based on these generic materials (Bennett, 1997). Meanwhile ICI has off-loaded it own bulk chemical business to firms content to compete primarily on price at the commodity end of this chain (Chemical Week, 1998).

Dicken's (2003) use of the production chain to analyse the dynamics of the global economy is revealing. In common with Porter's representation of the value chain[1], a range of critical support activities is modelled at each stage of this generic model. Dicken demonstrates the traditional view of the service sector as evidence of a "post-industrial" or advanced economy. The emergence of a dominant quaternary sector is seen as the logical development of a preponderance of intellectual capital over physical capital. The dynamic growth of deregulated financial services and the broadly perceived shift from manufacturing to service industries supports such a view.

The diversification of as prestigious an engineering company as General Electric into financial services that now yield greater turnover than its engineering efforts might seem to confirm services as the successor to primary, secondary and tertiary activities. However, primary production is linked with quaternary, post-delivery support of goods and services, a variety of service activities is wrapped around the core thread of the production chain. A clear distinction between primary, secondary and quaternary activity is difficult to justify since primary production is the essential precursor to all the other forms of activity. Consequently the most advanced technologies have been applied at every stage of the production process. Sophisticated artificial intelligence programs have been developed to optimise primary extractive mining activities in Australia. Currently global positioning (GPS) equipment is available in agriculture to monitor productivity via harvesting equipment (Forristal & Keppel, 2001) while satellite imagery is available to monitor the extent of reserve resources or environmental hazards (e.g. Bastiaanssen 1998, Sudhakar et al 1996).

Design Paradigms and Paradigm Shifts

For developing economies a successful paradigm shift from catch-up strategies based on rapid growth rates on a low cost base to technological leadership requires a broad level of analysis. Global links to regional economic activities must be considered. In addition, the repositioning of effort across the production network can be better understood from the perspective of the design philosophies and methods that have been applied to both product and processes during the second half of the twentieth century. A critical view of a region's resources and capabilities and their relevance to development requires a shift in the view of innovation and product-life cycle to that of process life-cycles. This is akin to a shift from single to double loop learning (Argyris and Schön, 1974).

Galbraith (1977) staked the claim that information system design was in effect organisation design. Information systems designers have in turn drawn heavily and effectively on the wide body of more general design research and theory outlined in Chapter 3.

In parallel to the development of organisation theory through and beyond the framework of systems theory discussed in Chapter 3, design methodologies have reflected a changing understanding of the processes and the role of the participants and wider stakeholders in them. Scott (1992) argued that organisation theory could be seen as developing from the closed rational systems view of classic management theory to an open natural systems view able to accommodate influences from the institutional and technical environments. Chapter 7 introduces the notion of institutional and technical time-frames while Chapter 8 looks at the wider relationship between institutional innovation and the absorptive capacity (Cohen & Levinthal, 1990) of national economies. This chapter examines the internal characteristics of the technical design process and in particular the nature of incremental and systemic change.

Jones (1980) presents design methods extant in the sixties and seventies, and relates them to generic models of the design process. This model, introduced in Chapter 1, consists of three stages:

- Divergent Search
- Transformation
- Convergence

In the *divergent* searching of the possible solution space for a design problem, the objectives are unstable and tentative, the problem boundary is unstable and undefined and the evaluation of alternatives is deferred. The design sponsors' brief is a starting point, subject to revision and the aim is to increase uncertainty and widen the range of possibilities.

The *transformation* process involves the imposition on to the results of a *divergent search* of a pattern which will allow convergence to a single solution. At this stage of the design process objectives, briefs and boundaries are fixed, critical variables and constraints are recognised and the problem is divided into sub-problems for parallel or serial treatment. The freedom to change sub-goals, and to evaluate alternative choices rapidly are needed and the personal capabilities and orientation of the design team are critical at this stage.

The *convergent* activities have as their objective the reduction of uncertainty. This stage requires a very different orientation and according to Jones, persistence and rigidity of mind become a virtue. Unforeseen sub-problems may present problems at this stage, and cause recycling to earlier stages. The models used to represent remaining alternatives become more detailed and concrete.

The transfer of mature technologies, and the cost-driven relocation of relatively labour intensive manufacture and assembly processes can be seen to reflect the convergent stage of design. In the context of the production chain presented by Dicken (2003), the relative success of the newly industrialising countries can be seen as a highly effective entry at the convergent stage of the design and production process. This requires mastery of efficient production utilising mature technologies.

The creation of new products from available technologies, is associated with the success of Japan, particularly in consumer electronics and automotive products from the nineteen-sixties to the nineteen-eighties. These capabilities map on to the transformation stage, and represent a more demanding set of analytical skills. Arguably Japan is accomplished in the transformation stage with highly innovative products derived from newer technologies, but less proficient at the divergent stage which can be likened to the development of basic research strategies and requires the uncertainty-generation of the divergent phase. Part of the recent policy response has been to increase the budget for basic science and to embark upon education reform (Goodman and Philips, 2003).

Economies such as Malaysia, despite efforts to shift to transformative and divergent activities via the Multimedia Super Corridor[2] and related initiatives, still retain a high proportion of the essentially convergent tasks of global production (Wilkinson et al; 2001).

Jones' essentially linear model of design can be seen in a different form as the "waterfall" model of information systems design (e.g. Birrell & Ould; 1985). Here the need for re-cycling indicated by Jones is accommodated between successive stages of development and refinement. The waterfall model can also be reflected in Dicken's chain: the global redistribution of the components of production can be seen to be dependent upon effective communication across the feedback loops linking each stage. In practice these are dependent, on globally available ICTs.

The variety of responses of players to the emerging new web-oriented "techno-economic paradigm" (Dosi, 1986) is instructive for both nation states and sub-national regions. For example, Taiwan's relatively effective response reflects a range of cultural and economic linkages, both to Japan as former colonial power, and Greater China[3].

Taiwan has followed a classic route of state sponsored development, particularly in the area of information technology (Tsai; 1993). Companies such as Tatung reflect the same Japanese colonial influence which produced the sprawling portfolios of the Korean *chaebols*. However, the *chaebols* closely mimic the strict hierarchies and rigidities of the pre-war Japanese *zaibatsu*. In addition, the nature of state patronage through credit rationing in Korea (Zeile; 1996) encouraged companies to second-guess areas of potential state support by moving into business sectors in anticipation of future support. This has created even greater diversity within the company groupings than in the original Japanese model.

In Taiwan the mix of traditional Chinese business networks described by Numazaki (1996) with a state provided or sponsored infrastructure has produced a different outcome from Korea, although both countries were colonised by Japan. The relatively narrowly targeted strategies of Taiwanese firms have delivered world class performance in key areas of information technology. Global dominance has been achieved in motherboard design and fabrication. The manufacturing capability in the "silicon forge" service provided to overseas designers requiring prototype microprocessor chips has allowed participation at key points in the production network. Foreign companies operating in Taiwan, such as Texas Instruments, do so in order achieve the timely production of high-value products, not to pursue outright cost advantage. From this level of performance, companies such as Acer have developed a more integrated presence as full-range manufacturers[4]. This chapter looks at aspects of design decision-making that reflect the capability to make such a transition.

Design Strategies: Incremental and Systemic

Part I argues that the accepted view of organisational relationships has moved towards a network or web paradigm. Models of the design process have shifted to accommodate less linear and more situational views of design. This shift from a hierarchical to a network or web view of organisations was foreshadowed by Williamson (1975) in his description of the substitution of markets for hierarchical relationships, Thompson (1967) in terms of coalition formation across the organisation, and by Mintzberg (1979) in the form of work constellations. Within design the acknowledgement of design participation by users (e.g. Cross; 1972) also shifted models of the design process into less hierarchical and more situated paradigms. Avison et al (1998) describe the evolution of Multiview-2, an information systems design methodology intended both to encompass soft systems methods and to accommodate a view of organisations as networks of related but varying interests and priorities.

Design can be regarded as the unifying activity or process throughout the production chain and across the production network. Design determines the output, whether artifact or service, it also determines the configuration of processes and deployment of resources across the network.

Design: Artefacts and Process

Design and engineering history often focuses attention on the visual aspects of the designed artifact, rather than the design process which gave rise to it. Smith (1983) complains that design historians tend to ignore the non-visual criteria which often determine success or failure. He argues that innovation in subsystems is often studied without reference to overall measures of relative performance. For example in aviation dramatic changes in propulsion from propeller to jet should not be considered in isolation from less obvious but equally significant performance related variables such as take-off weight and payload in aircraft. The invisible organisation underlying the selection and development of new technology is equally crucial to the resulting innovation. The preconditions of successful change inevitably involve the interaction of new and existing technologies.

The difference between successful and unsuccessful innovation can be examined through both physical and non-physical qualities. Innovations need to be robust to survive. Gardiner (1986) defines a *robust* design as one bringing together several divergent lines of development to form a new composite design. This radical or systemic innovation phase can then be followed by consolidation and stretching phases. The latter phases distinguish the robust design, which can be extended beyond its original capabilities by incremental change. A correspondingly innovative design which cannot be developed to this extent is termed *lean* by Gardiner. These arguments also encompass the role of clients in determining design specification and strategy (Gardiner and Rothwell, 1985).

The client-designer relationship is one of a range of contingencies affecting design decisions. However, the strategy which emerges during a complex project largely reflects the underlying range of technical choice available, which in turn reflects a range of contingencies which may be beyond the control of the designers themselves. The analyses which follow are based on developments in two key transportation systems: aviation and railways. They emphasise the importance of resources to the success of innovative design. Access to and competence with relevant resources are equally critical to meaningful participation in the development process.

Entering the Jet Age: resources and resourcefulness

Developments in the civil aviation industry provide evidence of the alternative trajectories of systemic, or radical innovation and the incremental, step by step introduction of innovation. Aerospace is a significant global industry, and one in which developing countries have attempted to compete. For example, Indonesia has used licensing arrangements to acquire the skill base for aircraft manufacture while Brazil has enjoyed significant success in competing in the design and manufacture of small capacity regional jet airliners.

Aircraft are a key resource for both development and disaster relief in most developing regions and, for better and worse, mass air transport has transformed the opportunities for the development of the global tourism industry.

In post World War II Britain, systemic innovation can be seen as an attempt to compensate for lack of breadth in technical development, in contrast to the position of the U.S. industry at this time. The lag in British civil aviation is often credited to the wartime agreement that the United States would meet allied requirements for transport aircraft, so that Britain could concentrate on combat types. However, Smith (1983) argues that considerable disparities in performance levels between British and North American civil aircraft already existed by 1939, as a result of British complacency developed in a captive Imperial market.

The post-war application of state of the art military technology to civil aviation, through the Comet airliner programme, was an attempt to overhaul U.S. practice in a single step. The result was an aircraft which Gardiner (1986) has termed a ‘lean design’. It was adequate for the traditional Empire routes with short route stages allowing frequent refuelling, but less well suited to the emerging transatlantic routes, and difficult to re-engine or stretch in specification. The Boeing 707, its U.S. rival was much more successful commercially, although appearing in prototype form five years after the Comet.

Detailed examination of the development of the Comet design, from the original Brabazon Committee No.4 specification for a “jet-propelled mail plane for the North Atlantic”, to the 1949 prototype airliner, reveals the successive revision of a radical design to a more conservative one (Air International, 1977). Early design studies indicated either canard or tailless layouts. By 1945 the DH106 was a 24 passenger four-jet passenger aircraft, but by May the following year a conventional tailplane had been added, although a 40 degree wing sweep was retained. The prototype finally appeared with a modest 20 degree sweep-back to the wing and a conventional unswept tail unit.

This development profile is in marked contrast to that of the B-47 and B-52 bombers, the precursors of Boeing’s 707 airliner. Initially the B-47 medium bomber was a straight-wing design. Marschak et al (1967), in tracing the development of the B-47 and B-52, show just how late in design studies the final six and eight engine layouts were determined. A total of fifty engine configurations were explored for the B-47 after it was selected in design competition in 1944. Subsequently further experimental bomber configurations were explored. In 1949 the XB-55 proposal utilised four T-40 turbo-props. In 1950 the XB-56 substituted four J-35 engines for the six J-57s of the B-47. During the development of the B-52, straight wings were replaced by swept as captured German war-time research was analysed and assimilated. Both turbo-props and turbo-jets were considered, as initially the latter were assumed essential for the required fuel economy and range. The final choice of J-57 turbo-jets came only after serious difficulties emerged in the development of the T-35 turbo-prop engine.

The brief account reveals a striking difference between the progressive retreat from a highly innovative design to a buildable compromise for the British project and the progressive radicalisation of relatively conservative designs for the U.S. programme. U.S. technical development involved no ab-initio commitment to a particular technology. This was the crucial difference from the British approach which was, from the outset, focussed on turbo-jet propulsion, a technology in which the country has a clear advantage. The U.S. designs were focussed on the problem of the intercontinental delivery of nuclear weapons, a military problem of little concern to the U.K.; from that perspective the precise technology employed was secondary.

The development of Boeing's commercial jet transports followed a similar path to that of the preceding military aircraft. The forerunner to the 707 was the Boeing Dash-80 private venture prototype. This was a speculative venture to demonstrate the practicality of air-to-air refuelling from jet powered tankers for the growing fleet of high-speed jet bombers. Consequently it benefited from the enormous research effort put into military aviation in the immediate post-war period in the U.S. Gardiner argues that the design exhibits 'robustness', as evidenced by the progressive extension of performance through successive versions. The relevant design features were derived from military requirements. These included placing engines in under-wing pods, not at the wing root, as in the Comet. This dispersed vital components and reduce the risk of catastrophic damage from aerial gunfire. Gardiner points out the advantage this gives in allowing the substitution of more advanced engines with minimum modification to the airframe in contrast to the wing-root location used in the Comet. Currently a new generation of engines for the surviving fleet of B-52 bombers which will extend their operational lives in to the second quarter of the twenty-first century is under consideration (Air International, 2003)

The Dash-80 design represented the effective assimilation of the rapidly growing understanding of the new technologies. The earliest design studies were essentially jet versions of the piston-engined Model 377 Stratocruiser and KC-97 tanker. Pentagon permission for the production of a civil version utilising the military jigs, was given in July 1955 (Gunston 1980). This represented a considerable cost advantage over rival aircraft, including the projected DC-8 from Douglas, even though not all of the jigs could be utilised.

From the outset Boeing offered a range of fuselage lengths and engine versions, including an adequate competitor to the intercontinental DC-8. Douglas offered only one fuselage length until the DC-8-61 model of 1966 which was stretched by 11.18m. What differentiated Boeing from both Douglas and de Havilland was an appreciation of the marketing advantage of exploiting the flexibility inherent in their design. Subsequently Douglas took this philosophy to heart with the development of its DC-9/MD80 model offering a variety of fuselage and wing combinations (Chant 1980, Whitford, 2002). Following the 1997 merger of Boeing and McDonnell-Douglas, the basic DC-9 design continued in production in the recognisable form of the Boeing 717, with radically updated engines, wings and avionics.

In Britain progressive development of the Comet design, from Comet 1 to 1A and 2 was halted after the discovery of extensive metal fatigue problems following several crashes in 1954. Despite the wing root location of the engines, the original de Havilland Ghost centrifugal flow jets had been replaced by axial flow Rolls Royce Avon engines. This option had first been discussed with its main customer, British Overseas Airways (BOAC), at the end of 1946 (Air International, 1977). In the Comet 4 series alternative outer wing sections produced short range and long range versions. While this version enjoyed brief fame in initiating a jet-powered transatlantic service, Gardiner (1986) points out, that it was operating at the extreme margin of its range and payload in comparison with the Boeing 707-120 and the later 707-320 intercontinental model. Gunston (1980) argues that, despite its original design specification as a trans-Atlantic mail carrier, the Comet was best suited to a medium haul role. A 4A version, with 2.14m cropped from its wing-span and 1.02m added to the fuselage, was developed but not built for the U.S. Capitol Airlines. This led to the Comet 4B version for British European Airways (BEA), with 1.98m added to the fuselage length. The 4C assimilated the long fuselage and the Comet 4 transatlantic wing. Such changes may have been more difficult than with the 707 configuration, nevertheless they represent the manipulation of sub-systems expected in the mature stage of a product life cycle, as suggested by Gardiner and Rothwell's diagram of stages in the evolution of robust design (Gardiner & Rothwell 1985). 'Lean' must be regarded as a comparative term in relation to the two designs and arguably the Comet proved robust within the envelope of its initial performance conception.

It should be noted that, while Boeing's subsequent 727 and 737 models enjoyed some 30% commonality with the 707, the 720 medium range version of the 707 was a substantially re-designed and re-tooled aircraft, despite its very similar appearance.

Gardiner and Rothwell (1985) argue more persuasively that such differences in design are a reflection of the quality of relationships between manufacturers and clients. They cite Boeing's collaboration with Pan American Airlines in the development of the 747 project as crucial to the ultimate success of the venture

Gunston (1980) confirms the importance of client participation in arriving at a marketable design, by recounting the restrictions placed upon the size and performance of the Hawker-Siddeley Trident jetliner by British European Airways. These prevented it competing effectively with Boeing's 727. The aircraft was one of three similar designs offered by Bristol, Avro and deHavilland in response to a 1957 BEA specification for a short-haul jet. As late as December 1956 BEA had insisted that the turbo-prop Vanguard, developed as a replacement for the highly successful Viscount, would meet its requirements for the sixties.

At the insistence of BEA the Trident aircraft was reduced in size, then recognised to be too small. Downsizing the original RB141 6350kg thrust engines for the RB163 4445kg Spey engine caused difficulties in the subsequent re-enlargement.

Attempts at development through the Trident 2 and 3 were hampered by the restriction of this crucial subsystem, ultimately producing the compromise of a fourth RB163 booster engine in the 3B to improve maximum take-off weight. By the time the 3B offered payload and performance equal to its American rival, Boeing's 727 had achieved a dominant position in this sector of the market. Only 117 Tridents were built, against more than 1,800 727s.

Gunston (1980) also acknowledges the delays in the development of the Trident design caused by a government insistence that the company selected by BEA should merge with at least one other manufacturer. This reflected the U.K. government's concern with the size and number of companies in the UK aviation industry. A consortium of the deHavilland, Fairey and Hunting companies was attempted, but this collapsed in 1959, with deHavilland joining the Hawker-Siddeley group. Given this kind of exogenous pressure it is not surprising that the designers should have concentrated on BEA's requirements, to the exclusion of broader marketing considerations.

The ultimate consequence of the disparity in resources between Britain and the United States in aviation has now been played out. While Britain retains a significant industry, it is networked into a number of partnerships and international collaborations. Airbus and the multinational Eurofighter provide significant activity, while British Aerospace Systems is a partner of Lockheed Martin in the development of a new fighter, the F35 most of which will be produced of the U.S. military. An advanced military trainer, the BAe Hawk, is the only completely British aircraft in production. In this key area of technology, even a major economy can no longer stand alone in the development and creation of new products.

British Railways: truncated incremental change

Railways have been a tool of colonisation development and determinant of development prospects (Headrick, 1981). A shift equivalent to that from piston engine to gas turbine propulsion in aviation in railway technology. The change from steam to diesel traction shows similar outcomes.

In Britain the motive power policy pursued immediately after the nationalisation of four large constituent companies in 1948 illustrates the successful application of an incremental approach to an existing, well understood steam technology. Failure to repeat the process with the then rapidly developing diesel technology reflected financial and commercial pressures rather than any lack of understanding of the difficulties involved. These pressures led in 1956 to the abandonment of a pilot diesel evaluation scheme intended to generate sufficient experience for informed selection of a small number of standard designs. Instead the wholesale construction of almost untried designs was initiated. The result was both an unnecessary variety of equipment for identical tasks, and, in several instances, outright failure to produce a useable locomotive.

Post-war conditions indicated that steam traction was most economical in both capital and running costs in comparison with electric and diesel haulage. The operating conditions favouring the adoption of the diesel in the United States during this period did not apply, except in the case of diesel shunting which had been investigated by the major British companies prior to nationalisation. Prototype diesel-electric and turbine main-line locomotives had been ordered or placed in traffic by three of the four private railway companies and these were used by the new owners to gain operating experience.

However, government restrictions on capital investment ruled out any large-scale experiments with new types of traction. Instead existing designs of steam locomotive were exchanged between the former companies, now operating as regions of British Railways for comparative trials. The result was a range of standard locomotives built to a variety of power classifications for both freight, passenger and mixed traffic reflecting the best of existing practise. Adaptations for post-war conditions included attention to ease of maintenance and the ability to deal with indifferent quality fuel.

With the exception of certain components, the designs reflected the practice of the London, Midland and Scottish Railway (LMS), the largest of the four companies nationalised in 1948. Under the direction of William Stanier a policy of standardisation had been followed in the pre-war period. LMS standard designs reflected an incremental adaptation of innovations which Stanier had brought from his training with the Great Western Railway (GWR), following Churchward and his successors. Churchward had produced the definitive design for the 20th century British 4-6-0 locomotive in 1902 and 1906 with the Saint and Star classes respectively. He achieved this with a careful blend of current British and European innovations, such as tapered boiler and four-cylinder engine – in Jones' (1980) terms, convergent developments within a mature technology.

The other two companies, The London and North Eastern (LNER) and Southern railways pursued, through Nigel Gresley and Oliver Bulleid respectively, a more adventurous policy. The latter, having worked under Gresley in the LNER, produced the last wholly innovative steam locomotive design in Britain. The Leader class was intended to achieve the operating efficiencies of diesel with steam traction. The LNER was a relatively under financed company in comparison with the LMS; on the Southern Railway the majority of traffic was carried by electrified lines in and around London. The more innovative approach to steam traction design could be attributed to a lack of the resources needed for a broadly based incremental approach, and to the relative marginality of steam operation on the Southern Railway.

In the modernisation plans drawn up in 1954 it was decided to build no new passenger steam locomotives after the 1956 programme and to terminate the construction of all steam locomotives soon after. The availability of labour was seen as a problem, given the character of steam maintenance work in contrast to working conditions offered by competing industries. Additional concern with the shortage of suitable coal and growing awareness of air pollution had already led to serious examination of alternative sources of motive power. Electrification was the ideal alternative, since the capital cost of such locomotives was between steam and diesel while maintenance was simpler and cheaper than either. The attendant capital costs of power supply equipment and re-signalling meant, however, that these advantages could only be applied to the most heavily used lines.

Diesel traction was chosen to replace steam on an area by area basis so that operating and maintenance practices could be adjusted to the new technology and a clear assessment of the cost and implications of diesel traction made. Nineteen-thousand steam locomotives remained in use, although the post-nationalisation standard types had been used to replace the oldest and least efficient classes. It was envisaged that the process of transfer and consolidation of modern steam locomotives would continue with the introduction of diesel types.

According to Rogers (1980) adequate diesel locomotives were available from foreign manufacturers. In particular the Electro-Motive division of General Motors had already established a standard range of locomotive types. In Britain the English Electric company had the capacity to produce all the components of a locomotive within its subsidiaries and had constructed the main-line locomotives introduced on an experimental basis to LMS and Southern designs. Industry lobbying and government policy favoured British construction, if necessary under licensing agreements, however, General Motors were not prepared to enter licensing agreements at this time.

The opportunity was taken to utilise public investment to create a capacity among British firms in the new traction technology and to create an export potential. A pilot programme of diesel types was developed. Different designs were ordered from a range of manufacturers for assessment during a three year period, prior. Haresnape (1982a; 1982b) details the pilot designs and their proposed distribution across the rail system. Each diesel type corresponded to an existing steam power classification so that traffic managers could readily substitute diesel for steam power on their rosters. The individual manufacturers, their designs and the power typology were to be assessed in use.

Private manufacturers, and BR's own workshops at Derby and Swindon contributed locomotive designs with diesel engines of both British, foreign and licensed manufacture. Both diesel-electric and diesel-hydraulic types were included. The latter were based on current German practice and offered weight advantages. On the Western Region, which alone had no electrified lines, hydraulic transmission was thought to offer greater continuity with steam practice than diesel-electric technology in which the diesel engine provided power for electric traction motors

Before the 174 pilot scheme locomotives were delivered, however, the British Transport Commission ordered the abandonment of the trial period and the accelerated adoption of diesel traction. The rationale for this decision was poor financial performance by the railway and the urgent need to realise projected savings in operating costs from the abandonment of steam in favour of diesel. A reduction in the variety of types was requested, and working parties representing each region convened to produce guidelines. The pilot scheme was a divergent exploration of a new technology, designed to utilise the widest variety of equipment at all levels: control, transmission and power. With little operating experience available, decisions for large scale production were made on the basis of the general performance of the manufacturers involved and reported experience from other railways.

Differential capacity between the companies involved meant that orders had to be tailored to the availability of components rather than traffic requirements. The result was a mixture of medium-speed diesel engines linked to electric transmission and high-speed engines linked to both electric and hydraulic transmission. The issue of electric versus hydraulic transmission was only resolved by comparative tests in 1965 which came down on the side of the former and the abandonment of hydraulic types was not completed until 1977. Several of the diesel engines and the locomotives utilising them were outright failures. One in particular, the Clayton Type 1, was not actually part of the pilot scheme, being ordered in bulk from the drawing board in an attempt to utilise diesel passenger rail-car experience.

Designing the Design Process

Successful innovation and subsequent adaptation to changed circumstances or new applications reflects the availability of technical choice. Success cannot be predicted from the examination of the specific instantiation of a technology in an individual design, since it reflects underlying processes. Continuous or incremental innovation will reflect a well resourced organisation which is able both to construct a range of choice and to identify intermediate stages of innovation, even in conditions of high technical uncertainty. Bold, large-scale single steps in systems innovation are as likely to reflect pressures of time and resources as any greater insight.

Gardiner (1986) regards incremental improvement as evidence of "robust design", and relates this robustness to the adequacy of the brief. Rothwell and Gardiner (1985) contrast the policies observed in two automobile companies, one British, one American, responsible for two models which had been judged equal "best buy" by a consumer magazine.

Ford of Britain held patents equivalent to all the innovations produced by their British rival, the British Motor Corporation (B.M.C.), during the sixties, but chose not to put them into production. The result was a greater range of customer options and retail pricing which delivered double the profit margin of B.M.C. (Gardiner 1986). The Ford designers were able to choose not to innovate. The less capitalised British company pursued technical innovation as a marketing strategy during the sixties, yet was unable to generate a level of profitability sufficient to improve its relative position or to sustain an adequate level of further technical innovation. Within twenty years, as British Leyland, the company was producing the Montego a model which relied on a gear-box produced by Volkswagen, a significant competitor, alongside a fully licensed Honda model marketed as the Triumph Acclaim.

While the aircraft examples raise doubts about the characterisation of particular designs as lean or robust, it supports Gardiner and Rothwell's (1985) focus on the client relationship. The British Railways example indicates how a basically sound design policy can be frustrated by the intervention of exogenous variables, and particularly the imposition of inappropriate decision time-frames, which will be discussed further in the next chapter.

The ‘Robust versus Lean’ design dichotomy introduced by Gardiner (1986) is a reflection of the technical base supporting a design. This base may offer a broad or narrow range of technical options on which specific designs may be based. Incremental innovation involves the manipulation of sub-systems through time to facilitate the introduction of a new technology and associated practices This is also a means of tailoring the technology to an extended range of applications. Such a view raises the issue of how clear the separation between incremental and systemic innovation can be, and whether in fact the key is an adequate understanding of the complex interaction of subsystems. The evidence from Marschak et al (1967) suggests that, when entering a new technology, existing understanding of the implications of design decisions must be extended through experience. The quality and effectiveness of the learning process will depend upon the character of the industry into which the technology is introduced and the nature of existing practices. The term systemic, rather than radical, acknowledges the continuum which leads from the incremental manipulation of variables within a well understood context, to a new design environment.

The product-life cycle perspective indicates a role for continuing innovation in both product and process. Process innovation allows the well-understood product to maintain a comparative advantage over a newer rival with great potential, by reinforcing economies of scale of production. At its initial deployment, a new technology may not achieve any of its potential advantages over a mature and well established alternative. The level of understanding of an existing technology will influence the point at which a commitment to a new alternative will be made. Such understanding may differ between organisations for the same technological base.

With its pilot scheme British Railways attempted to create both the knowledge-base and infrastructure necessary to the successful introduction of diesel traction. Exogenous factors forced the premature adoption of an immature technology and a laudable attempt to produce informed choice resulted in the propagation of untried designs. The forced abandonment of the incremental adoption of diesel traction was doubly unfortunate. The disinvestment from steam meant that many of Chief Mechanical Engineer Riddles’ standard locomotives went to the scrapyard after only a small fraction of their economic life. The investment in an unnecessary variety of diesel replacements and the need to recover the greater capital outlay delayed the subsequent electrification of suitable lines, a result foreseen by Riddles in 1948 (Rogers, 1980).

The Electro-Motive Division of General Motors Corporation was able to continue its own modular and incremental design policy to provide an increasingly powerful and varied range of locomotives utilising a range of well-tested sub-systems. British Rail Engineering was only able to place a comparable product in service in the nineteen-eighties when the Class 58 freight locomotive was designed with consideration of its export potential. In the late nineteen-nineties, following privatisation and the creation of a variety of passenger service providers and a single U.S. owned freight operator, General motors designs finally appeared in significant numbers on British tracks.

Gardiner (1986) relates incremental innovation to the 'consolidated' phase of a robust design, at a point where the basic parameters are understood, and can be manipulated to provide a range configurations and performance characteristics. Rothwell and Gardiner (1985) illustrate this point with the Rolls-Royce RB-211 family of fan-jet engines. The current Trent family of triple-shaft gas turbines represents a systemic innovation within a clear incremental framework.

Incremental innovation is a strategy more easily achieved by large and well resourced organisations. It requires a base of thorough and wide-ranging research which can provide a range of alternative solutions to main and sub systems. A less thorough research base and restricted resources will result in a premature focus on specific technologies and solutions. The range of configurations indicated by Marschak et al (1967) in U.S. post-war bomber studies, and the complex interrelationship between engines and airframes generated by the programmed transition to turbo-jet and turbo-prop propulsion indicates that effective consolidation depends on access to a range of significant alternatives.

The difference between the retreat from the original highly radical proposals for the deHavilland Comet, and the successive introduction of innovative sub-systems into the Boeing aircraft proposals of the same period reflects a fundamental difference in design strategy. A high-risk strategy of systemic innovation typified by the Comet programme indicates a relative lack of resources available to designers. The difference in design policies pursued by the major British railway companies prior to nationalisation can be attributed to similar disparities in resources between them. Paradoxically, well resourced conservatism seems the route to sustainable innovation.

The distinction between incremental and systemic innovation may appear to correspond to Kuhn's (1962) concept of normal science and paradigm shift. However, the accumulated change achieved through incremental design can at least equal the performance improvement of a systemic change. The problem for designers is that radical change reached by this route may not be recognised, and insufficient regard may be given to a new system environment.

Lack of practical experience with the emerging technologies led to similar mis-perceptions in the British Railways pilot diesel programme. The complexities of diesel-hydraulic locomotives were not fully recognised by Western Region engineers. They hoped to avoid the intricacies of electrical engineering in a region with no electrified lines, but as Rogers (1980) points out the control systems alone of these locomotives required sophisticated electronic and electrical care and management.

A specific difficulty with the new aircraft technologies of the post-war period was the difference in characteristics between the prototype aircraft, effectively hand-built, and those subsequently built on the production jigs. This loss of the previous level of continuity between development and production aircraft increased the importance of modification in the light of service experience. At the same time more sophisticated aircraft were being produced in smaller quantities and at much higher unit costs than in the previous decade, a trend that continues, and is discussed in Chapter 9.

The solution attempted was the elimination of separate prototype construction, and the modification of production aircraft on the basis of tests on the initial output of the line (Marschak et al, 1967). Such an approach appears attractive, but offers considerable cost penalties if production jigs must be substantially altered, and early aircraft retrospectively modified. Such a strategy was inadvertently imposed on British Railways by the revised diesel modernisation plan.

The earlier caveat for the users of incremental strategies is reinforced. The incremental adjustment of a number of design components can lead, unwittingly, to a systemic change in terms of performance and environment. Such change may not be recognised, especially in new areas of technology,. since it results from an accumulation of apparently minor adjustments.

In a complex environment, the alteration of a single design variable can lead to considerable interactions. Perrow (1983) examines the example of a change in U.S. naval propulsion systems to improve performance by increasing steam turbine working pressures. He points out that the contingencies of this single variation were not appreciated and necessary adjustments in the working environment were not made.

Perrow argues that the interactions exhibited in such situations consist of unfamiliar, unplanned or unexpected sequences of events. These may be either not visible or not immediately comprehensible. He labels such systems “complex”. They are characterised by proximity of parts not in the principal operating sequence. Common-mode connections may exist between such parts, so that a single error produces effects in apparently remote parts of the system. Unfamiliar or unintended feed-back loops, and many potential interactions between control parameters exist. Only indirect or inferential information sources and limited understanding of some processes may be available to the operators of such a system.

Perrow is principally describing the management of physical transformation processes, as in the chemical industry. However, his terminology can be applied to design problems generally, since a relatively simple design may be deployed in an environment which could involve it in complex interactions.

Perrow (1984) characterises the complexity of a variety of systems on a matrix with two dimensions: interaction –from linear to complex and coupling –from loose to tight. Perrow’s argument is that either high complexity or tight coupling can be handled separately, but when they coexist system management can become problematic, if not impossible. Here it is argued that incremental alteration of an established design can move a system into the area of high complexity and tight coupling, but such a change may not be recognised. Systemic innovation may place a design there, but in such circumstances, designers and operators are more likely to recognise a new environment.

Design and Development

Those characteristics of a problem which are amenable to design intervention may be obscured by complexity and uncertainty, from a variety of sources. If “robustness” can better be expressed in terms of client relations and resource availability and if the effects of uncertainty can be minimised through an incremental approach, will a new environment be recognised if it is entered by such a route ?

The disbenefits of transition to a new technology reflect the relative expense of first generation applications, and the lack of advantages of scale or established support infrastructure. Innovation case-studies indicate that in many areas of manufacturing technology, innovation is associated with new and growing companies which do not face the abandonment of existing capital assets related to the displaced technology. For developing countries there is the prospect of entry into a technology after initial risks have been explored by the early adopters, and with less sunk investment to abandon.

The adoption of specific innovations such as jet propulsion may be prompted by critical comparative advantage in performance that may be sufficient to overcome extreme drawbacks, such as the ten hour operating life between rebuilds of the 1943 Junkers Jumo turbojet. Clearly military technology is an area where small margins can yield decisive advantage and the design cultures engendered in military work are examined in Chapter 9. Kaldor (1981) argues that if an overview of the interactions of increased complexity is not maintained, innovation may become increasingly counter-productive in terms of realised, as opposed to potential performance. Thus Perrow's (1984) model of complexity might prove a valuable guide to the management of incremental innovation in complex systems.

The 707 aircraft and all its derivatives through to the 737 can be said to have benefited from the military market support enjoyed by the KC-135 air-to air refuelling aircraft and its transport variants. However, Gardiner and Rothwell (1985) argue that the lack of a military base for the 747 project was an advantage. It enabled the exacting commercial requirements of Pan American, their sponsoring customer, to be met while their main potential rivals, Lockheed, were engaged with the military C-5 transport. Increasing differentiation between military and civil requirements may be taken as a sign of a mature, or consolidated design environment compared with that existing at the opening of the "jet age" in the nineteen-fifties.

Military transport aircraft must meet a much wider range of airfield conditions than civil designs of a comparable capacity. However, several civil designs, including the 747 itself have been adapted for a variety of military uses. The military derivative of the Comet, the Nimrod anti-submarine aircraft, is still in front-line Royal Air Force service and a programme to re-manufacture the aircraft into a new version was embarked upon (Dawes, 2002), then abandoned on cost grounds.

Clearly for new entrants an adoption policy for technical innovation should aim at the point of greatest immediate comparative advantage. As understanding of the new technology increases, the range of application can be extended beyond the entry point. The Rolls Royce RB-211 engine family is a successful example of such a strategy, with development to both higher and lower power ranges following the troubled development of the initial models. Rothwell and Gardiner (1986) suggest that this initial systemic innovation was facilitated by the existence of a back-up programme. At the insistence of customers, a more traditional alternative to the to the Hyfil carbon-fibre fan blades originally selected was developed. When the innovative blades failed conventional impact tests, this back-up was the salvation of the development programme. This is therefore a case of technical choice being generated at the insistence of the product users.

The cost of developing new designs has increased steadily in the last fifty years. Gardiner (1986) illustrates changing design trajectories, by plotting design engineering time against development date. The utilisation of computer-aided design, shown by the correspondence of the development cost of the Boeing 757 with the nineteen-sixties 727 model, has to some extent broken this inexorable trend. Nevertheless Boeing and other companies are pursuing several strategies to broaden their design base without compromising the commercial prospects of new designs. The design programme for the Boeing 777 model was highly dependent on integrated computer aided design systems which allowed significant savings in development time, and reduced the need for physical models and prototypes to a minimum (Sabbagh, 1995).

One strategy, that of commonality, is not new to Boeing. The pre-war XB-15 bomber prototype, then the world's largest, provided the wing and tail surfaces for the Model 314 transatlantic flying boat. Both the B-17 and B-29 bombers provided wings, engines and control surfaces for corresponding civil aircraft, and some of Boeing's early jet transport studies were based on the B-47. As noted, the first Boeing 707 derivative, the re-engineered, lightweight 720, shared few components, but the later 727 and 737 shared 60% of components. The current 757 and 767 models, while being narrow and broad fuselage respectively, still enjoy over 40% commonality.

Airbus has followed Boeing's lead in producing a complete range of aircraft models, including the A-380, under development to outclass the Boeing 747. The focus of commonality has shifted, however, to the key systems of the aircraft rather than its basic structure and extends to the computerised flight control systems, minimising the re-training required when shifting crews between different types within the range (Airliner World, 2001). The "fly-by-wire" A320 model introduced a cockpit design which became standard for all subsequent types.

Boeing has adopting a risk-sharing approach to production. For example, in 767 production, aluminium extrusions are sent from Pittsburgh to Japan. Fuselage sections fabricated in Japan are then shipped to Seattle, for assembly. The involvement with the domestic industries of customer nations in production also tackles environmental uncertainty by increasing customer commitment, as with the 747 wing components produced in

Australia. This is of importance in an economy operating at the scale of Australia, where the delivery of a single 747-400 aircraft can produce an adverse monthly foreign trade balance.

Both commonality and complementarity benefit from computer-based support. However, the development of computer-integrated manufacturing systems offers a means of eliminating many of the constraints on design variation. It may be possible to offer more diverse options to customers, or to implement revisions in design at relatively little cost by utilising flexible manufacturing techniques. This key process innovation has begun to impact on design maturity and product life cycle, as evidenced by the claims made for gains in the development of the Boeing 777 aircraft (Sabbagh, 1995).

The sophisticated integrated computer-aided design and manufacturing systems pioneered in the aerospace industry have the potential to alter the time required for critical stages of development and production. Interactions between the decision-making time-frames of the different levels of a design system add to the overall uncertainties facing designers. In the case of the British Railways modernisation scheme, they disrupted the generation of knowledge essential to sound technical choice. Any adequate design strategy will have to offer some means of dealing with them.

Chapter 7 examines in more detail the interaction between time-frames. inherent in technologies and in the organisations that develop and utilise them.

Notes

1 See Dicken (2003) fig 2.3, figs and Porter (1990) figs 2.3 and 2.4
2 See http://www.mdc.com.my/
3 This term first appeared in mandarin business literature in the early nineteen-nineties. As the handover of sovereignty approached it became the accepted term for the Peoples Republic of China plus the Special Administrative Regions of Hong Kong and Macao plus Taiwan.
4 See Poon (2002) for a detailed account of the development of this sector of the Taiwanese economy and of the key companies involved.