15

Organizational Innovation and the Articulation of the Design Space

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ABSTRACT

In this report of a case study of the work of a design team we describe some of the organizational contingencies that provided the conditions for the team's work and the ways in which the teams responded to these. We focus on the strategies by which the design team managed their circumstances in innovatory ways and manipulated the design space within which they were operating.

> Constraints run through the whole (design) process from beginning to end. Constraints though are not given a priori but must be fleshed out, filled in, fabricated, even thrown away or simply forgotten in the process of dialogue and negotiation. Constraints, in a sense, are to be designed. (Bucciarelli & Schön, 1991, p. 19–20)

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CONTENTS

1. INTRODUCTION: ARTICULATING THE DESIGN SPACE
2. CENTAUR AND ITS PROBLEMS
   2.1. Keeping to Schedule Was the Paramount Concern
   2.2. Standard Decision Procedures Had to Be Circumvented
   2.3. Flux in the Environment Had Its Effects
   2.4. UMC: A Problem That Wouldn't Go Away
3. MANAGING THE DESIGN SPACE
   3.1. Improvising on the Formal Procedures
   3.2. Working With and Around the Normal Work Practices
   3.3. Revising the Design Requirements From Within the Design
4. CONCLUSIONS
   4.1. Some Features for Tools
   4.2. Context of Use
5. POSTSCRIPT

1. INTRODUCTION: ARTICULATING THE DESIGN SPACE

When we first began working on our contribution to this volume, we found it hard to encapsulate what was meant by "a" or "the" *design rationale.* As the term was being used in the sources we consulted (Carroll & Rosson, 1990; Conklin & Burgess-Yakemovic, 1991, [chapter 14 in this book]; MacLean, Young, & Moran, 1989), the concept seemed many sided and by no means uniformly employed (Lee & Lai, 1991 [chapter 2 in this book]). As we proceeded though, it became clear that there was a common thread between other studies of design rationale-related topics and the discussion we wished to present of our materials. This thread was a preoccupation with delineating and exploring what we have come to call the unfolding of the design train of thought.

As we discuss more fully in a moment, our materials were gathered in the course of a field study of a large development organization. As a consequence, they reflect somewhat different emphases and objectives to more standard investigation of design processes. At the cost of oversimplification, we would suggest the more traditional studies are:

1. Primarily interested in the deliberations and decisions of individual designers. Even where the focus is on team design, less attention is paid to the role of the group as a group. Though this has been satisfactory for many purposes, as we indicate later, we detect a movement away from this tradition, with design rationale studies themselves being part of this movement, routinely concerned with design as part of group work. The emerging approach places more central emphasis on designers working in teams and on projects in organizational settings. Several studies have sought to tie the unfolding of design decisions back to the group and organizational processes within which they are embedded. Olson and Olson (1991), for example, used the notion of distributed cognition to make this connection, whereas Conklin and Burgess-Yakemovic (1991, [chapter 14 in this book]) and Grudin (1995, [chapter 16 in this book]) stressed the important issues of usability of design rationale tools in commercial design and development environments. Grudin (1995) in particular brought out some of the features of large-scale organization that, by implication, will constrain opportunities to deploy design rationale tools.

2. Prone to be "design-centric" in outlook. Issues and possibilities are reviewed almost exclusively from the point of view of the design, whereas we have less to say about the way their design skills are involved in delivering a well-designed product and more about the way in which their skills are deployed in keeping the project "on the road" in "working the system" and "stretching resources."

3. Concerned with explicating design-in-principle; that is, with attempting to isolate general principles and methods of design practice rather than with design-as-work, with this latter emphasis turning attention much more toward the environments within which design projects must be carried through and within which design methodologies, tools, and so on, must be implemented.

We focus on the organizational setting of design. Through the analysis of a single case, we analyze the ways in which organizational exigencies affected design activities and the *design train of thought.* We intend the notion of design train of thought to capture the sense in which the work of the design team comprised a succession of tasks in hand and of problems to be solved, activities and problems that were unified by their perceived place within the process of working out and implementing a design. It contrasts with the selective tracing of design-relevant considerations found in, for example, QOC constructions through its emphasis on the sheer multiplicity of considerations that must be contended with in working through a design. Later we describe a tendency that we detect in studies of design to pay more explicit attention to the "practicalities" of design, which include increasing recognition of the collective nature of design work and the practical character of tool use in actual working environments as well as in research and experimental situations. The tendency, which is manifest in other studies in this volume, is to broaden their focus beyond narrowly conceived design issues and to consider any of those aspects of work and its organization that bear on the carrying out of design. In particular, we want to bring out the ways in which, as part of their carrying through the design, the designers on Centaur (an "add-on" high-capacity photocopier feeder) creatively sought to manage both the design and the unclear and changing circumstances within which they found themselves.

Many people will ask if anything valuable can really be learned from a single case. For ourselves, we are wary of rushing to generalization from any set of materials and certainly would not claim any easy universalization of our limited experience. The issue, we suspect, has a more methodological frame to it. It could be heard as an objection to case-based analyses as an entirety. There are at least two possible responses to this. One is simply to refer to the body of literature outlining and defending the use of case studies in the social and related sciences (Dilman, 1973; Mitchell, 1983; Schwartz & Jacobs, 1979). The other is to argue that it seems likely that the phenomena we are interested in understanding are particularly suited to investigation on a case-by-case basis, for such things as engineering projects are likely to vary significantly one to another. This is especially so when one of those phenomena is the designers' own conception of their situation. For them, each new project may well be a mixture of the old and the new, the recognizably familiar and the largely unknown, the standard and the unprecedented. Because our concern is with the character of the designers' day-to-day work, then we automatically notice the extent to which designers have to be adaptive to whatever circumstances they find themselves in. These circumstances are often less than ideal.[1] The very emphasis of our description is that of designers managing their work under problematic conditions.

We have chosen to use the notion of a *design space* as the fulcrum for our discussion. In some discussions on design rationale, the idea of a design space is used deliberately to bring out the fact that an artifact emerges from the design process as the result of decisions and selections. Design problems (being typically "ill-structured" problems; Simon, 1984) rarely have unique solutions. The solution implemented is selected from among alternatives. The identification of possible solutions and the process of selection involve the elaboration of the features the solution might require, the arrangements that will provide these, and the criteria to be applied for discriminating among these solutions and arrangements. The configuration of decisions that, from a design point of view, makes up the artifact is, then, drawn from a "space" of possibilities. We do not want to take the expression design space too literally and most particularly we want to avoid reifying the idea. In our view, the notion that the expression seeks to capture is more widely employed than the expression itself. The coinage design space is a useful shorthand for the fact that there is a range of candidate solutions to any design problem. In turn, this range is constrained by features of the design task and its environment that delimit

1. We are sure that we deliver no news to many working designers when we remark about the "unsatisfactory" character of the circumstances under which they are called on to achieve adequate results. For another description of designers contending with less-than-ideal conditions drawn from our researches see Button and Sharrock (in press).

what can be included among serious candidates for the solution of a given problem.

As it is used in design rationale, the notion of space is an analytical conception. The space being created and explored is a conceptual one: namely the repertoire of questions, options, and criteria (MacLean, Young, Bellotti, & Moran, 1991 [chapter 3 in this book]), the sequence of decision points mapped (Conklin & Burgess-Yakemovic, 1991 [chapter 14 in this book]), or in terms of arguments (Fischer, Lemke, McCall, & Morch, 1991 [chapter 9 in this book]). What is attractive about this way of speaking, though, is that it allows analysts to play off the senses in which the space is both cleared and opened up for design. For designers, design is, at once, a process of survey and systematization as well as exploration and discovery.

We think of formation of the design space for a project as its *articulation.* We use this term in a double sense to mean both "spelled out" and "arranged in a structured way." By viewing it this way, we try to emphasize how the boundaries of specific design activities are explicitly drawn and the opportunities that the room for maneuver thus created makes available are expressly identified and deliberated on. At the same time, we are also concerned with the ways in which the activities of drawing out, working within, and deliberating on the design space are themselves interrelated. Obviously, design rationale techniques seek to ensure that the space will be more—and more reflectively—articulated in both senses. As a result, design possibilities will be more consciously spelled out and more methodically ordered. It follows that the focus of design rationale techniques is on capturing, preserving, and supporting the flow of designer reasoning that can be seen at the level of the technical issues surrounding the design of a particular artifact. The design rationale is not solely a history of the project, but a record of its unfolding "train of thought"—the course of reasoning about the design questions posed and the answers given.

Just as the development of an artifact through the design process is an exigent outcome of decisions within the design space, so too is the development of the design train of thought. In many respects, the eventual dimensions of the design space are also the outcome of other processes relating to the organization and conduct of work that are not usually brought within the explicit remit of the design rationale. Those engaged in design rationale work are, of course, very aware of the presence and influence of these processes, as are designers themselves. They feature for designers as things with which they must, practically, come to terms if they are to do their work. Hence, their presence is and can be extensively taken for granted by those seeking to explicate the technical aspects of design rationale. However, because design rationale approaches aim to have an effect on the way that actual design teams in actual settings go about their work, it will be important at some point to adumbrate the interconnect-

edness of the technical and the organizational constraints on the dimensions of the design space more fully.

The materials we discuss are drawn from fieldwork carried out on a project to design and develop a high-capacity feeder for a photocopier. One of us (Sharrock) spent from early February to mid-April 1990 working alongside the Centaur team, attending their meetings, following design activities, sitting with designers. Many of these sessions were audiotape recorded and all of them summarized in field notes. In addition we accumulated copies of diagrams, meeting agendas, summaries of actions to be taken, report forms, and all the other multifarious bric-a-brac ethnographic field-workers accumulate. Our motivation for following the day-to-day, hour-by-hour life of the Centaur project was to try to come to some understanding about design in practice and in real-world circumstances. We were also interested in the temporal features of designing and hence in the arrangement and synchronization of design activities in real time. Although, after the event, it is always possible for analysts (or anyone else) to see why things had to turn out the way they did, at the time and in the middle of it all, 20/20 hindsight is not available. Decisions have to be made in the light of whatever information can be got to hand and in the certain knowledge that things will almost always turn out in ways one could not have foreseen. Following designers through their daily round is, then, the best way we can think of to get some grasp of the real-time realities of their work, of what it is they are trying to do, and of the local culture that informs their understandings of what is going on around them. Although snapshot visits and knowledge-capturing interviews will always provide some insights, in our view if you want to get close to and understand the day-by-day, week-by-week rhythm and pacing of project activities, the project's local history, and its own unique character, there is no alternative to being there.

Our description of these materials brings out some of the exigencies that shaped the evolution of the design space. In particular, we want to concentrate on (a) aspects of the way in which the design task is defined, structured, and redefined and restructured, and (b) the way in which the design task is carried out under those definitions and structures. In other, plainer words: We look at an organizational context and its consequences for a project.

2. CENTAUR AND ITS PROBLEMS

Centaur was a comparatively small project (involving between 8 and 18 people at any one time in an organization where projects would routinely involve up to 200 participants) delivering a high-capacity feeder for a model of photocopier that had already been launched, but that was not selling as well as had been hoped. There was a pressing need to increase the sales of the model and so reduce the inventory. Centaur was a possible solution

to this problem. There was a potential market niche created by the copier's particular suitability for use in (college) libraries. The only drawback was its lack of a high-capacity feeder. In addition, it appeared there was a narrowly defined window of opportunity, framed by the buying cycles of the targeted organizations and the imminent launch by a rival firm of a closely comparable machine. These combined to set a time limit to the project. The whole thing would have to be carried through, from inception to launch, in a little over a year.

It is this context that determined the predominant feature of the Centaur project. The team was "up against it" right from the start. Everyone recognized there were serious, possibly insuperable problems to be confronted. Those on the project were unable to tell whether they were going to be able to overcome them. In any event, it was clear that even if they did, it would, to quote the Duke of Wellington, be "a damn close run thing."

Here are the most prominent of these problems and the implications that they had for the project's definition of its design objectives.

2.1. Keeping to Schedule Was the Paramount Concern

The aim of the project was not just to produce a viable and marketable product, but to devise an add-on that would transform the sales prospects for an existing model and thereby to contribute to the solution of pressing budgetary problems. But this opportunity was rigidly confined. If a machine was not available for display at the relevant equipment exhibitions that were themselves timed relative to the annual buying cycles of the targeted library organizations, then the sales would be foregone for a further year, perhaps forever. Then there was the launch of the rival machine to be taken into account. Any schedule slippage would be fatal to the plan.

Once the project got underway there was even more pressure to expedite things. A demand was received for the early provision of a version to be located for trial use at a prominent user site. This could provide advance advertising of the machine's availability and demonstration of its particular suitability. In addition, because the project was always specifically rationalized as a solution to a problem, there was the perennial possibility that other solutions to that problem might be found elsewhere. Significant price discounting was repeatedly rumored to be another, very viable alternative option being considered.

This urgency meant that the scheduling was worked out on the explicit assumption that "everything goes right first time." There was no room for iteration, even at the prototyping stage. Further, the scheduling was done against the background of an unresolved and major practical difficulty resulting from a discrepancy between the requirements of the formal product development procedures and the lead-time requirements of manufacture.

2.2. Standard Decision Procedures Had to Be Circumvented

The site at which the project was initiated had recently undergone significant staff reductions, the character of which had been dictated by the quality of redundancy entitlements and the prospect of employment elsewhere. Reductions in the size of departments had been uneven. Some were virtually depopulated. One so affected was responsible for the site's marketing activities. The formal product development procedures (collectively known as the Product Development Process or PDP) require the provision of a business case to show that the product could be an economically viable. In the absence of anyone formally designated to do this for Centaur, the working out of exactly what opportunity the project might take advantage of had proceeded relatively informally.

In addition, the formal processes for product development require explicit phasing, with reviews to evaluate success at the end of each phase and to make commitments to subsequent phases. The steps and requirements involved in these phases effectively set an irreducible time line for the project as a whole and for individual phases. Even with the assumption that everything that needed to be done before a review could be held would be completed in optimum time, there was still a limit as to how soon the review can take place and hence a decision to proceed be made. Of course, such limits and phases are negotiable (and more negotiable for some than for others—indeed, the situation under consideration was itself subject to negotiations). However, invoking the standard procedures would inevitably have meant that the earliest possible point at which a review could authorize movement from the concept and design development to manufacturing, was later than the date at which lead times required that manufacturing operations be initiated. In other words, if the serial review procedure was adhered to, expenditure on manufacturing preparations could not be authorized early enough to allow manufacturing targets to be achieved.

2.3. Flux in the Environment Had Its Effects

Contraction in the site's staffing impacted the team structure. The staff reduction process had been driven by the need to achieve downsizing rather than by attempts to retain a balance of skills of those who would remain. This meant that project teams had to draw on whoever was available or call on the assistance of other sites. For Centaur, this meant (a) because the site was now "top heavy" with relatively senior staff, some four out of the eight main participants were of equivalent seniority, including the project manager; (b) the skills available to the project did not always match the project's precise requirements; in several respects the team was operating with "the next best thing" to what they needed, and sometimes less;

and (c) for one important role, they had to begin the project with stand-ins while attempts were made to find someone suitable.

2.4. UMC: A Problem That Wouldn't Go Away

By no means least among the problems that Centaur was up against from the start was that of the unit manufacturing cost (UMC). The project was targeted at a particular market niche. The estimated size of that niche indicated a production run of 4,000 high-capacity feeders. The high costs of production tooling are typically defrayed over a long production run. In this case the run was not long enough. the target unit manufacturing cost was, of course, set with an eye to the pricing of the product. Given the tooling problems, a realistic estimation of the tooling cost meant that the UMC would inevitably be much greater (almost double) than the target cost.

3. MANAGING THE DESIGN SPACE

The problems we have just outlined might appear to be intractable. This is certainly a view that was at times shared by the project team. Nonetheless, they proceeded to look for ways to make the intractable, if not tractable exactly, then at least less of an obstacle. In effect, what they did was to look for innovatory strategies for managing their design space. What they innovated upon and around were the prescribed procedures for design and product delivery. Some of the unorthodox approaches they used are institutionalized in this site, and presumably elsewhere. Others were unique responses to the particularities of their case. As each was put in motion, it generated its own complexity and complication that had, in turn, to be handled within the ongoing project. In their own ways, each one had its effect upon the course of design thinking that was being explored. As the design team saw it, they were faced with two sets of problems. One was to design a specific device, the feeder. The other was to find ways of reducing production costs to a level that would be acceptable and to initiate manufacturing early enough to allow targets to be met. The first problem appeared to be relatively straightforward, although not without its own wrinkles. The second looked to be a killer. Given that this was the case, the problems readily prioritized themselves, with almost all the innovative energy being directed to finding ways of managing the cost and time constraints.

For the purposes of this discussion, we concentrate on just three of the innovative strategies that members of the Centaur project used. These are: (a) improvising on the formal procedures, (b) working around the normal work practices, and (c) revising the design task from within the design.

3.1. Improvising on the Formal Procedures

Within the design organization that we studied, standard procedures and protocols are used for every stage in the product delivery process (PDP). The purpose of these procedures is, of course, to ensure quality control, comparability of cases, and standardization of decision making. As we have seen, if Centaur were to have followed these procedures to the letter, it would be impossible for them to have delivered on their targets in time. The team's response was not to disregard the formal steps and processes. Rather, they sought to fulfill them while at the same time reducing the constraints they imposed on the team's room for maneuver. Here are some of the ways this was done.

Informalizing the Review. One of the major problems, it should be remembered, was that of bringing the project to a point at which a formal review was possible. This meant both achieving the conditions required for review and organizing the allocation of time to be taken from other project work in order to prepare for such a review. One way of dealing with this might be to arrange a relatively early and informal review. In particular, this offered the possibility of a timely commitment to manufacturing spending. Extensive telephone and email negotiations were undertaken to seek official approval for such a proposal and to bargain for the staff time required. Eventually, they were successful. By being able to hold an informal review, the team was able to get "in principle" permission to proceed before they were actually ready to ask for definitive permission. This meant that they could begin to think about addressing the manufacturing problems, for instance, before they actually reached the phase in the project where that activity would normally have been scheduled.

Opportunistically Exploiting the Black Economy. The problem of unit cost was constantly with them. Though it seemed they could not make more than marginal differences to the discrepancy between the target and projected cost, matters of detailed costings were nonetheless carefully attended to. Much satisfaction was derived from anything that was judged low cost. Complaints were registered about and close scrutiny given to anything that made a "hit" against costs. Endless negotiations between the project team and the managers at the proposed manufacturing sites continued to see what could be done about the cost and schedule problems.

A chance conversation between managers at the local site revealed that, as one of the by-products of restructuring mentioned earlier, the Procurements Department was short of work, and was casting about for things to do. Through its knowledge of and relations with suppliers, a shadow operation was set up by which the Procurements Department compiled an alternative costing and scheduling of parts production to that being provided by the official manufacturing operation. The aim was to see if lead times (and costs) could be significantly cut by contracting out. In turn, such possibilities might be used to force a relaxation of the UMC and time constraints being insisted upon by the manufacturing groups. Achieving the latter might relieve the pressure of getting everything right first time and offer the chance of at least some limited iterative prototyping.

Massaging the UMC. The UMC was affected by two principal things: the cost of developing tooling for the manufacture of nonstandard parts and the size of the production run. Because these were the only two things that could be varied, ways of varying them had to be considered.

The extension of the production run was one possibility. Lifting the run from 4,000 to 10,000 units would have brought the UMC considerably closer to target. It would still be high, but by a "reasonable" amount. A search for someone within the organization who might be able to advise on the source of a significant demand for these units was, therefore, set in motion. If such a demand could be discovered, it could be factored into the UMC calculations.

The cost of tooling was usually looked at in two parts: the development of "soft tooling," that is, tools made out of inferior materials for producing the parts required for the prototype; and the development of "hard tools" for use in the production run. Soft tools are intended only to produce a small number of prototype parts, and are, in any event, likely to require redesign for the production run. Because this project had only one shot at the prototype and because the production run was short, the possibility of using soft tools in production was considered. Negotiations with parts suppliers on this possibility were initiated.

Adopting a Deflationary Approach to Problems. The organization uses a "management by problem solving" approach to the conduct of projects. This provides mechanisms whereby project monitoring is carried out. These include a weekly project meeting for the identification and recording of problems according to certain formal processes and classifications. Part of this means that problems are classified by seriousness. There are three levels: ordinary, major, and critical. The ordinary are effectively minor problems: They have not been solved, but only routine measures are required for their resolution. Major problems are ones whose solution will have consequences for the cost, quality, or delivery of the product. Critical ones are identified as difficult to solve and may even be insoluble, and to which attention must be given. The existence of critical problems calls the continuation of the project into question.

Given the position in which it found itself, Centaur adopted a "go ahead anyway" approach even to critical problems. They were known to exist and strategies for dealing with them were underway. But they were not as yet resolved. In the meantime, it was necessary to get on with the project's other tasks. In effect, the formal classification system was applied and then recalibrated, with critical problems being treated as if they were major. In addition, Centaur's schedule was, as we have mentioned, constructed on a "right first time" basis. When things, as they inevitably did, failed to go right first time, it was impossible to halt work on dependent problems because, then, the schedule would slip irrevocably. The net result was that the formal requirements of problem solving were circumvented from the start. There was no time for serial problem solving, iteration, trial and error, and refinement.

3.2. Working With and Around the Normal Work Practices

The culture of design in this organization is, as with any work group, composed of the patterns of normative activity and the value systems espoused by those who identify with it. These are what any designer in the organization knows about how things are to be done. In the course of actual designing, the making of decisions and the solving of problems, this knowledge is deployed not as procedural rules or even as rules of thumb, but as ways of making design sense of the issues on hand, and therefore deciding just what to do. Knowing, then, how long some activity should take to complete or what quality of output from some process one should expect is determined *in media res*. As the design goes along, and as the design tasks are encountered, the configuration of this knowledge changes. In turn, this dynamism resonates back onto the ordering of design decisions, the possibilities explored, and the route to be taken. On the Centaur project, this reciprocal fitting of work practice and workplace knowledge to the design tasks in hand could be seen in a number of ways. We detail just a few.

Cutting Corners and Watching for Potholes Became a Way of Design Life. Schedules are usually compiled more in hope than expectation. The interlocking of steps in sequences means that exceeding the estimated time always has knock-on effects that have to be either anticipated or actively managed. One case that occurred on Centaur involved working out the detailed features of the design and the production of the technical drawings. The concern was to get decisions to the point at which technical drawing could begin while at the same time attempting both to truncate the process of producing usable drawings and to prevent any slippage at that point. To do this, a policy was adopted of using less-than-finished drawings wherever possible. Where it was thought that the supplier of a part was well enough

known to be relied on to understand and implement a rough drawing, it was agreed these could be issued at an early stage. Even so, the quantity of drawings to be produced was under the demanding scheduling, recognized to be such as to require longer than was previously allowed for and thus to threaten delays.

In addition, the production of technical drawings was recognized to be at risk from the 90% finished problem. Compared to the total number of drawings to be produced, it may seem that most are done and there is not much left to do. However, the relatively small number remaining may be the ones that are going to take a long time and may even be left to the last because they are the difficult ones to do. On Centaur, the lead designer sought to avoid the 90% finished problem by making his own calculation of the relative difficulty of particular tasks and therefore of the proportions of the available time particular jobs should take. Projecting the rate of work actually done against the rate required to meet the schedule meant that deviations from the necessary rate would show up early. Corrective steps could then be taken and the work got back on schedule before it was too late.

Problems Were Traded Off Against One Another. We mentioned that the composition of the Centaur team was affected by the contraction of the site's work force. The team was made up of individuals, many of whom were senior and long serving, and who regarded themselves as equally experienced in project leading as their project manager. These individuals treated their mutual relations as delicate. There was a ready possibility for misreading motives, and especially for disagreement to be construed as personal criticism. Objections to aspects of the project's organization particularly might have been (mis)understood as expressions of sour grapes. Any attempt to force disagreements to conclusions in design meetings might well have been taken as attempts to "show up" the project manager in front of colleagues. This does not mean disagreements did not occur, but they were muted and were not pressed particularly far. If dissent on some point revealed that the project manager had a strong preference, then this was deferred to. This display of restraint as a way of handling this issue had one crucial consequence for the development of the project.

Timing diagrams are a particularly important tool for the design of photocopiers. They involve working out the precise timings for the movement of paper sheets through the machine. One important aim in photocopier design is to achieve maximum possible speed in the copying of sheets and, thus, to keep the sheets moving through the paper path as close together as possible, but without leading to overlaps or conflicts and hence misfeeds or paper jams. Some of these separations are timed in milliseconds. The timing diagrams provide a working out by the millisecond how the designed system will move paper. Whether or not the design will work (at

all, or without significant revision) cannot be a matter of intuition. It has to be a matter of calculation. The difference between a working design and one with a serious problem may be a matter of a few hundred milliseconds. The production of the timing diagrams for Centaur was, then, a matter of some importance. However, there was disagreement on just how urgent it was. The project manager appreciated the task was important, but did not feel it was quite as critical or urgent as did some of his colleagues.

From the project manager's point of view, although working out the timings would be a difficult task, the team had no one who was experienced or appropriately skilled in it. On the other hand, the feeder was to be compatible with a machine that had already been built, and for which there would or ought to be extant timing diagrams. He also knew there was someone on the site who was experienced in the work. Furthermore, she had done the very timing diagrams for the relevant copier. The project manager set about tracking down these diagrams and tried to borrow the relevant skilled person from the project to which she was currently attached. In his view, the diagrams were in hand. He had other more pressing issues to resolve. The structure of problem classification no doubt played a compounding role in his prioritization here. Naturally attention is likely to focus on the "critical" matters, especially on a time scale as short as Centaur's. The provision of the timing diagrams, although being seen as something important to do, was not even worth classifying as a problem. Anyway, it was in hand.

Other members of the team did not agree. They regarded the timing diagrams as critically important, and thought that they should be produced as soon as possible. When it became clear that the project manager did not share their view, they acceded to his argument, without accepting it for one moment. They foresaw problems resulting from delay in getting the timing diagrams out. However, their choice was between two kinds of trouble on the project: that which would result from late availability of the diagrams, and that which would result from creating personal animosities. Furthermore, those animosities would have been created without necessarily getting the result they wanted anyway. It seemed better to deal with the problems created by postponing working out the timings when they arose than to create conflicts over the running of the project.

Necessity Was the Mother of Redeployment. Relative to the project's life, the search for the copier's timing diagrams and the negotiations with the other project for assistance in working them out was protracted. The necessary diagrams were eventually found and then only by happy coincidence. The negotiations to borrow the skilled person were not successful, and so the work had to be done—now belatedly—by someone within the team. Even here, the one who had the most relevant skills was not the one who did the

work. He already had his hands full with other, equally critical tasks, such as designing the printed wiring boards (PWB). These tasks were not further deferrable, so working out of the timings had to be assigned to someone who had just enough skill to do them effectively, albeit with difficulty, and who had other tasks that could be deferred. It was not that delay in the performance of these tasks might not eventually create problems of its own, simply that it would make no immediate, tangible difference.

3.3. Revising the Design Requirements From Within the Design

Clearly, one of the ways to find an achievable route through Centaur's design space, would be to relax some of the constraints encapsulated in the design requirements. If this could be done, then the problems being faced might reorder themselves sufficiently to enable some relatively obvious design solutions to be offered. A several points a number of attempts to relax these constraints were made.

Amending the Customer Requirements. A key feature of the project was that the attachment of the Centaur feeder should not require any communications with the central processor of the host machine. This meant that the design was constrained to use the communications facilities already designed into the host. This gave rise to one of the tricky design problems, namely the use of the host's sensors to communicate the various states of the paper trays. Much time was devoted to working out the possible arrangements of trays, sensors, and papers. It became apparent that all possible combinations could not be accommodated, and so one of the immediate responses was to see if the range of possibilities could be constricted in some way.

The issue could only be resolved at the level of marketing strategy. The design had been developed on the assumption that the machine was to be produced in the routine way to meet the requirements of various markets of an international company. It would have to operate in different climatic conditions, with different sizes and qualities of paper, with instructions in different languages, and so on. The difficulties in accommodating all these possibilities without independently communicating with the central processor led the team to ask if this was realistic. The project was, as everyone was well aware, designed to solve a specific problem by exploiting a specific market niche, one most prominently based in the United States. How many actual markets, therefore, was the machine to be designed for? How much variability in paper sizes and climatic conditions should be involved? What was the actual pattern of paper use within the main projected market? Answers to these questions might allow a drastic reduction in the range of alternatives to be designed for. And that might enable them to design the communications systems according to specification.

This example illustrates the ways in which the various strategies the team engaged in interacted with each other and how problems can move in and out of the foreground of the design team's attention. We pointed out earlier that the project had been initiated relatively informally. This informality now began to have consequences, in that there was no formal mechanism to clarify the actual requirements for the design. There were informal contacts with relevant parties in the local marketing function, but these were rendered problematic by changes in personnel. In the event, an agreement was made with someone in the main marketing organization to collate information on the actual pattern of paper types, sizes, and so forth, in the target market. The need to obtain clarification of the marketing policy and to establish whether the feeder could be launched in one or two countries only was also recognized. Launching the machine for specific markets offered the possibility not only of restricting the combinations to be designed for—and thus simplifying the task—but also of being able to dispense with the need to design packaging and arrange translations for all the different markets. This promised cost savings. However, though this information was badly needed, it could not be speedily obtained. There appeared to be no easy way to clarify market potential. Personnel in the international marketing arm were changing positions, and the steps involved in moving informal support for Centaur to formal decisions about its launch policy had not been taken. They had gone as far as deciding that Centaur should be aimed at the North American college market, but no further.

Assuming the Best Solution Will Be Available. Obviously decisions are interdependent. Designers seek to line them up so that one decision can determine the character of others. On Centaur one issue was how much power it was going to need. This would depend on the size of motor required which, in its turn, would fix the amount of space available for the installation of the PWBs. Engineering lore lays down that the final size of a motor is always greater than that envisaged or wanted. Hence, the size of the motor could not be determined prior to decisions about the power supply or about the architecture of the boards. The investigation of the available motors, the decision about the power supply, and the design of the PWBs all had to proceed simultaneously, with decisions about each involving a certain amount of risk. Allowing for the worst possible outcome with respect to the size of the motor was not possible because there was a constraint on the space into which the motor and PWBs had to go. The risk was in judging what one would get away with in terms of motor size and then hoping that this estimation would be fulfilled.

It is this kind of problem that puts designers in "no choice" situations. There are things they would like to know and decisions they would like to have settled, but the speed of the formal "decision loops" and the time scale of design tasks mean that important considerations cannot be resolved. The designers have no choice save to go on working out the design—even its detailed features—while awaiting the resolution of issues on which the effectiveness of their decisions depend. These are not decisions with defined contingencies: The designers do not know what they are going to do if and when the assumptions they have made prove false. That is something to be faced if and when it comes to it. They have no choice, in the circumstances, but to assume a favorable outcome and continue designing on its basis.

Adopting an Alexandrian Approach to Requirements. The final production of the timing diagrams revealed serious problems in the timing and tracking of sheet movements. There were, too, still unresolved questions about the capacity to communicate between the feeder and the host machine. These were both "life threatening" problems for the project. To enter a review (even an informal one) with two critical problems of this order would almost certainly be fatal. Time was running out. It was becoming clear that a drastic solution was needed. As various possibilities were examined to solve the paper-feeding problems, it became increasingly apparent that the main obstacle was the requirement about communication with the central processor. If that requirement was not in place, then there was a simple solution. All that would be needed to solve the timing problems successfully was a single wire between the feeder and the central processor. The installation of such a wire would make only marginal difference to the installation work. (Minimizing the installation task was a prime reason for the prohibition on communication with the central processor.) But if communication with the central processor was available then other outstanding problems would also be solved. Signaling the state of paper and trays could also be done through that connection (and with minimal alteration to the software). The only way forward was to go back on what had hitherto been treated as an immutable constraint, and cut the gordian knot it had created. Once it was accepted that this must be done, the outstanding problems evaporated and the project entered the review in sufficiently good condition to have its mechanical and electrical designs approved.

4. CONCLUSIONS

Our account has instantiated the ways in which the development of the design train of thought is intimately and elaborately intertwined with organizational contingencies bearing on the project and with which the project team has to cope. It is this emphasis that marks our materials off from those of QOC and similar analyses, especially insofar as those draw on experimentally contrived situations, for these usually enable the participants to disregard anything other than the explicit features of the design

concept. For our designers, the elaboration of the design concept was the very least of their problems. Their troubles began once the design concept had been defined. In bringing this chapter to a conclusion, we consider some implications of our materials for the development of tools to support design rationale methodologies. To keep the discussion within bounds, we focus on just two aspects. In both cases, let us hasten to add, we do not see the issues we raise as invalidating attempts to build tools. Rather, we offer our comments in the spirit of furthering this as joint endeavor. As was recently noticed in another but closely related context, "... maintaining a user-centered perspective during design must be done in concert with engineering realities of function to be provided, schedules to be met, and development costs to be managed" (Karat & Bennett, 1991, p. 270). We see our contribution as the elaboration of some of these realities from the point of view of the organization of design. What we seek to provide is a set of sensitivities to the ways in which the tools being used might interact with the organizational setting of design.

4.1. Some Features for Tools

The decision what to include within the specification of design rationale tools obviously depends on the envisaged uses to which they are to be put. We can imagine two such different functions and would like to make the following observations about them.

An Account or Record of Design. If design rationale tools provide a record for and of the design project, then it seems clear that they will also have to find ways of marking and tracing through a number of organizationally generated contingencies. Again, to be succinct, we nominate just three:

1. Project team membership is generally changing. Any tool will have to mark the variability of skills available and courses of action decided on as a response to the variability of membership.
2. Every member of a project team is simultaneously a member of other project teams. Each of these requires a commitment of time and effort. The prioritizations of activities are not always in the hands of the designers concerned and can be affected by a multitude of exogenous forces. Tools should adaptive to the consequences for design scheduling of potential discontinuities in the management of the prioritization process.
3. Organizationally defined procedures such as the PDP are constantly under review and subject to upgrade, improvement, and/or reconfiguration at almost any level of granularity and at any stage. Design rationale tools should indicate just how such changes impact design decisions and those reformulations of the formal procedures.

A Forcing Device Within Design Decision Making. One commonly agreed use of design rationale tools is as a device for deliberately expanding the design space beyond what might be intuitively obvious. In principle such an exploratory strategy could refuse to be bound by any of the presuppositions apparently built into a set of specifications. However, from the material we have gathered, two forms of resistance are likely to prevent this radicalisation of design from occurring.

The possibilities that are laid out for any design and the constraints that operate on them are not all of the same order. Designers have a sense of their relative weightings and the interactions between them. Choices are made in the context of these weightings. One of the most important elements in the weighting system is the family of solutions embedded within a particular development organization. These *standard solutions to standard problems* have what we might think of as an *interactional efficiency* in design. The overhead of discussion, explanation, and plausibility construction is greatly reduced by their use. This being the case, "blank sheet design" is by and large a myth.[2] Forcing explicit review of a wider range of design possibilities may merely provide in the eyes of designers a more roundabout route to conclusions they would have reached in any case. Like the skilled chess player, it is part of their competence to cut through possibilities, eliminating many without consideration. They may, therefore, treat the explication of the design space as a mere formality, one more requirement to be satisfied only because it is formally necessary and because someone else wants it done.

4.2. Context of Use

No tool can be introduced into any set of working practices without some consequential effects. Indeed, the purpose of introducing the tool is often to bring about certain kinds of effects. We would recommend the following be borne in mind when thinking through how it is envisaged that any particular design rationale tool might be used:

1. Records are organizationally pertinent documents. They have particular orders of usage, lifetimes, and necessary components. Given their

2. It has been suggested to us that our talk of resort to standard solutions carries a pessimistic implication with respect to innovation in design, but it is not intended to do so. First of all, we do not mean to suggest that designers were thoughtlessly bound to such solutions, merely that the availability of these could facilitate many aspects of their work and that exploration purely for exploration's sake or purely for the record would seem to them superfluous to the needs of their work in hand. On the Centaur project itself, an exercise in "value engineering" was scheduled to provide a testing reexamination of the prototype, particularly with respect to cost.

consequential nature, their production is often formatted in particular ways—as with the minutes of meetings—or ritualized—as with roll calls of attendees. In organizational settings, organizational consequences are known to need management. In Centaur, to get the documentation kept, assurances sometimes had to be given that there would be "no witch hunts," that is, that records would not be used to attribute blame for any problems they revealed. In view of this, the presumption of goodwill on the part of all current and subsequent parties to the record may well be misplaced. This, indeed, may feature quite intrusively in situations where what the record shows may be held to be consequential for the allocation of responsibility for outcomes or a matter of controversy. In such cases, the work of constructing the record can tend to displace that which it is supposed to record.

2. The point of constructing design rationale is to preserve an account of design decisions for later reengineering or maintenance. There seems to be an inherent uncertainty in this. What specifically will later users of the rationale wish to have available? How much is enough? Who will want to know what? It is not until the information is needed that its utility can be estimated. In addition, there is the problem of reworking at some later date, precisely why some record has the shape and contents it does.

3. To the aforementioned considerations, we have to add the mobility of design. In our study, important design decisions were made on the phone, in the corridor, in the car park, as well as in formally constituted meetings. Indeed, often they only appeared in such meetings as confirmations or even consecrations (such as formal sign-offs). Any tool that was to be of real practicable value would have to be usable in all these contexts. It is in this respect that the practical fact of life that information is not a free good becomes visible. If a design rationale tool imposes an overhead of information management, then it is unlikely to be seen as of value unless the obligation to provide this information clearly, concisely, and intelligibly expressed, often for the benefit of unknown others, conformity to the demands of the tool may be seen as adding another bureaucratic task to the work load of individuals who already feel bureaucratically imposed on by the range of form filling and record keeping they currently manage.

4. Even where design decisions are made in formal and informal meetings, our experience is that this is often a delicate balance between being persuasive and seeking control, allowing adequate turn management and giving everyone sufficient air time, managing the meeting and managing the activity the meeting is in support of. If we then introduce all the impedimenta of meeting support likely to be required for any effective design rationale tool, do we know what the impact on the character of such decisions will be? Do we know enough about any kind of meeting structure to predict effects, let along those between people from different background and management groups and with vastly different interest?

As we said at the beginning of this chapter, ours is a less design-centric approach to design than is more usually encountered in design rationale studies and our emphasis has been on the ways in which the development had to be adapted to the practicalities of project work and to the unclear and shifting circumstances of the project. This difference is on view in the range of issues we have outlined. It can also be seen in the conclusion that we draw from our experience and that we found to be somewhat ruefully shared by many of the designers we met. In the end, the fate of a project and hence the success or failure of the design team is only partially under the control of or even the business of the designers themselves. A reminder of that fact alone may be the most important contribution our approach can make to design rationale.

5. POSTSCRIPT

Several readers of earlier drafts have wondered about the fate of Centaur. Did it ever get into production? Or did it go the way of premature cancellation many predicted for it? Some time after the review we described previously, the project was terminated. At the meeting at which this was announced, some of the team insinuated that they had been let down by the project managers. This was met by the response that experienced members of this environment know that cancellation is a common fate of development work. The team was quickly redeployed although some effort was made to assemble and retain whatever remnants of the project could be preserved. Those who did this did so on the grounds that they would not be surprised if the project was resurrected at some future point. Some 6 months later there was a brief attempt to resuscitate Centaur and a few months after that there was speculation it was about to be revived. On a visit to the United States, the project's manager discovered a firm that specialized in customized items. This firm was already producing a high-capacity feeder. Not long after, he found one of his own company's other sites was manufacturing a comparable add-on. And that really was the end of Centaur.

NOTES

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