Chapter 8

Finding a Place to Stand: a "metatechnical" framework

This chapter presents an overall framework to encompass the perplexing range of influences both on individual design projects and on the development of the design policies described in the preceding chapters. It provides a socio-technical framework to link national and wider cultural and institutional contexts to the decision-making levels of an individual organisation, or network of organisations where technical tasks are planned. Both task and institutional levels are influenced by the technical dynamics of the emergent economic paradigm discussed in Part I. In this chapter it is argued that conflicts between the rationalities appropriate to institutional and task environments produce inconsistency and suboptimization.

To be successful projects and policies must address both task and institutional orientations. The alternative is to allow the conflict between technocratic consciousness originating at a technical level and overconformity attributable to the institutional level to give rise to pathological outcomes. The development of the space shuttle - the NASA Space Transportation System (STS) - is used to illustrate this argument, and a metatechnical framework is advocated as necessary to the successful linking of task and institutional orientations.

The NASA Shuttle represents the pinnacle of aerospace development in terms of performance and operating environment. At the same time it is a key component of an infrastructure of relevance to the most remote and least resourced regions on the planet. In addition to its scientific and military role it is one of a number of launch systems delivering communications satellites to earth orbit.

While geo-stationary orbit (GEO) satellites serve a specific footprint below their position, middle and low earth orbit (MEO and LEO) satellites provide the same potential of coverage, regardless of per-capita income, to all those who dwell beneath their orbits. Chapter 5 described some of the systems under development with at least the technical potential to eradicate the digital divide by delivering high quality communications infrastructure to previously neglected regions.

Pathological Development

The gap between the levels of performance delivered by complex systems and their designer's expectations or assurances has attracted a range of criticism. There is a popular appreciation that systemic problems occur within complex organisations. These can be regarded as a form of pathology. Evidence of such organisational pathology can be identified in works ranging from Parkinson's Law (Parkinson, 1958) via *Up the Organization* (Townsend, 1970) to Brooks' "mythical man-month" (Brooks, 1975). There is a general recognition and acceptance of dysfunction, often as a natural consequence of large and impersonal scales of organisation. Typically, Peter (1986) talks of growth in levels of bureaucratic control as "proliferating pathology".

The concept of organisational pathology has also been used by several organisation theorists to account for unintended outcomes and outputs from organisations. In examining the design process, the concept may be extended to embrace the actions of those designers who appear to make or acquiesce to decisions which frustrate their own overt objectives.

Scott's (1987) analysis of the use of the concept in existing organisation literature. Scott's discussion of organisational pathology yields two key concepts of value here:

Overconformity in an extreme form is exemplified by Milgram's experiments demonstrating the ease with which individuals defer to authority (Milgram's 1974). In a less acute form, insistence on minute conformity to regulations is the "common sense" understanding of bureaucratic behaviour.

Goal displacement is a feature of any complex society, and not necessarily pathological, since generalised goals must be pursued through identifiable sub-goals. Perrow (1986) argues that in practice much apparent goal displacement serves the interests of dominant organisational actors. March and Simon (1958) describe a means-end chain by which general goals can lead to specific sub-goals. Typically, however, goal displacement results in survival becoming the principal concern of an organisation, as shown in the analysis of the Tennessee Valley Authority in the post war period by Couto (1988) described in Chapter 7.

There is ample evidence of the existence of pathologies in complex projects and design decision-making processes, despite attempts to facilitate effective communication and decision-making. The crossed fingers of the engineers at the Marshall Space Flight Centre, cited in McConnell's (1987) account of the background to the fatal STS mission 51-L or their attempts to use an auditor as a channel through which to communicate their concern with the technical shortcomings of the solid rocket booster field joints, are particularly striking evidence of failures in management information systems. The development and operational failures of NASA's Space Transportation System reveals how a changed environment can lead to suboptimisation which effectively reverses the function of critical components of a management information system.

If a systems perspective is applied, the impacts of these conflicts may be considered as *suboptimisation.* Any decomposition of a complex system offers the possibility of suboptimisation, and to that extent it may be regarded as a normal consequence of the division of intellectual labour required by complex organisations. The danger is that suboptimisation may only be revealed by an attempt to re-assemble the outcomes of delegated decisions. The narrower viewpoint of a subsystem level can lead to apparently sound local solutions which create problems for the system as a whole.

Designers are familiar with the concept through their experience with conflicting requirements which can only be satisfactorily resolved at the level of the project as a whole. Technology in the form of computer-aided design (CAD) has been used as a means of avoiding sub-optimisation across the disciplines within a design team by providing a global real-time data base on to which all design decisions are mapped (Little, 1988).

The notion of suboptimisation implies a supervening rationality by which the system as a whole can be judged. The implications of a distinction between the rationality applied at the level of the task with the rationality developed at an institutional level are discussed below.

Thompson (1967) sees the purpose of much of the structure of a complex organisation as the protection of its technical core so that it can achieve efficient operation. Boundary-spanning sections of an organisation therefore achieve influence because they can mediate transactions with the external environment and minimise perturbations at the core. In Thompson's terms, suboptimisation is the result of the penetration of the technical core by environmental and external influences. He argues that technical rationality can only suffice at the core of an organisation if it is adequately buffered from environmental influences.

The concept of an organisational core buffered from and linked to the organisation's environment is a key to understanding the impact of external contingencies on the design process. Time-frame discrepancies between areas affecting or affected by design decisions are one source of core penetration, and the imposition of inappropriate decision-making frameworks reflects the discrepancy of time-frames linking the different levels between core and environment.

The significance of time-frames for design projects was touched upon in the analysis of British Railways modernisation strategy in Chapter 6, and in the description of SSHA in Chapter 7. Here it is argued that these differences are symptomatic of the varying orientations of actors at different levels and that any design team must fulfil a critical bridging role between the concerns of the task environment at the technical core and the wider environment.

Task Environments and Institutional Environments

Scott (1987a) distinguishes between the *task* environment of organisations and their *institutional* environment. He points out that the latter is a relatively recent concern of organisation theorists, and requires very different responses from the better understood task environment. Institutional theory is currently gaining interest among organisation researchers, since it addresses very different concerns from the task oriented views commonly incorporated into management science.

The two principle concerns of task environment management are the protection of the central work processes, principally through "buffering" strategies and the management of the relationship with the task environment as a social and political system, dealt with through "bridging" strategies. The task oriented view sees the environment as a source of inputs, markets for outputs, competition and regulation.

However, the demands of institutional environments require a different mechanism for transactions from those demanded by task environments. The institutional orientation seeks to build bridges into the environment by conforming to expected categories of staff and structure. Scott argues that organisations *exchange* elements with their technical environments, but are *constituted by* elements from their institutional environments. These elements are not transformed by the organisation as are technical elements and inputs. Instead they are made visible to outsiders with their distinctive features remaining intact. The purpose is to legitimise the organisation and to reassure clients. Bridging, not buffering, is the key strategy with regard to institutional environment.

Within business and industrial sectors, organisations will become more alike over time, as they draw upon a common institutional framework. This view goes some way to explaining Stinchcombe's (1965) finding that the age of an industry was a much better predictor of an organisation's characteristics than the age of an individual organisation within it. Organisational culture can be seen to be as closely associated with institutional choice as with technical choice and task environment.

Scott describes these mechanisms for bridging into the institutional environment in terms of conformity:

Categorical conformity in which institutional rules provide guidelines which can pattern structures.

Structural conformity in which environmental actors may impose very specific structural requirements upon organisations as a condition for acceptance and support.

Procedural conformity resulting from the pressures from institutional environments to carry out procedures in a particular way, and again, under uncertainty familiar and accepted procedures may be adopted by an organisation, such as those commonly used in accounting systems.

Personnel conformity arising within the complex, differentiated organisations likely to contain large numbers of educated, certified workers who assume specialised roles within them.

Following Peters and Waterman (1982), many writers have looked at these institutional arrangements in preference to task oriented variables, as an explanation of organisational performance. Thus they promote, among others, the model of Kelly Johnson's "Skunkworks", the independent and secret development team within Lockheed Aircraft responsible for the U2 and SR-71 spy planes, as a successful institutional model for highly uncertain tasks. However, the need to mimic the secrecy of a military "black project" (that is one beyond the scrutiny of the U.S. government's General Accounting Office) can be regarded as evidence of organisational weakness, if not outright pathology (Brown, 2001).

A developmental perspective might suggest that early in their existence, organisations would be more dominated by technical processes and that over time they may come to reflect institutional processes. Selznick (1957) accounts for the institutionalisation of organisations in terms of organic growth and the emergence of distinctive "character" or culture over time.

Parsons (1960) identifies three level of organisational structure: the bottom level is the technical system, above this is the managerial system which mediates between the organisation and the task environment. At the top is the institutional system which relates the organisation to its function in the larger society. Parsons sees a clear analytical distinction between technical, managerial and institutional levels, arguing that there is a qualitative break at the interfaces of the three. The systems views of organisations described by Scott (1987a) can easily be related to these levels. However, it can be argued that although task and institutional environments require the different strategies enumerated by Scott, these overlap in some cases, and the two areas are less easily separated than is implied by Parsons.

Influences from different levels encompassing institutional and task environments coexist in the decision-space of project managers and designers, Chapter 7 suggested that these can be understood in the form of conflicting time-frames imposed upon their decision-making. However, interaction with the two different types of environment also makes very different demands on the skills and attention of actors.

According to Thompson (1967), the technical core strives for technical rationality, even though it exists in an open, natural system requiring environmental transactions. Managers and departments in an organisation exist to buffer the technical core and work at the managerial level requires an appreciation of conflict and motivation given by a natural systems approach. This involves an appreciation of the variety of human resources as an essential ingredient. The institutional level of the organisation must deal with external relationships with other organisations in the environment, so it must embrace an open systems view.

All the above indicates that, in the design of complex systems, the character and dynamics of transactions at the institutional level are very different from those of the technical level at which information technology design decisions are traditionally made. Conflict may develop between the technical requirements of this support technology and the objectives it is intended to serve at the institutional or organisational level. If such technical considerations prevail, an elegant system may gather dust because it does not address an organisation's perceived problems. If institutional concerns overwhelm technical capabilities, over-ambitious projects may be tackled with inadequate resources.

The reconciliation of technical and institutional orientation is the key to the success of complex design projects. An effective design project or intervention must address both levels of analysis and the implications of the different orientations which exist at each level.

From Challenger to Columbia: Developing the Space Shuttle

To achieve a robust outcome, a design coalition must address both task and institutional environments. There are ample examples of technical success which yields no effective outcome, and of institutional constraints giving rise to inadequate technology. The space shuttle programme provides a striking demonstration of the difficulty of changing the institutional dynamics of complex organisations. Between January 28th 1986 and 2nd February 2003 the U.S. Space Shuttle Program completed 87 successful missions. However on the first of these dates the *Challenger* shuttle was lost on take-off following failure of an O-ring joint in a solid rocket booster. On the second the *Columbi*a was lost during reentry owing to damage sustained during take-off by collision with insulating foam shed from the main propellant tank. Despite the intervening fifteen years, the organisational context of these accidents displayed striking similarities, with many of the recommendations implemented after the first accident inquiry having been quietly reversed in the intervening period.

The crossed fingers of the engineers at the Marshall Space Flight Centre while observing shuttle launches, or the attempts by desperate designers to use an auditor, Richard Cook, as a channel through which to communicate their concern with the technical shortcomings of the solid rocket booster, give ample evidence of the impact of pathologies on design and project decision-making within an organisation of the quality and track record of NASA. A complete failure of formal mechanisms was evident. The very committees which were established to share critical information and to identify problems became arenas in which various groups sought to disguise their own problems. Each hoped that some other constituency would reveal a problem to which any delay could be attributed.

Magnuson (1986a) graphically indicates the interface between technically and institutionally oriented actors within Morton Thiokol, the sub-contractors responsible for the solid rocket boosters. He shows which individuals responded to the request of Marshall Space Flight Center to “put on their managerial hats”. At the notorious teleconference held the night before the fatal *Challenger* launch, a clear division emerged between engineers still oriented to the task environment, and aware of the potentially catastrophic consequences of a booster joint failure, and managers, many with engineering backgrounds, who were aware only of the institutional consequences of a delay attributable to their company or division. The task oriented engineers were challenged to demonstrate that a launch was unsafe in the prevailing conditions. This represented a reversal of established practice in which the onus was to demonstrate safety and a triumph of procedural conformity over technical analysis.

The complex reporting structure of NASA's organisation was effectively inverted. Nodes in a communication network became the mechanisms for a massive gate-keeping exercise which prevented the communication of technical problems to the institutional level of the organisation.

McConnell describes how launch constraints were placed on the solid rocket boosters when it was realised that the designed redundancy of the O-ring seal system was not reliable. Despite the criticality of these components, however, the constraints were routinely waived before each mission. The Presidential Commission on the Space Shuttle Challenger Accident (1986), known as the Rogers Report, discovered documentation on the problems with the booster joints dated October 21st 1977, almost a decade before the *Challenger* accident. O-ring erosion appeared on the second orbiter mission in 1981, but was dealt with within the confines of the Marshall Center. McConnell also describes the autocratic management style of this division of NASA in contrast to the overall culture of the organisation. No problem or delay was permitted to be attributable to Marshall. By the eve of the final *Challenger* mission, Thiokol's representatives were claiming that there was no clear relationship between launch temperatures and the severity of the well established O-ring erosion. They were only able to do so because they had not attempted the simplest numerical analysis of the relevant data.

The situation which emerged at the Rogers Commission enquiry is in stark contrast to that recounted by Sayles and Chandler (1971) in explaining the success of NASA's organisation in the sixties. One major difference between these two periods of activities is the loss of a single integrating objective for manned space flight provided by the *Apollo* programme, and a consequent increase in environmental uncertainty for the Agency.

Following the loss in flight of a second shuttle on 1st February 2003, the Columbia Accident Investigation Board (CAIB, 2003) pointed out that may of the organisational changes introduced following the Rogers Report hade been undermined. This was either through simple reversal, as in the return of control of the overall programme to the Marshall Space Flight Center, or through further reductions of resources and the outsourcing of critical aspects of the safety programme. One of the members of the second board, John Logsdon had provided some of the most trenchant criticism of NASA after the *Challenger* accident (Logsdon, 1986)and the 2003 document contains many of the same criticisms.

An Institutional Narrative

The uncertainty extended to the institutional environment in which the agency had to operate, and involved the U.S. Congress, the industries involved in the space programme, institutions competing for public resources, and the public itself. As Couto (1988) has shown with the TVA, it can be argued that attention given to the management of the institutional environment was ultimately at the expense of the task environment.

Uncertainty is seen as the enemy of rationality within organisations in the systems context constructed by Scott (1987a). From this perspective, environmental and task variety will lead to asymmetric distribution of power, which may not correspond to the formal or nominal hierarchy within an organisation. This asymmetry leads in turn to the displacement of the organisation's goals in the direction of the interests of the constituencies to whom power accrues. Unfortunately, much organisation literature ignores the issue of power. The socio-technical approach (Mumford and Weir, 1979) attempts to account for the incorporation of technology by organisations, and to provide appropriate prescriptions for its deployment. It fails in this respect by incorporating uncritically the dominant managerial rationalities.

NASA and Government

The fact that approval to proceed with the space shuttle programme was given on 5th January 1972, at the outset of a presidential election year, leads Logsdon (1986) to argue that the "normal" party political bargaining process among coalitions had impinged on what should have been a long range national commitment. By 1972 the Deputy Administrator of NASA was talking about "multiple use, standardized systems" and the myth of the "space truck" making routine trips into space was in the making. This view survived for fourteen years, to be shattered in January 1986. However the CAIB reports that by 1995 the system was again being described as routine and mature[1]. On this basis cost savings were sought through the outsourcing to commercial organisations of safety-critical activities previously kept within NASA itself.

Fries (1988), in an analysis of NASA's changing proposals for a manned space station, argues that Kennedy's famous political commitment to a manned lunar mission during the sixties disrupted an emerging technical programme which involved the development of orbiting research and development facilities. The lunar mission was accomplished without any earth-orbit assembly or supply requirements, but with lunar orbit rendezvous. As terrestrial concerns began to impinge on the prospects of post-*Apollo* activities, during the Johnson administration, a scientific role emerged for manned space flight.

Fries points out that both the Johnson Space Center and the Marshall Space Flight Center enjoyed the support of powerful industrial and political constituencies which were committed to the continuation of manned space activities. She argues that two separate orbiting space stations were proposed in 1966 in order to serve the requirements of a sufficiently broad section of the scientific community and thus to ensure funding. Even within NASA there was a lobby for unmanned scientific research and no single orbit could have served the full range of proposed research. However, because of budget constraints, the actual outcome of these ambitious plans for the post-Lunar period was the Apollo Applications Programme, utilising *Apollo-Saturn* hardware from the lunar programme, and achieving the relatively successful *Skylab* missions, launched in May 1973. By 1968 it had been decided to phase out the expendable *Saturn* system in favour of a Space Transportation System utilising a reusable orbiter and boosters.

The shuttle concept was formulated in terms of the supply requirements of permanently manned low-orbit space stations, but the White House had rejected these proposals. McConnell (1987) argues that there was a further hidden agenda of manned Mars missions beyond the establishment of orbiting stations, and that the capacity of the earliest shuttle proposals only makes sense in this full context.

In order to secure funding for what was seen as the most promising manned programme, NASA had to embark upon a series of compromises to achieve a programme capable of occupying its development engineers. Routine low-cost access to low orbit was attractive to the Department of Defense and replacing all existing launch systems for unmanned military satellites locked in the DoD as a supporter. This led NASA to resist the development of less ambitious systems and the maintenance of back-up resources. The Shuttle became an omnibus design, as defined in the next chapter.

The lack of alternative manned space-flight systems led to a five year gap in U.S. efforts following the completion of the essentially political *Apollo-Soyuz* mission in 1975. Delays in shuttle development and the inability to mount a re-supply mission also led to the uncontrolled reentry into the atmosphere of the massive *Skylab* structure in 1979, an event of relevance to those currently responsible for maintaining the International Space Station.

While pursuing the stringent requirements of the Defense Department, however, NASA had to deal with the criterion of cost-effectiveness imposed by the Office of Management and Budget (OMB). Logsdon (1986) argues that the outcome of a series of budget-driven design changes was approval in 1972 for a system which was unlikely to be able to meet the wide range of requirements it attempted to address. The shuttle was the first space programme subjected to formal economic analysis, and the early and optimistic claims of cost-effectiveness became a further burden.

It became essential to NASA to capture all military missions proposed for the eighties, yet the military requirements, particularly those relating to cross-range maneuverability, that is the capability to significantly alter course in flight, were adding to the weight, complexity and cost of the orbiter. Despite their considerable impact on the shuttle design, Logsdon suggests that the military clients were not particularly committed to the concept. The Air Force, in particular, had access to the substantial capacity of the *Titan III* rocket. Nevertheless, in spite of an October 1971 offer from the Secretary of Defense to modify the stringent cross-range requirements, James Fletcher as head of NASA insisted that the agency would meet all military requirements.

Logsdon plots the evolution of the shuttle configuration, from a fully reusable system of a manned winged booster plus orbiter, burning in series, to the current parallel-burning reusable solid rocket boosters and orbiter, with disposable external fuel tank. Removing the shuttle fuel-tanks from its airframe made the use of an expendable booster system possible. The design changes were prompted by a five-year budget profile imposed by the OMB, and concentrated on the reduction of capital cost with less concern for operating costs. Eventually solid rocket boosters were chosen over liquid fuel because of their lower development costs.

Unfortunately the range of alternative configurations investigated by NASA, coupled with scepticism about cost projections, led some OMB staff to conclude that the imposition of an even lower fixed total cost limit would still produce some form of reusable spacecraft. NASA was preparing to compromise on its preferred 15x60ft by 65,000lb capacity cargo bay when the White House gave the go-ahead for the full size proposal. According to Logsdon, the grounds included the greater military capability and job-creation potential of the full proposal.

NASA's Wider Environment

The potential scope and influence of space exploration has been likened, in NASA sponsored research, to that of the railroad industry in

North America (Mazlish, 1965). The scale of this potential impact meant that as well as balancing the requirements of their military customer with budgetary constraints, NASA has had to consider wider industrial and political constituencies. The discourse involved went beyond agency and government to broader industrial and political concerns. The ultimately fatal solid-rocket booster field joint only existed because NASA were concerned to allow tenders from contractors remote from the Florida launch site, despite the fact that the Aerojet company could have provided monolithic rocket casings transported by barge. Management of such interplay between industry lobbies, employment considerations and sensitive Congressional constituencies has become a key feature of the military-industrial complex in the United States, and is described at length by Coates and Kilian (1986) and Franklin (1986).

The Thiokol Corporation won the massive booster contract, with the overt support of James Fletcher, the director of NASA. By 1985 Congressional pressure had prompted NASA to consider the competitive award of a further billion dollar extension to the contract. Negotiations with Thiokol were proceeding right up to the accident. A teleconference was scheduled between Marshall Space Flight Center and Thiokol for 28th January 1986, the day following the fatal launch decision. This context suggests that the graphic division between the attitudes of engineering and management participants plotted by Magnuson (1986a) represents the interface of institutional and task environments.

As the commercial use of space expanded, so NASA’s environment expanded to include competition for non-military payloads from the European Space Agency ESA, the Soviet Union and China. Australia, for example, has launched domestic satellites with the Shuttle, the European *Ariane* booster, and the Chinese *Long March* system. Among these competitors, differing task and institutional environments have resulted in greater flexibility.

McConnell (1987) and D’Allest (1988) both describe the Ariane family of launch vehicles developed by the ESA in terms of the incremental design development examined in Chapter 6. Vallerani (1988) evaluates space station experience and proposals and comes to similar conclusions about the development of the Soviet *Salyut* and *Mir* systems.

The *Mir* permanently manned space station was the result of an incremental development of the earlier *Salyut* series and the Soviet Union maintained a continuous presence in space from the seventies to the nineties through the success of this incremental policy. The success of the U.S. *Skylab* was undercut by the phasing out of the Saturn system in favour of the shuttle. The *Saturn*-derived elements were also phased out in favour of a new booster system. The consequence, as predicted by Vallerani (1988), was that the U.S. space station, now the International Space Station was ten years behind *Mir* in deployment and flight experience.

During this period the Soviet Union had tested its *Buran* shuttle and the ESA had developed detailed proposals for its *Hermes* space plane. Despite aerodynamic similarities, these systems are both in marked contrast to the U.S. design. Each utilised a much simpler reusable orbiter, with no main engines, although the Soviet version had air-breathing engines for landing and, as a consequence of military competition, was clearly intended to match the U.S. shuttle in overall performance.

Alternative expendable systems continue in use for non-manned satellites. The USSR developed *Energia*, a *Saturn* class expendable booster capable of lifting 100 tonnes into low Earth orbit, but retained a development of the SS-6 missile, first tested in 1957, and used to place Gagarin in orbit in 1961, for both routine unmanned payloads and ferrying cosmonauts to orbit. China's initial entry into manned space flight has followed the Russian route, with a low-cost expendable vehicle delivered into space by the Long March III system.

If the less safety-critical tasks are uncoupled from manned space flight, then the manned systems can be deployed for highly specialised tasks such as recovery and repair, and maintenance of space platforms (Feustel-Beucht, 1988). Perrow (1984) presents the notion of uncoupling as a crucial tool for the development of manageable high-risk technologies. If a system must be complexly interactive in order to achieve its required performance, then the introduction of redundancy and substitutability can reduce the risk of catastrophic failure.

Technical versus Institutional Fixes

NASA's strategy with regard to its institutional environment actually increased the tight coupling and complexity in its task environment. The combination of a complex and tightly coupled technical system and the increasing launch schedule pressure originating with the early and over optimistic payload cost estimates for the mythical "space-truck" led to what Perrow describes as a "normal accident": one which is the inevitable result of system characteristics. Here the system characteristics must include those of the institutional environment. Technical mechanisms which were intended to monitor and control the development and deployment of a complex and high-risk technology came to serve a largely symbolic function in the institutional environment. In the post-*Apollo* period the staff responsible for monitoring safety were drastically reduced in number and buried within the operating divisions.

In addition to a restructuring of the safety programme to achieve much higher visibility, the Rogers Report on the Challenger accident (1986) recommends attention to a range of safety critical items, ranging from tyres and brakes on the orbiter to flight rates. Immediately after the accident there was speculation about direct pressure from the White House to have *Challenger* in orbit during President Reagan's State of the Union address. The existence or absence of such overt influence was irrelevant, since NASA had thoroughly absorbed the concerns of its institutional environment. Despite a backlog of critical issues, and increasing pressure on resources, Trento (1987) describes fraught negotiations over whether Pepsi or Coca Cola should be the first carbonated beverage in outer space (both had to be carried to placate their respective manufacturers).

NASA's goal was displaced from a technical mission, with an explicit concern for safety, to a classic organisational concern with survival in an increasingly uncertain institutional environment. This can be compared with Couto's narrative of the TVA in Chapter 7. Between the two shuttle accidents came the end of the Cold War and this led to further reductions in overall resource levels for NASA, who themselves diverted money for the shuttle to other programmes. From 1991 to 1994 Shuttle operating costs were reduced by 21% (CAIB, 2003). As part of these savings control was returned to the Marshall Space Flight Center, triggering the resignation of the head of the Shuttle programme.

Both technical and institutional fixes can be seen in NASAs actions. Alongside the implementation of the Rogers Report recommendations, the canonisation of the STS 51-L crew, described by McConnell in the 1988 appendix to his book, indicates that the organisation continues to regard the institutional arena as the effective route to resources. The Agency incorporated its own failure into its organisational mythology, turning it into a resource for the continuing pursuit of its mission at an institutional level. Unfortunately the success of this tactic resurrected some of the problems which led to the original disaster.

Conflicting Rationalities in Technical Development

The distortions of normal technical reasoning used in NASA's Flight Readiness Reviews and revealed by the Rogers enquiry raises the issue of the conflicting rationalities applied by task and institutionally oriented actors. Richard Feynman, a Nobel laureate and Commission member, suggested that the reasoning applied to the growing evidence of O-ring erosion was the opposite of what was required: "It flies, and nothing happens, then it is suggested that the risk is no longer so high for the next flight, we can lower our standards a bit because we got away with it last time" (Magnuson, 1986b). In fact, the 53°F minimum launch temperature for which the rearguard of task-oriented Marshall engineers were pressing had produced by far the worst erosion experienced prior to the *Challenger* accident.

The 2003 accident report describes a similar history of the loss of insulation foam during launches, much of it documented by visual recordings. Again the full implications of the issue were not understood. Clearly, any understanding of such pathological outcomes from a complex design system requires an examination of the rationalities adopted by the actors involved.

Selznick (1957) distinguishes between administration as a rational, means-guided process, and institutionalisation, which he sees as value-laden and adaptive. Thus goal-displacement might be regarded as a symptom of institutionalisation. In one sense organisations are seen to become institutions when they develop distinctive characters, or cultural values. Other writers distinguish institutions from organisations. Douglas (1983), in discussing "how institutions think", suggests that they play a key role in establishing and maintaining rationalities by providing cognitive economy and removing larger contextual issues from the arena of discussion. This analysis of rationality acknowledges that the "bounding" of rationality described by Simon (1957) is an understandable consequence of human attempts to deal with too great a range of interdependent variables. It corresponds to the strategies enumerated by Jones (1980) as means of reducing extensive design solution search spaces.

The restriction of a decision space, whether in terms of time or information resources, may also be part of a deliberate strategy to pre-empt the range of possible outcomes of a design or management process, as with the manipulation of decision time-frames discussed in Chapter 7. Such strategies may serve the interests of particular constituencies, but if the process is viewed from outside the perspective of Thompson's (1967) dominant coalition of constituencies, they will be seen to lead both to goal displacement, and to problems with effectiveness.

Arriving at a single rationality for any significant undertaking remains problematic. Brubaker (1984) points out that Max Weber utilises no fewer than sixteen apparent meanings of 'rational' in his writings. There is, nevertheless, a central concern with the irreconcilable tension between formal and substantive rationality:

> "The distinction between formal and substantive rationality implies that what is rational from one point of view may be non-rational or irrational from another, and vice versa... ...to the extent that people share beliefs they can agree in their judgements of rationality and irrationality; but to the extent ends and beliefs diverge, so too will judgements of rationality and irrationality." (Brubaker, 1984 p.4)

According to Weber, the modern economy has a double rationality: *subjectively* rational, and thus purely instrumental, market transactions guided by *objectively* rational, and thus purely quantitative calculations. *Formal* rationality is concerned with calculability of means and procedures and ultimately with *efficiency*. *Substantive* rationality addresses the value of ends and results and is ultimately concerned with *effectiveness.*

Brubaker (1984) argues that for Weber formal rationality rests on institutional foundations that are morally and politically problematic: unrestrained pursuit of formal rationality will produce substantive irrationality. This is one analysis of pathology in organisational action, which is reflected in Scott's (1992) definitions of overconformity and relentlessness through which the internal objectives of constituencies are pursued with disregard for the consequences elsewhere.

Brubaker is principally concerned to establish the limits to rationality, as set out by Weber. For Weber, ultimately the choice of values which underlie substantive rationality (Wertrational) can only be chosen by non-rational means. Only formal rationality (Zweckrational) may be analytically examined in its own terms. The ultimate choice of which values to accept must be criterionless. The problem is that the separate "value spheres of the world stand in irreconcilable conflict with each other" (Weber, 1947, p.147).

It must be emphasised that much prescriptive advice offered by management literature, and which may influence designers, simply adopts what is seen as an unproblematic managerial perspective towards rationality in organisations. The evidence above from the Shuttle case-history, and studies by Kaldor (1976) and Coates and Kilian (1986) of the inefficiencies of the military-industrial complex reveals the inadequacies of such an approach in practice. Coates and Kilian in particular are criticising the defence industry of the United States from a technical perspective which examines its institutional dynamics from a task orientation. They reveal how irreconcilable this can be with an instrumental managerial concern with institutional issues.

Design and technical development are engrossing activities. Creativity and innovation require an immersion in process, but there is an ever present danger that the intrinsic challenge of a particular technical sub-goal may loosen the designer's grasp of the overall implications of their technical decisions. The sub-optimisation identified by Scott (1987a) and Galbraith (1977) must be overcome through a framework which can assess effectiveness over the range of rationalities operating at task and institutional levels.

Scott points out that conceptions of organisations and goals, participants and constituencies have become progressively more complex. Complex organisations are composed of subgroups with different social characteristics, social locations and views and interests. External constituencies can form part of the political system of the organisation, by holding goals "for" it. The output of a design coalition can only be evaluated by its impact beyond the boundaries of that coalition. Any evaluation implies some target against which performance can be measured, by definition such measures must transcend the design coalition and its members.

Design Objectives and Development Goals

Goals are used both to motivate and direct activity, and to evaluate it. However, the criteria developed to direct organisations are not always the same as those employed to evaluate them. Motivation may utilise broad and vague goals, but evaluation requires specific goals. Since evaluation goals are often quantitative and limited, goal displacement can arise when actors realise the limited range on which they themselves are likely to be assessed.

Varying goals will also be used by different types of participant: top management, middle-level personnel, performers, or external constituencies. Scott reminds us that researchers also fit into a framework of interests and objectives, and must be aware that their own criteria will influence not only the interpretation of data, but the identification of situations of potential interest. By extension, designers will also have a set of criteria for effectiveness related to their technical expertise which equally may serve the interests of some groups rather than others. Scott presents three predictions to guide investigation:

1: Criteria proposed by each group will be self-interested
2: They will be presented as universalistic and objective
3: There will be little commonality or convergence between groups, and some conflict.
(Scott 1987, pp.324-325)

Any assessment of effectiveness requires the selection of standards, indicators and an appropriate sample. Cyert and March (1963) attempt to adapt the psychological concept of "aspiration level" to the setting of standards, arguing that current goals reflect the organisation's goals from the previous time-period, organisational experience with those goals and experience of comparable organisations. Thompson (1967) constructs a more complex model of standards and beliefs about cause and effect relations in which he relates beliefs about cause and effect to standards of desirability

Where cause and effect and desirable standards are clear, efficiency tests can assess whether the desired end was reached with the minimum use of resources. Where cause and effect relationships are only partially understood, instrumental tests can determine whether the desired end has been reached, but if required standards and/or cause and effect relationships are ambiguous, social tests must be used. These can only assess the validity of an organisation's efforts by consensus or by authority.

Difficulties in the evaluation of any design process start with the problem of an appropriate metric. A successful metric must address adequately both the task requirements of appropriateness and adequate sensitivity and the institutional requirements of perspicuity and ease of application. If these frameworks are neglected, then in effect, overconformity and technocracy meet at the level of codified design constraints. Examples from architectural design can illustrate the difficulties.

As noted in the previous chapter, Lawson (1982) examines the relationship between building codes and design decision-making. Overconformity or goal displacement may be attributed to the application of rules which are designed for ease of enforcement, not for ease of incorporation into the design process. However, this in turn reflects the necessity of enforcement, and may not constitute a pathology in itself. A more extreme outcome of the need to comply with regulation and inspection was seen in Chapter 7 in the impact of delays in certification which led to the design of the control room at Three Mile Island Unit 2 being ten years out of date at the commissioning of the station.

Edwards (1974) analyses the difference between the furnishing of houses indicated on British local authority architects' plans with that subsequently carried out by householders. This is presented as evidence of a predictive failure on the part of the designers. However, as noted in Chapter 3, the furniture placing on architects' house plans reflected the requirements of the mandatory Parker Morris standard, as much as any predictive activity on the part of designers. These specific items of furniture had to be indicated in each room of a house plan to qualify it for government finance.

The impact of such codified design constraints means that under everyday production pressures, meeting quantified requirements becomes a substitute for fresh analysis and solution. Richard Feynman's description of the logic implicit in Flight Readiness Reviews for the Shuttle missions (Magnuson, 1986b) suggests that such procedural conformity became a ritual which precluded any proper evaluation of the situation.

Inappropriate criteria for assessment may be selected simply because of their relative ease of use and communication. Jay Galbraith (1977) points out that any increase in information capacity brought about by the formalisation of communication channels must be offset against a loss of qualitative information. In conditions of high task uncertainty, irrelevant quantitative measures are likely to enjoy an edge over relevant qualitative ones. In addition, commissioning clients are likely to have little expertise with which to judge choices made on their behalf at a subsystem level.

Dreyfus and Dreyfus (1986) emphasise the predominance of quantitative methods in much management and decision theory. They argue that such "calculative rationality" is likely to degrade expert performance by focussing on quantitative criteria at the expense of experientially based qualitative understanding. McConnell (1987) quotes the complaints of engineers chastised in Flight Readiness Reviews at the Marshall Center because they used terms such as "I feel" and I expect" which were dismissed as "not supported by engineering evidence". In contrast to the low value placed on experiential assessments, Dickson (1976) describes the deferential treatment of the output of a formal information system. He describes the deployment of sophisticated computer-based information systems during the Vietnam war, contrasting the lack of quality control over the information fed in at the bottom of the system with the importance accorded the aggregated and transformed results, an institutional example of the *garbage in - garbage out* phenomenon.

A "Metatechnical" Framework

The evaluation of the outcome of large-scale technical projects is likely to require social tests. Even if clear criteria are available for identifiable sub-systems, the issue of the effectiveness of any remotely complex system will impinge on a range of potentially conflicting values. The next chapter looks at the source of cost overruns and technical deficiencies in the products of the military-industrial complex. The proponents of what has been described as military Keynsianism (Coates and Kilian, 1986), may attribute higher priority to broad economic objectives than technical performance[2].

The evaluation of design outcomes requires a framework that acknowledges the coexistence of technical and institutional dimensions to organisations by presenting the task of design and management as a dialectic. The design process cannot be isolated from the everyday concerns of organisational survival without compromising its product, nor can managers and clients expect a free technical fix for institutional problems. The term "metatechnical" is intended to avoid the implications of a technical versus non-technical dichotomy. It implies that managerial and institutional concerns are also technical and therefore any framework embracing both design and its organisational context is *meta*-technical. It presupposes a systems view of design and its place in the organisation, but not a consensual one.

Open systems theory argues that explanatory variables must be as varied as the phenomena they seek to explain. The contingency approach to organisation theory argues that organisations whose internal features best match the demands of their technologies or their task environments can be expected to be most effective. However, contingency models can overlook the issue of equifinality: different conditions and causes may give rise to the same outcomes. It should be remembered that "the effectiveness of an organisation is a socio-political question" (Pfeffer and Salancik, 1974). Nevertheless, little is said about real interests of participants and groups. There may be real benefits for actors in the sub-optimizing decisions which we are trying to eliminate in the pursuit of our understanding of efficiency and effectiveness. Power relations may be well entrenched and difficult to counter, extending to the institutional level of cognition.

Douglas (1987) argues that the high triumph of institutional thinking is to make the institutions appear invisible and this invisibility can compound the difficulty of getting an expanded context accepted within any established institutional and organisational framework.

Clegg (1987) makes an important distinction between the established view of uncertainty as a contingency and the use of uncertainty in support of the exercise of power, illustrating the point with the ambiguity evident in the interpretation of building contracts by the actors involved in the construction process. It may be argued that the former understanding is apparent in a task orientation, the latter in an institutional orientation. Clegg indicates the way in which uncertainty may offer a resource with which to resist the control implicit in the constraints to action from the institutional.

As suggested in the previous chapter, production pressures may be deliberately manipulated through such devices as accounting time-frames, where budgets are confirmed at the latest possible date for full expenditure within a fixed time. In such circumstances a constituency will have little time for forward planning or coalition. Even without any deliberate exacerbation such pressure will be present in complex technical systems, as shown by Stephens' (1980) account of the commissioning of the Three Mile Island nuclear power plant. In such circumstances it is hard for actors to take a sufficiently broad view of their situation. However, to be successful, the design activity must bridge the discontinuity between task and institutional orientation. Designers must balance both technical and institutional considerations even though the design coalition is pulled in both directions. The OMB squeeze on NASA's 1971 shuttle design proposals represents an institutional approach with little or no concern or understanding for technical difficulties. This typifies the "black box" view of technology evident in economic theory (Rosenberg, 1982).

Attempts to incorporate such considerations in the design process are problematic, given the existing technical complexities and uncertainties which must be addressed. If a formal system of design control and accountability is perceived as cumbersome by its intended users, it may be subject to by-passing with informal and undocumented decision processes, just as production pressures lead to by-passing of physical safety features in processing and manufacturing. The critique implicit in McConnell (1987) must be addressed at an organisational and a societal level if measurable improvements in the performance of high risk systems are to be made. This is the ultimate implication of a metatechnical framework for the consideration of systems development.

Conflicting Cultures, Conflicting Rationalities

The practices and expectations established within organisations over time acquire a cultural dimension. Selznick (1957) invoked notions of culture in his explanation of the emergence of institutionalised organisations. The concept of organisational culture has been invoked to explain the relative success of individual organisations and entrepreneurs (e.g. Peters and Waterman, 1982). It is by no means a new concept in organisational sociology, but has been used in a variety of ways.

Some writers refer to culture in terms of national differences in social and economic organisation. Latin and Anglo-Saxon and traditional cultures are reflected in distinctive organisational types identified in studies examined by Lammers and Hickson (1979). In this context it is as well to remember that U.S. President Truman thought it unlikely that the Soviet Union would develop nuclear weapons, since they were an Asiatic nation (York, 1976).

Turner (1971) describes industrial subcultures which can be identified across individual organisations, and are distinctive from the larger society, Eldridge and Crombie (1974) define organisational culture as characteristic for individual organisations while Strauss et al (1973) describe a range of cultures within a single organisation. Thompson (1967) utilised the concept of an organisational constituency capable of entering into coalition with other constituencies in order to promote its interest. Such a conception allows the formal elements of an organisation to be related to the informal communication and negotiation which often modifies, or in extreme cases frustrates, the intention of management. It also allows consideration of intra-organisational variations in culture, arising from these differences of interest and experience.

Part I discussed the differences in institutional culture between Western and Asian forms of capitalism. Johnson (1983) defines a “market rationality” as seen in the U.S. where the state is interested in maintaining, through regulation, the mechanisms of competition in order to maximise efficiency. He contrasts this with a “plan rationality” as seen in Japan where a close working relationship exists between industrial sectors and government departments such as the Ministry of International Trade and Industry, and its successor the Ministry of Economy, Trade and Industry (METI), in order to pursue common goals with maximum effectiveness. He argues that this essentially different view of the role of public institutions in the economic arena accounts for a great deal of misunderstanding between these trading partners over what constitutes “fair trade”.

The cultural dimension may be regarded as mediating between technical and institutional orientations. The next chapter introduces the notion of distinctive design cultures as reflections of the institutional framework in which technologies are developed. The example used is the difference between American and Soviet military design philosophy and their differing institutional environments.

The work of Elliot Jaques, initially with the Glacier Metal Company (Brown and Jaques, 1965), led him to the formulation of a relationship between the hierarchy of bureaucracy and the time-span of control of actors. From these empirical observations Jaques develops an argument that a *natural* metric based on time-span of discretion may be used to ensure that an organisation is appropriately divided into efficient decision-making levels. Jaques promotes the levels of his hierarchy as the foundation of an empirically based general theory of bureaucracy, which encompasses the qualitative difference between tasks. While it offers a valuable adjunct to Thomson's (1967) constituencies and coalitions, it cannot address the critical assessment of the calculative rationality deriving from the increasing abstraction implicit in its levels in the terms defined by Dreyfus and Dreyfus (1986).

Thompson's model of standards and beliefs about cause and effect relationships is echoed by Perrow's discussion of rationality in the context of risk perception. Perrow (1984) suggests that the difference in outlook between risk assessors and "public" and the conflicting perceptions of risk we display as individuals can be attributed to differing frameworks of rationality.

"Absolute" technical rationality is attributed to engineers and economists by Perrow. In technical rational terms, nuclear power generation can be demonstrated to cause less loss of life and disablement than coal-fired generation, taking into account the risks of coal mining, transportation and sulphur emissions etc, provided the prevailing assessments of level of risk are accepted.

"Bounded" rationality, after Simon, can be used to account for the different assessment made by individuals using their experiential heuristics. Perrow argues that heuristic, rule-of-thumb judgement appears to work because the world is relatively loosely coupled and approximations can be absorbed by slack and buffers. Unfortunately decision-makers may find themselves outside the familiar context they had assumed, and may apply an inappropriate interpretation and rationality to a new situation needing to be approached from first principles.

This is the principal danger of an otherwise robust incremental strategy of development, which, by its success may take a system into a new performance environment as in the case of the Comet airliner described in Chapter 6. In 1988 the inability of the crew of the U.S.S. Vincennes to alter their initial identification of an Iran Air A-300 passenger plane as an F-14 fighter-bomber indicates the danger of established heuristic behaviour. A psychological set can be created in which additional evidence is either used to confirm the original judgement, or is simply ignored.

The difference between the above positions is illustrated by Perrow through possible reactions to the Three Mile Island nuclear power plant accident. For absolute rationalists, the fact that a one in three hundred year event occurred less than a year after start up was of no significance, they did not revise their assessment of the reliability of the system. For users of bounded rationality, the rapid failure is valuable evidence that there may be a problem with the risk estimates. Bounded rationality is efficient, according to Perrow, because it leads to pointed questions being put to the engineers, it examines the outcome of a serious accident and judges its acceptability, without massive technical evaluation.

"Social and cultural" rationality departs further from absolute rationality, but argues that the consequences of human cognitive limits are less consequential than usually assumed. Social rationality emphasises the complementary nature of social decision-making. Individuals have different interests and abilities, an expert has useful analytical skills, but needs some cultural guidance to ensure that appropriate problems are addressed. Individual limits on cognitive ability provide the motivation for social bonding and consensus.

Perrow suggests that the public emphasises social rationality over the absolute rationality of the technician and the bounded rationality of the economists and risk assessors. He regards social rationality as an extension of the "garbage can" theory (Cohen et al 1972) which grew out of the work of Simon and March: a range of approaches and options are generated by organisations, and alternatives are drawn upon as and when they seem useful or appropriate. However, Perrow suggests that cognitive psychologists still see their task as one of reconciling the heuristic reaction of the general public with the absolute rationality of the experts. Douglas and Wildavsky (1982) demonstrate the degree of social selection involved in the identification of risks, and attitudes towards them. Their position could be regarded as linking Perrow's conception of social/cultural and cognitive rationalities. It should be evident that any attempt to link institutional and task orientations must also be capable of accomodating and interpreting between these rationalities.

Design Paths for Development

The design activity has been identified as linking two very different spheres, the task and institutional environments of organisations. Examples of each have been examined in terms of existing literature and the concept of a “metatechnical” framework introduced to indicate the breadth of view necessary to encompass both.

An awareness of a hierarchy of rationalities relating to the hierarchy of task and institutional environments allows an understanding of the implications of the term “metatechnical” as a replacement for “socio-technical” or “non-technical” aspects of design. However, technical and contextual issues are inextricably linked, and task and institutional concerns may not always be clearly distinguishable. Metatechnology is necessary to counter goal displacement, which may arise as a defensive response to institutional uncertainty, and to counter overconformity reflecting the relative power of the institutional level. There are very real dangers in pursuing pathological or suboptimized goals with the increasingly powerful tools and technologies now available to designers. Either allowing the institutional environment to overwhelm the task environment or allowing technical rationality to ignore institutional concerns will result in outcomes such as the space shuttle accidents, or in attempted technical fixes for political and diplomatic issues such as the Strategic Defense Initiative.

The design process inevitably bridges the technical and institutional spheres and the metatechnical framework provides the starting point for the development of methods to avoid design pathologies. However, the design coalition can also be seen as the meat in the sandwich, with little power to influence those decisions at an institutional level which may severely impact on its freedom of action.

Their education and training may give designers an exaggerated view of their power over the material world. Among designers, architects are particularly prone to volunteer responsibility for the outcomes of institutional influences. Chapter 3 contrasted the narrative of the genesis and development of industrialised building provided by Russell (1981) with the post-modern narrative which ignores the networks of interest which produced this phenomenon, instead ascribing it to the hubris of individual modernist architects.

Scott (1987b) speaks of the “adolesence of institutional theory”, suggesting that it has not yet reached maturity, but is becoming more established and developed. In effect this paper draws upon the cutting edge of organisation theory. It is unreasonable to expect working designers to maintain such a level of sophistication in conjunction with their technical skills. A metatechnical approach is proposed as a framework for the solution of the problems identified in the case studies in this and the preceding chapters. The post-modern approaches to design such as Actor-Network Theory, introduced in Chapter 3, offer a means of creating a collectivity which could hold the range of skills necessary for a reasonable resolution of complex design problems at a metatechnical level.

The next chapter extends the examination of the metatechnical framework of technical development. It analyses the nature of the broad determination of high technology design and application by the dominance of military technology in the Cold War and post-Cold War periods.

Notes

1 See Chapter 5 of the Board's report which deals in detail with the relationship between pre-and post-*Challenger* activities, structures, funding and the situation prevailing in February 2003.

2 Chapter 9 examines the implications of Coates and Kilian's position in detail.