Managing Experts and Competing through Innovation: An Activity Theoretical Analysis

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Abstract

An activity theoretical analysis is presented of an organisation that is operating in a rapidly changing sector and whose competitiveness depends upon the design skills of its engineers, a number of whom are world experts in their fields. The Company designs high-technology, make-to-order products. Like other organisations that compete through knowledge and innovation the prosperity of this Company depends upon its organisational learning, that is, upon the effectiveness with which it can mobilise, apply and develop its distinctive knowledge base as circumstances change. In the difficult context that the Company faces the speed with which projects can move from the initial concept phase through design to production has become especially important. The paper outlines a general strategy for change that was developed as the Company sought to control this process and traces the consequences for design practices. An activity theoretical approach is used to model the changes that were attempted, the outcomes which emerged and possible future options. The approach emphasises the relevance of an historical perspective on organisational change, features the changing nature of expertise in contemporary manufacturing and draws attention to the potential significance for collective learning of tensions and incoherencies within a work system.

Research Approach: Activity Theory and the Nature of Expertise

The authors are part of a multi-disciplinary research team studying the management of innovation in high technology organisations. Our approach has been to regard innovation as a complex series of developments from product conception, design and manufacture, to adoption. We are seeking to identify and to study key processes within this sequence, to feature the interactions between individuals and contexts and to explore ways in which innovation processes may best be managed. In Slappenedel's (1996) terms, we are developing an interactive process approach to organisational innovation.

Activity theory, as developed by the Finnish scholar Engestrom (1987) and initially applied to organisational analysis by Blackler (1993, 1995) and Holt and Morris (1993), has provided the basis for our approach (see also Blackler, Crump and McDonald, 1997). Work in the activity theoretical tradition has influenced organisation studies through Lave and Wenger's (1991) theory of situated learning, Brown and Duguid's (1991) approach to organisational learning, and recent approaches to knowledge and competition such as Spender (1995). The approach has its roots in Soviet scholarship, especially in Vygotsky's psychology. Like theories of practice more generally (see Chaiklin and Lave, 1993) activity theory analyses the nature of practical activities and their relationship to the broader cultural, social and physical contexts of which they are a part.

Applied to management and organisation studies, the approach theorises expertise. It points to the recurrent and embedded nature of human activities, the tentative nature of knowledge and its action orientation, and the significance for collective learning of the tensions that inevitably develop within and between activity systems. In this paper we apply the approach to model alternative heterogeneous networks of activity and the changing nature of expertise within manufacturing organisations. We also use the approach to analyse the difficulties of moving from one system of organising to another, and to explore the opportunities that may be created for organisational learning.

The unit of analysis associated with the orientation is the *activity system.* Engestrom's (1987) treatise offers a careful analysis of the term, and suggests a general model for representing the relationships between personal knowledge and the cultural infrastructure of knowledge, and between individual actions and the broader pattern of activities of which they are a part. The notion of "activity" is broader than the notion of "action" or "operation" (examples of activity are work, play, research, war) yet more restricted than the term "culture". As used by activity theorists the notion of activity offers a way of linking events to the contexts within which they occur. As adapted on Figure 1, Engestrom's approach models the relationship between individuals, their work colleagues, and the activity in which they are jointly engaged (the inner triangle of the figure) and the factors that mediate these relationships (the outer triangles of the figure). Thus the model features the processes through which technologies mediate the relationship between a worker and his or her activity, social rules mediate the relationship between an individual and his or her work community, and the division of labour mediates the relationship between community members and their shared activity. Expertise is analysed as technologically mediated, culturally situated and socially distributed.

It would be a mistake to assume that the relationships between intentional, psychological, technological, structural and processual factors that are depicted on Figure 1 are tidy and clear cut. In a manner that is reminiscent of the analysis of social process developed by symbolic interactionists, see for example Star's (1997) discussion, the activity theory approach emphasises how incoherencies, inconsistencies and tensions are integral elements of activity systems. The point is represented by the wavy lines on Figure 1. It is the conceptions that people have of their activities, featured in italics on the right of the internal triangle, that gives
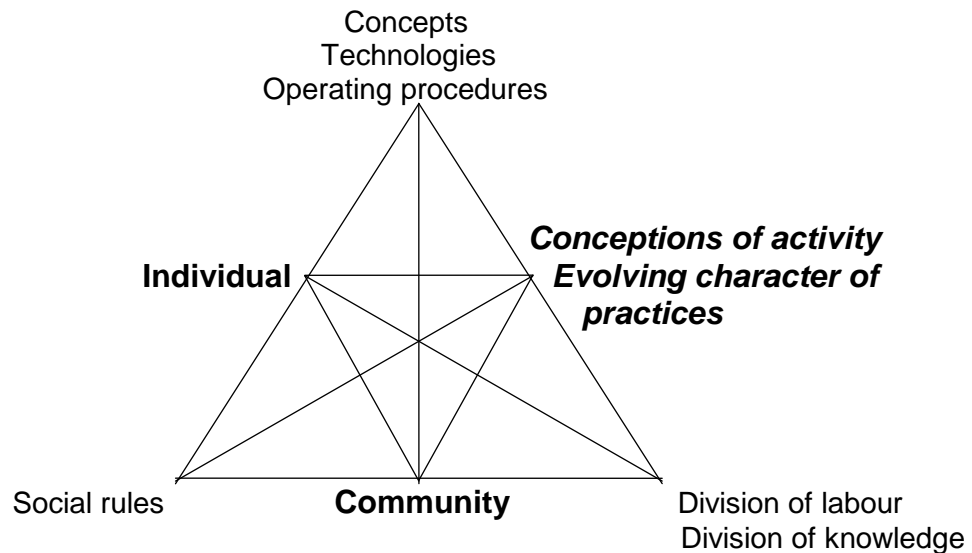
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Concepts
Technologies
Operating procedures

Conceptions of activity
Evolving character of
practices

Individual

Community

Social rules

Division of labour
Division of knowledge

Figure 1
A General Model of Activity Systems
Activity systems can be characterised as disturbance producing systems. The wavy lines
represent incoherencies within and between the elements of an activity system.

coherence to their individual actions. Through the determination and creativity that people show in enacting their (emerging) conceptions of their activities the tensions and "normal accidents" that inevitably and routinely arise within activity systems are, as a matter of course, overcome. Familiar social arrangements do, of course, often become entrenched in peoples' imaginations and practices yet, activity theory suggests, the inconsistencies and tensions that routinely arise within and between activity systems provide important opportunities for collective learning. As incoherencies and tensions are recognised participants may begin, directly or indirectly, to address underlying issues and dilemmas. The outcome may be the development of new conceptions of activity and a reconstitution (or, in activity theoretical terms, a remediation) of the elements of an activity system. This, typically hesitant, cyclic process of change is represented in Figure 2. Activity theory is unusual in the centrality it attributes to inconsistency and tension in collective learning and in its preoccupation with the dynamics of social and personal change.

A Strategy of Change

The study discussed here was undertaken in a leading design and manufacturing organisation that specialises in made-to-order opto-electronic products that are used in a range of advanced technology defence environments. It is located on three sites, each of which has been a company in its own right prior to being taken over by its current owner. This paper reports developments at the longest established site, East Site.
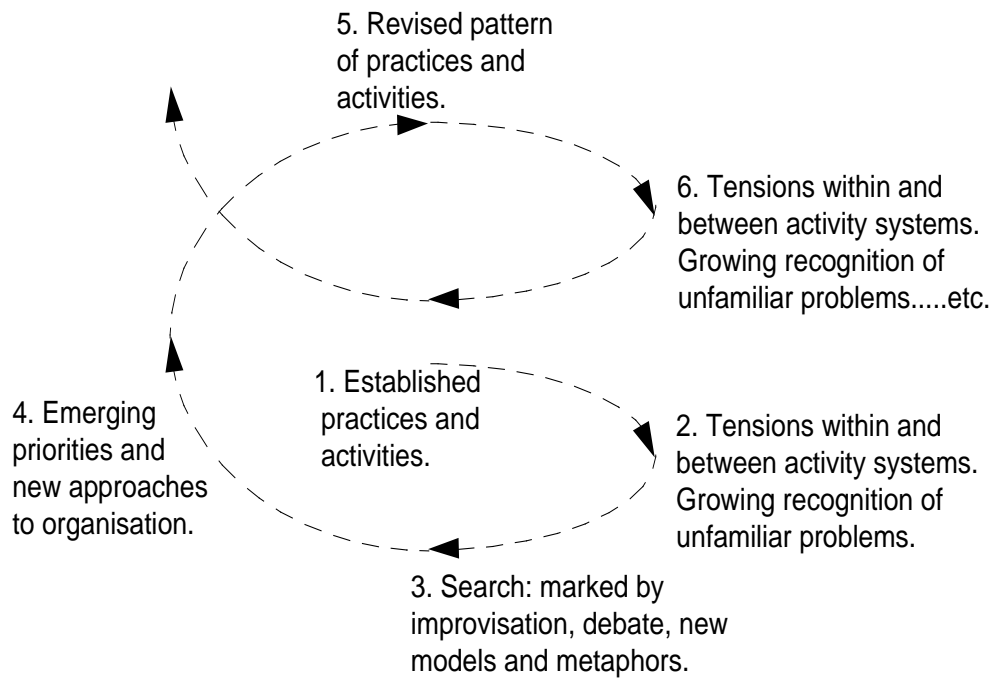
Figure 2:
Tensions and Possible Developments within Activity Systems
The dotted lines indicate that progression around the
cycle of development depicted here is typically hesitant and uncertain.

Until 1987 the Company as a whole had been trading profitably, however the sudden unfreezing of East-West relations saw the company's markets contract and slump and by 1990 its losses stood in excess of £10m. Government defence contracting had also been reorganised in the UK around this time, from a "cost-plus" system that paid for development and production costs plus a flat 10%, to a system of fixed-price contracting. A new top management team was brought in to devise a strategy that would salvage their position. Their review of the business showed that the Company was in relatively poor competitive shape, over-manned, top-heavy and bureaucratic, with a bad record for meeting orders on time. Its saving grace was its world-class range of products and technology.

At East Site the new management team set about their task of creating an organisation that was nimble, responsive and ultra-efficient. They became convinced that only by working towards Computer Integrated Manufacturing, supported by a range of organisational changes could they bring about the productivity gains necessary. They produced a ten year change strategy which depended on making a series of evolutionary changes in organisational structure, each step building on the achievements of the preceding step. The strategy built upon the ideas of the Harvard academic Jaikumar who argued (Jaikumar and Bohn, 1992) that manufacturing industries need to move away from a static approach to the application of technological solutions to organisational problems to recognise the importance of contingencies, learning and problem solving.

Equipped with such ideas East Site management evolved its approach to the development and application of the strategy. The process was conceived as four distinct phases: (i) Co-ordination, (ii) Process Control, (iii) Automation and (iv) Systems Integration. The programme anticipated a shift away from improving efficiency by applying established knowledge to a system of manufacture based on continual learning about the manufacturing system itself. An integrated personnel strategy was envisaged to support these plans. A clear implication from the start was that the new business would need fewer but better trained employees and, largely through voluntary methods, between 1990 and 1994 the Company reduced its payroll from approximately 3,000 to 1,050 employees.

Phase one of the change programme, the co-ordination phase, began initially in the manufacturing function then moved to design engineering. Central to this phase was the introduction of MRPII (Manufacturing Resource Planning), a computer based method. Team working was also adopted and management levels were flattened. These changes were supported by a move into a new purpose built factory. The factory move took place in 1992 and provided the Company with an exceptional opportunity to incorporate their new culture and aspirations into the design and layout of the working environment. Many specialist functions that were not part of the core of the business were out-sourced. The whole organisation was involved in a benchmarking exercise to establish what features needed to be incorporated into the new building. For East Site the result has been the creation of a totally open plan, egalitarian and potentially participative environment.

Phase two of the four phase change programme concentrates on quality via process control, doing things error free and on time. The slogan "Right First Time" is used to encapsulate this phase. Phase two is underway within manufacturing while within design and marketing work still proceeds to achieve the level of co-ordination associated with phase one. Phases three and four which will complete the present vision of an organisation that is "better, faster and cheaper" than their competitors are seen to be 3-5 years away at the present time.

The Changing Activity Systems of Manufacturing Organisations

To begin to understand the complexity of the change programme at East Site we used the general model of activity systems to represent the distinctive features of different "epochs" (or, to adopt Hinings and Greenwood's, 1988, term "organisational archetypes") of machine tool-based organisations that had inspired the management team at East Site, see Figure 3. Two additional models are included in the figure: a prior historical phase (craftwork) and a possible additional stage ("innovation-intensive" organisations, extrapolated from accounts of recent trends in manufacturing, e.g. Florida and Kenny 1994).

Three general points highlighted by this analysis are:

> 1) Figure 3 represents the complexity of the changes that are involved in the
> move from one work system to another. Such transitions involve the

1) Craft Work

Simple tools
Tacit, embodied know-how

Craftsman

Relatively indeterminate object of work, evolving in the exercise of craft skills ("Artistry")

Codes of practice
Codes of self protection

Guild

Division of labour based on individual adaptation, in the context of custom and practice

2) Fordism, Taylorism

Complex machinery
Workers as tools
Explicit know-how embedded
in organisational routines

Manager

Predetermined object of work ("Repeatability")

Procedural rules

Other Managers

Hierarchical, demarcated division of labour

3) Process Control

Increasingly complex machinery
Workers as tools
Techniques for improving control (e.g. MRP2)

Manager

Integration for control ("Efficiency")

Procedural rules

Other managers
Overall system

Hierarchical, demarcated division of labour

Figure 3: (continued below)
Changes in Activity Systems within Manufacturing Industry

4) Process Improvement

Tightly controlled systems
Explicit know-how and problem solving
Techniques for process improvement

**Manager and
work group**

*Continuous improvement
of product and methods
("Effectiveness")*

Rules, plus **Work group** Some flexibility
group co-ordination **and related groups** in division of labour
and co-operation **Overall system** through teamworking
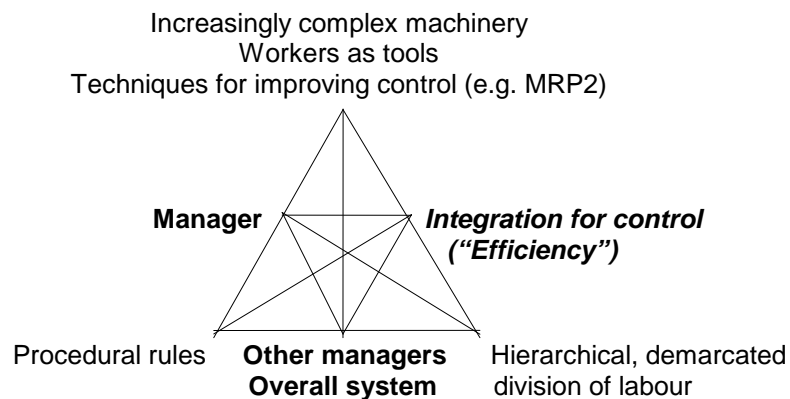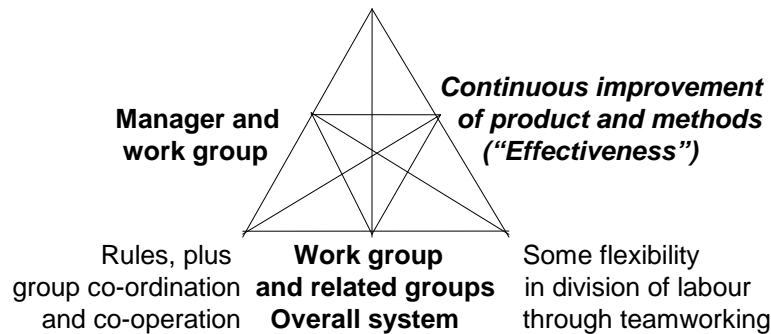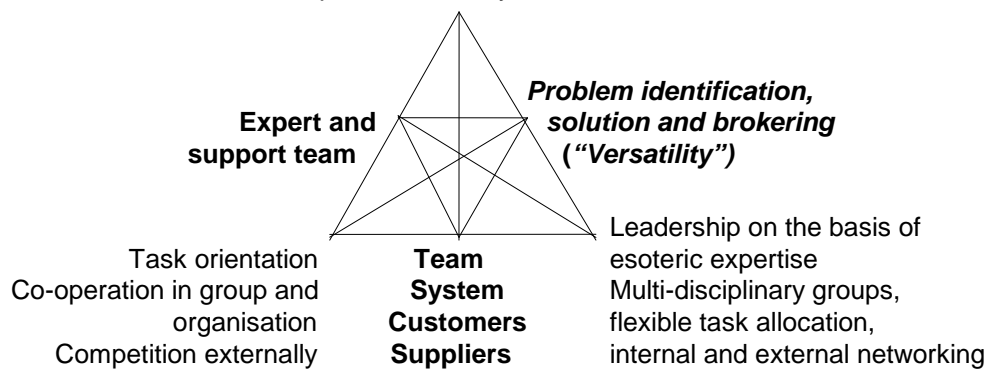
5) Versatile Manufacturing

Integrated technologies
Technical and organisational
competencies of key individuals

**Expert and
support team**

*Problem identification,
solution and brokering
("Versatility")*

Leadership on the basis of
Task orientation **Team** esoteric expertise
Co-operation in group and **System** Multi-disciplinary groups,
organisation **Customers** flexible task allocation,
Competition externally **Suppliers** internal and external networking

6) Innovation Intensive

Highly integrated technologies
Methods for developing collective competencies
("think the unthinkable")

**Expert in
team of experts**

*The developing object and changing
context of the activity network
("Intervention")*

Task and service orientation **"Communities of** Collaboration in
Dialogue, questioning, within **knowing"** supra-disciplinary groups
and between teams **Project team** Matrix organisation
Institutional framework for trust **The Organisation** "Knowledge links" externally
Competition externally **Its (global) network** and to partner organisations

**Figure 3: (concluded)
Changes in Activity Systems within Manufacturing Industry**

reconfiguration of a complex series of relationships, including conceptual, technological, social and structural factors, which are often analysed as if they are independent from each other.

2) The activity theory approach emphasises that each new work system involves, indeed depends upon, the development of new practices and conceptions of activity. Whilst management can, relatively easily, provide new terminologies, procedures and technologies (and thus influence what Schutz, 1967, called the "in-order-to" aspects of actions), changes in peoples' underlying sense of their activities (what Schutz called the "because of" aspects of action) are likely to be more difficult to achieve. For this reason alone movement from one paradigm of practice to another is unlikely to be achieved smoothly.

3) The changing activity systems depicted in Figure 3 point to changes in the nature of expertise and to new managerial and organisational challenges. (a) Regarding changes in the nature of expertise, activity systems within the manufacturing sector are getting more complex internally and more closely interrelated to adjacent activity systems. (b) Regarding emerging managerial challenges, later activity systems depicted in the Figure place a premium on new approaches to integration, replacing a system of co-ordination based on rules and hierarchy with a system that depends upon collaboration, mutual adjustment and shared sense making.

Alternative Approaches to Engineering and its Management

Over a five month period we interviewed sixty eight design engineers and members of the management team associated with the general reorganisation; this included about twenty five percent of the total number of design engineers at East Site. Following a period of introductory interviews to orient us towards the problems of the Company we developed a semi-structured interview schedule. We then undertook a retrospective study of lessons learned from a project that pioneered movement away from "cost-plus" contracts, and subsequently undertook two studies of on-going design projects that were of critical relevance to East Site's future.

Whilst the aims and objectives of the Company's change programme were well understood throughout the organisation a multitude of conceptions of the past and emerging situation featured in these interviews. For example, it became clear that there was no single "organisational memory" of the lessons that could be learned from the project that we studied retrospectively and no single account of the ongoing projects, but that there were various different interpretations of the relevant events.

As we assembled this range of viewpoints we were at first tempted to contrast the forward looking but sometimes impatient voice in our interviews of those enthusiastic about the four phase change programme with the occasionally reluctant attitudes of esoteric experts whose work practices had been transformed by it. We soon realised, however, that something other than a simple clash between old and new management style was emerging from our data. Although the engineers who expressed reservations

to us about certain aspects of their new work systems did draw from traditional images of design expertise, for the most part they were certainly not harking back to the past in a nostalgic way. Many of them, in fact, were quite likely to ridicule some of the practices associated with the cost-plus era. The criticisms of current arrangements that they did raise questioned the practicality of particular aspects of their new activity systems and the relevance of procedures and policies of the professed object of activity for East Site in future. We were to conclude that our data reflected less a continuing debate between the old and the new and more a growing awareness of tensions that were a feature of the new activity systems of engineers and East Site.

The general cycle of tensions and possible developments within activity systems depicted in Figure 2 above provides a way of illustrating this point. In Figure 4 we have adopted the approach to summarise key tensions and the sequence in which they emerged in the activity systems of design engineers at East Site. In the remainder of this section we draw from our interview data to illustrate this sequence of events. Following the sequence presented on Figure 4 we describe engineering activity as it was practised in the cost-plus era, trace the problems that emerged as cost-plus contracting was abandoned, delineate the new approach to engineering that was then introduced, and trace some of the tensions that engineers currently experience.
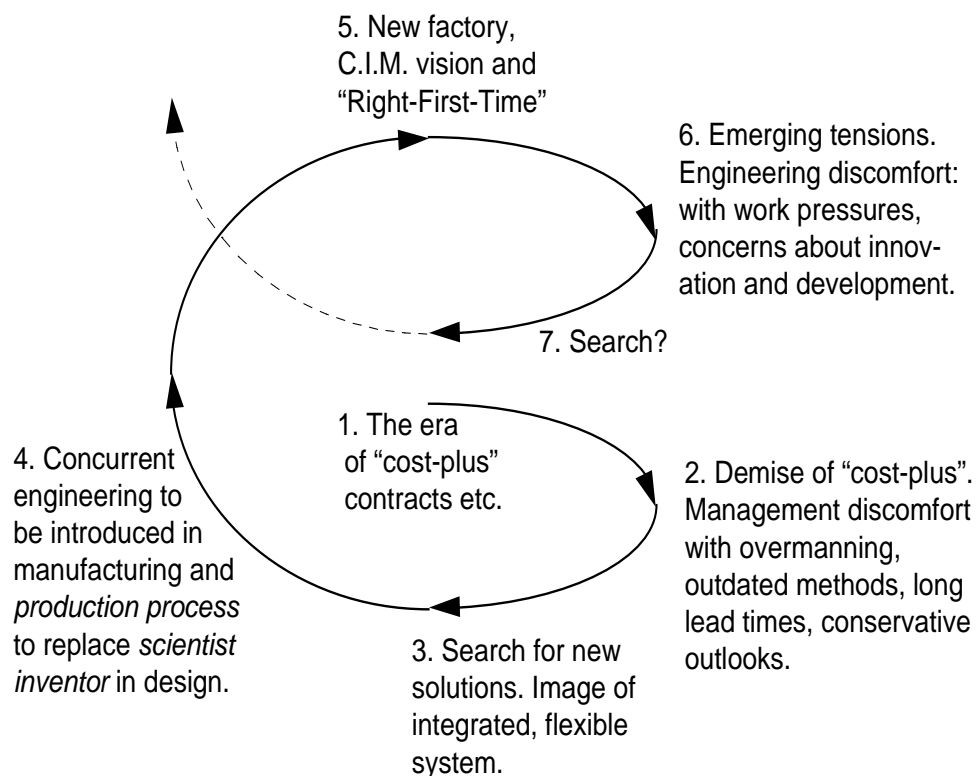
5. New factory,
C.I.M. vision and
"Right-First-Time"

6. Emerging tensions.
Engineering discomfort:
with work pressures,
concerns about innov-
ation and development.

7. Search?

4. Concurrent
engineering to
be introduced in
manufacturing and
production process
to replace *scientist
inventor* in design.

1. The era
of "cost-plus"
contracts etc.

2. Demise of "cost-plus".
Management discomfort
with overmanning,
outdated methods, long
lead times, conservative
outlooks.

3. Search for new
solutions. Image of
integrated, flexible
system.

Figure 4:
Tensions and Developments in the Activity Systems
of Engineers at East Site
a) The Era of Cost Plus Contracts (Stage 1 on Figure 4)

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A number of stories about engineering in the cost-plus era featured in our interview data. In these accounts engineering as an activity was equated with problem solving, engineering expertise was assessed in terms of the mastery of technological complexity, design was practised as a process of trial and error, and heavy emphasis was placed on the professional autonomy of individual engineers. The metaphor of the engineer as *scientist-inventor* can be used to summarise this general approach to engineering. For simplicity of presentation we use the past tense in the description of this outlook that we present here although, as we note below, elements of this conception of engineering do still remain in the Company.

East Site itself has a long, proud history, the original company being founded late in the last century by two academics. These men were a powerful partnership of entrepreneur and inventor and there is no doubt that it is with them that the image of engineer as scientist-inventor began. In the tradition of engineering associated with them engineering products were conceived as solutions to technical problems and a product was deemed successful when it worked.

In order to be able to continue to solve more and more difficult (and interesting) problems the engineer as scientist inventor needed to develop his or her (usually his) professional excellence. One of the ways that this was achieved at East Site was by the engineer making sure that each new product contained some novel technology or application of technology. Indeed we were told that East Site prided itself in its reputation of making products that frequently surpassed the expectations of its customers. The products East Site supplied would, we were told, often exceed product specifications and include extra features, known colloquially as "bells and whistles".

Central to the culture of professional excellence of the scientist-inventor was the idea of mentoring. Design engineers straight from college or university would be supported with informal guidance from older, more experienced individuals in the same field. Having completed a programme of 'book learning' the design engineers were regarded as novices who needed to be introduced to the ways of the real world of engineering. This was done gradually, each task set being slightly more difficult than the last. If the new engineers had problems with their tasks they were expected to ask their mentor for advice and if they were to fail the disappointments would often be tolerated and be put down to experience. This system of trial and error for rounding off the rough understandings of college courses was related to us by many members of the organisation. One, quite senior, engineer told of his first day at East Site, many years previously, when he was asked to go and test a piece of equipment. Not having a clear understanding about what he was doing and being too shy to ask for clarification, his efforts were quickly to destroy the unit at a cost which he can still recall precisely. His mentor simply told him he was stupid and that he had better not do that too often, and then explained how the equipment worked. In such a way, mentoring worked as a crude form of risk management. Failure was not seen as a completely negative outcome, rather, as the price of learning.

As is suggested by such stories of learning through mentoring, combined with a problem solving ethos, the design process of the scientist-inventor featured trial and error. Design was an iterative practice of "build and test". Each prototype would be

different and better than the last until a stable, reliable, predictable unit was fashioned. The process could be likened to the experiments of the science laboratory, and has its roots in the idea of engineering as the practical application of the natural sciences.

Associated with the practices of mentoring was a sophisticated "pecking order" amongst the engineers. The significance of this was perhaps best illustrated in a story we heard about the drawing office in the old factory. This office had been heavily staffed in its heyday, with each employee standing at a drawing board. The drawing boards were arranged in rows across the floor, facing a large window at one end of the room. A Senior Designer told us how the Chief Draughtsman had his drawing board in the prime position for getting the best benefit from the daylight. All the other draughtsmen were arranged in order of seniority by this premise, with the most junior being next to the door at the other end of the room. New draughtsmen would be located next to the door, gradual promotion would involve movement from left to right across the room and up the rows until, perhaps, the window would be reached.

The engineer as scientist-inventor was primarily concerned with technology, its advancement and application. Experts in different branches of engineering would each have different specialist interests that were unlikely readily to be understood by others. Where the success of a product involved problems from several disciplines, different experts would work separately from the others; each was concerned with the specialist contribution of his or her branch of engineering, trusting the others and expecting their own judgements also to be accepted. Indeed the autonomy of design engineers was, we learned, generally accepted by their managers. This point was illustrated in a story we were told about the behaviour of one manager, himself an engineer, when he was invited to meet one of East Site's major customers. He was, we were told, taken on a factory tour, shown work in progress, invited to lunch, and informed about the pressures the client was under from a crucial client in government to conclude a certain project that awaited a now overdue component on order from East Site. Eventually, when the manager from East Site volunteered no specific information on how near this work was to completion, his hosts resorted to blunt questioning about when they could expect to get the unit they urgently needed. The manager, we were told, simply replied "when it works". He was, this story suggested, more inclined to respect the discretion of his engineers to judge when they felt the product was "ready" than to respond to urgent pressures from a client.

b) Tensions (Stage 2 on Figure 4)

As we have already noted in our earlier summary of the change strategy developed at East Site, the ending of the cost plus era precipitated the development of extensive reorganisation. As senior managers developed the four phase strategy for introducing change each aspect of the image of engineer as *scientist inventor* was to be called into question, then challenged.

Senior managers at East Site were well aware of the way in which inefficiencies had been masked, or even encouraged, by contracting arrangements that paid for development and production costs plus 10%. Iterative approaches to design had often led to an extension of a projected timescale for a project which added costs but, under the cost-plus contracting system, had also added profit. In this way engineers had not

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had to consider what one senior engineer described to us as "the cost of failure"; indeed, prior to the demise of cost-plus contracting the actual costs of design modifications had rarely been made explicit. Analysis undertaken subsequently was to reveal that delays or modifications necessitated by "silly little errors" (e.g. specifying 10mm screws for 8mm holes or not choosing a big enough plate on which to engrave the product identification code) could involve very substantial additional costs when they were identified at the manufacturing stage. Designers' additions of "bells and whistles" to their projects could also involve significant extra expenditure.

As indicated above, one of the features of the design ethos associated with *scientist-inventor* and its learning through mentoring was its sense of tradition. This was viewed as inflexible by management and also by some of the younger engineers we interviewed, who explained their frustration with the attitude that the old ways were the only ways. One engineer told us that older designers could be reluctant to consider using new materials in their designs, favouring as they did tried and tested approaches. We were told how, on questioning one such aspect of a design produced by a senior colleague, a young engineer was told "we design Rolls Royces here, my boy, not Minis".

We heard also how, under traditional ways of working, engineers could find it difficult to extend their conceptions of the success of a product to include the needs of others later in the production cycle. One story concerned an engineer who had been asked to alter his design because the people who were assembling it were having a great deal of difficulty inserting one of the screws into a really awkward place on the casing of the product. He could not, we were told, see any need to make changes to his original design; "but it works" he assured his project leader. In fact, the way work was traditionally organised in the Company meant that many of the design problems that were to come to light during the manufacturing phase were rarely passed back to designers. Once a design was in production staff were, we were told, loath to call on the design engineers who they felt were not used to dealing with urgent requests and that anyway there was little chance of getting access to a designer who had worked on the original design. One told us that he felt that if he was to "go back upstairs with a change they'd just give me anybody and they would panic and give me some fix off the top of their head to buy time. Sometimes I would go and order parts to try it out, they would come back to me before the parts even arrived and tell me 'it won't work, try this instead'". Often assembly problems would be solved by manufacturing engineers or by technicians assembling the product, both of these groups having acquired a wealth of experience in such matters over the years. Another told us that because of such skills "the product that finally went out through the door often bore little resemblance to the drawings from which they were supposed to have been produced".

A senior manager at East Site described to us that whilst the company was highly regarded for its clever ideas and engineering solutions it also had had a reputation for delivering late goods which were often later to be recalled for upgrading. He alleged that during the cost-plus era as much as 80% of the goods made by East Site had been delivered to customers late. A similar point was made by an engineer who ironically (but proudly) described a project that he had been responsible for as the "least late project ever". Another manager told us that there was a culture of last minute effort in

East Site alleging that "70% of sales were achieved in the last quarter of each year, and 90% in the last week of the month". Often such results had been achieved through the heroic efforts of individuals who, as year-end or month-end approached, would work through the night and inspire their teams to gruelling overtime schedules. When they succeeded, such efforts would be rewarded with peer group respect (and promotion in some cases) although, as our interviewee pointed out, the fact that projects were behind schedule in the first place was often the fault of the very same managers who, later, were to work so hard to save the situation.

Figure 5 summarises the activity system of design engineering as *science and invention* and the key problems that were to become associated with it.
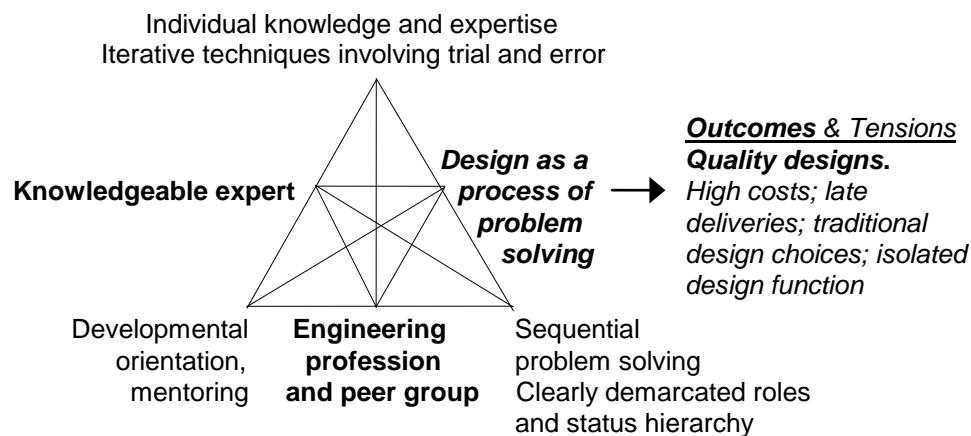
Individual knowledge and expertise
Iterative techniques involving trial and error

Design as a process of problem solving

Knowledgeable expert

Outcomes & Tensions
Quality designs.
High costs; late deliveries; traditional design choices; isolated design function

Developmental orientation, mentoring

Engineering profession and peer group

Sequential problem solving
Clearly demarcated roles and status hierarchy

**Figure 5:
Engineering as Science and Invention,
Outcomes and Tensions**

c) Development and Application: Design as "Production Process" Replaces Design as "Science and Invention" (Stages 3, 4 and 5 on Figure 4)

We have already described how, in the changing circumstances in which it found itself, management at East Site utilised Jaikumar's analysis of developments in manufacturing to formulate a four phased programme of change. Because of the immediate priorities that East Site faced, the initial launch of the programme of strategic change concentrated on the manufacturing function, but an early aim was to introduce new approaches to design. As this began to happen, and in the spirit of co-ordination and control emphasised in the early phases of the Company's strategic change programme, the new approach featured the importance of objective indicators of progress, the adoption of cross-disciplinary teamworking, the "back scheduling" of purchasing, and new techniques for managing risk. The metaphor of design engineering as a *production process* summarises the new outlook that management was seeking to introduce.

As the term suggests, engineering as production process is concerned less with the autonomy of the individual expert, more with the successful functioning of the overall

system. The aim is to design products in a systematic way, based upon the application of pre-determined, optimal techniques so that the customer requirements in the areas of technology, timescale and cost could be met with the minimum possible outlay of resource by the Company. Judgement about whether or not a product meets relevant aims is no longer left to the discretion of an individual, but is based on objective indications of progress towards "milestones", budgets and specifications. The introduction of new CAD systems, the use of publicly displayed progress charts, and a system of regular progress review meetings are tangible examples of the new approach in practice.

The tenets of engineering as production process, although informed by the four phase change programme specifically, are consistent with many of the techniques and tools used in contemporary production and operations management and in particular with Concurrent Engineering (see for example Dilworth, 1992). Central to the approach that was adopted at East Site are multi-disciplinary teamworking and resource scheduling.

Team working in East Site was facilitated by the move to a new, open-plan, building in the early 90's. Multi-disciplinary project teams are collocated within this building, i.e. the various specialists which are working on particular projects work at desks that are located in the same area for the duration of the project (which, typically, is many months or even years). Where possible this combination of individuals is kept constant throughout the whole design life-cycle. As staff explained to us, the arrangement supports greatly improved communications within the teams. Under the previous system the 'concept', 'design' and 'manufacturing' phases would have been the responsibility of different people, now the whole team has an influence on each stage, regardless of functional disciplines. Thus, for example, manufacturing engineers will be consulted in the very first stages of the design process so that they can comment on the potential manufacturability of an emerging design before changes would become costly or difficult to introduce.

Such arrangements also mean, we were told, that there is much more joint ownership of the design process than previously had been the case. Prior to the adoption of Concurrent Engineering techniques product design, including the building and testing of prototypes, had been undertaken completely within the design function. Once a design had satisfied the East Site designers, they "threw the design over the wall" to be made by others and the design team was disbanded. Under the new system, however, individuals remain responsible for the design from conception to delivery and it should in principle, therefore, be easier for staff to learn from their mistakes.

In order to have more control over the lead time of product design, concurrent engineering techniques place a great deal of emphasis on planning processes, indeed, the issue of resource timings is perhaps the single most profound change in the activity systems of design engineers at East Site. Each of the tasks associated with the design of a product is identified and specified in terms of time, cost and personnel resource at the outset of the project. By working back from the final delivery date (a process known as back-scheduling) necessary tasks, purchases needed, machinery required etc. etc. can be scheduled, ordered and booked in advance. One design engineer explained for example, that if he needed to order three items for building a

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unit and the first took two weeks to come while the second had to be ordered from overseas and would take four, while the third had to be made especially for the project by another company and would take three months, then the first two components would not be ordered until two and four weeks respectively before the third would be ready. Operated in conjunction with MRPII tools, considerable savings and efficiencies could thus be achieved. East Site uses the slogans of "Right First Time" and "Better, Faster, Cheaper" to characterise the values embedded in these practices

Finally, one other key aspect of the image of design engineering as production process at East Site is the development and use of procedures aimed at standardising and optimising the design process. There are a number of these initiatives, but perhaps the most visible at the time of our fieldwork was the introduction of new techniques for risk management. These fit very well with the ideas of concurrent engineering and "Right First Time". During the concept design phase at the start of a new project an initial plan for the product is presented and debated by the specialists from all the fields involved in the design process. Participants endeavour to be critical of the proposed design and to anticipate elements which are particular risky. Subsequently efforts are made to concentrate on risks that such discussions have identified as crucial to the overall success of the project, with targets set and resources allocated accordingly.

d) New Tensions (Stage 6 on Figure 4)

As we have explained the conception of engineering as *production process* was developed in response to the problematic features of the image of engineering as *science and invention* outlined above. The new approach does, however bring its own problems and there is a view amongst engineers in the organisation that the pendulum may have been pushed too far the other way.

In our interviews we heard that the rigorous planning that is associated with Concurrent Engineering has not proved to be entirely beneficial for innovation processes. Engineers are very uncomfortable with the "Right First Time" goal as they feel that, while it certainly is important to think through the product concept early in the development process, it is simply impossible to anticipate every eventuality. Since the design process is by nature a journey of discovery, engineers explained, they expect to encounter problems along the way. Indeed, many of the engineers we spoke to continued to characterise their role as problem-solving and, they felt, too much time invested in early detailed plans is likely to be wasted if problems not identified at that stage later necessitate a change of plan. Similarly it was suggested that the back scheduling of parts ordering can mean that by the time a part arrives in the factory, a design change may have made it redundant.

One engineer summarised the difficulty saying that "after the concept phase, the last thing you need is another good idea". If an engineer does happen to recognise a better way of doing something on a project than was initially planned he or she may either ignore the good idea and continue with the original plan, thus producing a sub-optimal product, or the engineer can follow up the new strategy, leading to a time over-run perhaps resulting in the project being judged unsuccessful. Within such a context, design risks assume a new importance. We were told that the risk is sometimes

understood to be the *risk of failure*, rather than *a measure of uncertainty*   Risk management in too rigid a system can therefore become a strategy of risk avoidance, with engineers no longer being sure that innovation is what is wanted. Technological risks which have outcomes which are too uncertain to be incorporated in the planning process, or which look expensive, are likely to be avoided. One leading engineer pointed out that if return on investment calculations at the outset of a project was the only valid measuring stick, then the design for the Boeing 747 would never have been pursued (in fact, of course, the 747 was proved to be extremely successful commercially and the design approaches it embodies are now widely accepted). Another design engineer said that, "if you treat risk as bad and rely on CAD you'll never design anything very different than what already exists". For a company relying on innovation it would, he observed, be unfortunate if the gains in control that have been achieved in the design process began to stifle the creativity of the designers.

Compressing the timescales of a project may not only restrict engineers' room for manoeuvre in managing contingencies, it may also make it difficult for them to learn. When development work is costed as if it is a production run little regard will be given to the fact that the issues involved may be new to the individuals concerned. Where margins are added to reflect a learning curve, it was suggested to us that they are often very slight. One of the hopes of the top management at East Site was that time saved through use of new ways of working could partly be used to experiment with new approaches and to disseminate the outcome of such experiences throughout the organisation. What seems to have happened, however, is that engineers sometimes work long hours in order to work through the inevitable, but unscheduled, iterations necessary to see a design through to completion. They may also work long hours in order to familiarise themselves with new tools and techniques. Rather than freeing up their time, therefore, some of the engineers we spoke to felt that Concurrent Engineering techniques were somewhat inflexible and that they had introduced an element of work intensification leaving them with "no time to think".

A number of the people we spoke to pointed to certain difficulties associated with the system of collocated teamworking. Whilst there was widespread agreement that multi-disciplinary working is essential in the new competitive environment it was pointed out to us that the future success of the organisation depends upon the continuing abilities of design engineers to work at the forefront of their own fields. One of the problems of moving from a functionally based company, where experts are located amongst others with similar backgrounds and interests, to one based on project teams is that much cross fertilisation of ideas within disciplines is lost. Two years spent working on a project with little peer contact or time to keep abreast of their specialist fields inevitably make it difficult for people to stay in touch with new developments in their fields. This issue tended to be associated in our interviewees minds with concerns about their career prospects.

The debates listed in this subsection present worries about the new way of organising design engineering at East Site as seen by the designers themselves. From management's point of view, however, it was not altogether clear that the reorganisation had yet gone far enough. One manager told us how, when walking around the factory he noticed an engineer staring blankly out of a window. He asked the engineer what he was doing and he replied "thinking" while continuing to stare out

of the window apparently unconcerned or unaware of the possible censure of his boss. Managers certainly recognised that considerable improvements have been made in the efficiency of their engineers at East Site but, in the harsh environment facing the Company, the opaque nature of design work continues to concern them. It was suggested to us that, although facts are hard to assemble, engineers probably still spend far too small a percentage of their time on engineering (as against routine administration, for example), on the right engineering problems, or utilising the most appropriate approaches.

Figure 6 summarises the activity of design engineering as production process and the tensions that are associated with it.
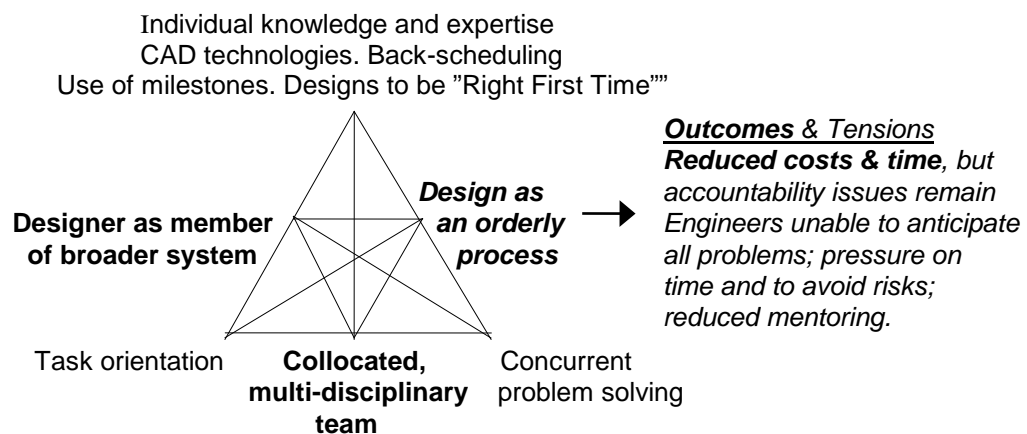
Individual knowledge and expertise
CAD technologies. Back-scheduling
Use of milestones. Designs to be "Right First Time""

Design as an orderly process

Designer as member of broader system

Task orientation

Collocated, multi-disciplinary team

Concurrent problem solving

Outcomes *& Tensions*
Reduced costs & time*, but accountability issues remain Engineers unable to anticipate all problems; pressure on time and to avoid risks; reduced mentoring.*

Figure 6
Engineering Design as Production Process,
Outcomes and Tensions

Conclusion: Activity Theory and the Future Organisation of East Site

(a) Activity theory and the analysis of organisational change

Earlier we used activity theory to compare different approaches to organisation in manufacturing industries. Commenting on the sequence depicted in Figure 3 we highlighted (i) the network of changes that movement from one type of activity system to another inevitably involves, (ii) the significance of new conceptions of activity to such changes, and (iii) changes in the nature of expertise and in approaches to management as activity systems become more complex and interrelated.

The East Site case illustrates problems that can occur in relation to each of these points.

     (i) *The network of changes involved in movement from one type of activity system to another.* Design as *science and invention* has strong links with craftworking, while design as *production process* has many similarities with the activity systems of Fordism and Process Control. Looking back on what has happened, staff at East Site are well aware of the significance of the range of changes that have been introduced in the reorganisation of their work. However as efforts are made to move from one paradigm of practice to another it is difficult to predict all the issues that may arise. While East Site invested very heavily in new technologies, procedures and systems to support the move to *production process* little had been done also to develop the group and leadership skills that are essential for multi-disciplinary groupworking.

     (ii) *The significance of new conceptions of activity to such changes.* Considerable successes have been achieved in the Company's change programme (the strategy of change, the reorganisation, the new factory and plans for expansion are now everyday features of life at East Site) and overt expressions of discontent are rare. However a number of our interviewees did express reservations about the conception of engineering activity that has underpinned the early phases of East Site's change strategy. As the name we have given it suggests, *production process* has its origins in an analysis of manufacturing organisations; criticisms we heard amounted to the suggestion that the tenets of mass production are of limited value as guidelines for design engineering practices in make to order firms. The discontent with *production process* that was expressed to us could be interpreted as an expression of dismay at the passing of older approaches to design, or perhaps of irritation with the inevitable increases in accountability and control that are a feature of Concurrent Engineering systems. Indeed, as we have already noted, at the start of our interview programme we anticipated that staff might well express nostalgia for the past. In fact, however, we did not encounter this to any significant degree. New approaches to engineering at East Site were criticised on pragmatic grounds. Expectations that the design process should be "Right First Time" are unrealistic or even unwise, we were told.

     The issue is complex. Some branches of engineering do lend themselves to advanced planning more satisfactorily than others. Also, even in situations

where a total product run may be no more that four or five units design solutions developed for earlier, related products undoubtedly need to be incorporated within them. Nonetheless, we were told, mass production engineering does not provide a good model for this process. One interviewee expressed the point as follows. In car manufacturing, where designers work with enormous data sets gathered from years of 'build and test' work, there is hardly 'black art' left at all he said. "There is probably no axle design left unthought of, untested, unrecorded and the designers have all that experience and certainty at their fingertips". In such circumstance computer simulation of potential problems with design variations can achieve much, and continual minor but cumulatively significant improvements can be attained in the production process. But where more significant innovations are required (as an example the interviewee compared their work to the development of the internal combustion engine) a different orientation is required. Where significant new design challenges are continually appearing design must be treated as an experimental, iterative process. A new metaphor for engineering, as yet not articulated at East Site, is needed to capture the current imperatives for system's integration on the one hand and for iterative approaches to problem solving on the other.

(iii) *Changes in the nature of expertise and in approaches to management as activity systems become more complex and interrelated.* The activity systems of the Engineers at East Site are now undoubtedly more complex and interrelated than they were in previous times. New CAD technologies and "back-scheduling" techniques, multi-disciplinary team working and concurrent problem solving, pressures to reduce lead times and to work ever more closely with customers and suppliers are obvious examples. Changes anticipated in the ongoing change programme are likely to contribute further to the process, for example, new systems are being introduced to link design ever more closely to sales and marketing. In such circumstances new approaches to integration are likely to assume increasing importance. For example, the strong leadership that was necessary to steer East Site rapidly from one clear and well understood work system to another is likely to be less effective as a method for integrating the highly complex and interrelated work systems that are currently emerging.

(b) Activity theory and the management of future developments

Through the overview it offers of relevant processes, activity theory can be used to explore what might usefully be done to stimulate new conceptions of activity, to achieve improved integration within expanded activity systems and to manage movement between different paradigms of practice.

First, regarding the development of new concepts of activity and improved integration within activity systems, the approach we have used to analyse developments at East Site suggests that in organisations where activity systems are growing in complexity and interrelatedness a range of new skills, outlooks and resources are required. First, as Dreyfus and Dreyfus (1986) report in their general analysis of expertise, the process through which novices become expert involves a developing fusion of classroom

instruction and experience, a growing ability to plan ahead and to focus less on details more on total situations, and finally the ability to act both spontaneously and skilfully. The process through which experts learn to act "as one" with their tasks is, in activity theoretical terms, the process through which learners become skilful in utilising the infrastructure of their activity systems to pursue the object of their activities. Situations where the infrastructure of activity systems is becoming increasingly complex present new challenges to experts who must, in these circumstances, become competent in the use of a wider range of techniques and procedures. Second, note that the introduction of the new elements in an activity systems do not necessarily merely make it easier for experts to do things that they would have done anyway but, as at East Site, they can transform the overall character of the activity system. As activity systems grow in complexity and interrelatedness participants need to become aware of the broader endeavour of which their contributions are but a part and preoccupation with restricted functional priorities must give way to an expanded sense of activity. Finally, integral to this development is the development of new approaches to integration and control. Multi-disciplinary working, which involves the co-ordination of different specialists each of whom are applying their specialist approaches, must give way to supra-disciplinary working, where collaboration takes place between experts who are all contributing to the joint development of a shared agenda.

Their are few models in the literature which describe this process. Eisenhardt and Tabrizi's (1995) description of strategies used by American firms in order to reduce the lead times for new products is consistent with this outlook however (they concluded that iterative learning and flexible processes within multi-functional teams were more effective than efforts merely to speed up traditionally organised systems) and Weick and Robert's (1993) analysis of collaboration on an aircraft carrier mirrors the account developed in this paper. Organisations that need to achieve high reliability rather than high efficiency need, Weick and Roberts suggest, to reconsider conventional approaches to co-ordination. Using the example of the operation of an aircraft carrier under combat conditions they suggest that a complex process of collective self-regulation (which they describe as a "collective mind") can be developed. This involves a process of "heedful interrelating" as participants simultaneously contribute to an activity, represent to themselves what is happening around them, and interrelate and subordinate their actions within the unfolding situation. The speed at which interactions must take place in the situation Weick and Roberts analyse is unusual. Nonetheless their analysis resonates with the account offered here of the significance of new and complex infrastructures of action within manufacturing industry, the importance of expanded conceptions of activity, and the need for new patterns of interdependency.

Second, regarding movement between paradigms of practice, central to activity approach as we have depicted it on Figure 2 is the recognition of tensions within and between activity systems and the development of *search processes* for their resolution (stages 2 and 3 on the figure). Note that, in the case of East Site, it was senior management who first recognised the gravity of problems revealed by the ending of the cost-plus era (Figure 5) and who worked determinedly to develop, communicate and apply a new blueprint for the future. On the other hand, current tensions in the activity systems of engineers (Figure 6) are primarily the concern of design engineers and reflect a new set of difficulties.

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Situations change and, as this case illustrates, solutions to past problems may themselves become the source of future difficulties. However participants may not always recognise how things have moved on. In the particular case of East Site there is a danger that management may remain unsympathetic to the current concerns of the engineers, confusing their current concerns with any past reluctance to move from *science and invention* to *production process*. Nor may people easily appreciate the need to develop new ways of solving emerging problems. Despite the recent successes of a top-down approach (stage 3 on Figure 4) in transforming practices at East Site, given the complexity of the current situations solutions may most effectively be developed not just by senior managers but also by those most intimately affected by them, i.e. the engineers themselves.

In fact the need for new metaphors of design has been recognised by certain senior staff at East Site. For example, reflecting on the uncertainty of the future one senior manager mused to us "what is life like on Mars?" and within the Company possible bases for new approaches currently exist. The slogan "Right On Time" was proposed to us as an alternative to the phrase "Right First Time" and key figures in the Company are attracted to the discourse of "competency" which, as du Gay, Salaman and Rees (1996) have discussed, would involve the championing of proactive, empowered and entrepreneurial leaders and a strong emphasis on market relationships within the organisation itself. Still another approach (that might have certain attractions in an engineering environment) is suggested by the metaphor of "managing chaos" (e.g. Stacey, 1992) with its analysis, drawn from the physical sciences, of emergent properties, self-organising systems and multiple solutions.

Our own view, however, is that while new metaphors certainly must be sought it would probably be a mistake to place too much emphasis on any particular metaphor too early in the search process. In the highly complex and internally stressed activity systems that are likely to be characteristic of Versatile Manufacturing and Innovation Intensive organisations of the future (see Figure 3) tolerance of, indeed the cultivation of *multiple metaphors,* might be a more appropriate aim. Gergen (1992) has developed a similar point. He argued that while dialogue in organisations may, at first sight, appear to threaten stability, paradoxically it is the suppression of dialogue that robs an organisation of its vitality and ability to act. Gergen's concern was to alert managers to the way in which the image of organisations as machines can stifle organisational creativity. To facilitate movement around the cycle of questioning depicted in Figure 2 the cultivation of multiple images is, Gergen's argument suggests, crucial to the process of search and experimentation.

Questions of how the generation of dialogue and alternative images can be managed are, of course, crucial. Pava's (1983) analysis of the importance of forums of deliberation is of interest in this respect. In addition to encouraging the articulation of multiple perspectives managers need also to attend to the location, ground rules and norms for the exchange of views. In the case of East Site, for example, we formed the impression that, at the time of our study, there are insufficient forums to support debate between engineers and managers about the relative merits of the *production process* versus the *scientist-inventor* metaphors and the alternatives that might be usefully be considered.

To conclude, metaphors and images in management represent alternative systems of beliefs, values and assumptions about the design process. They imply action and suggest appropriate institutional supports. A robust and vigorous design process is the key the continued success of the Company described in this paper but the complexity of the activity systems engineers must work within presents a range of unfamiliar problems. If the full potential of the knowledge workers upon whom organisations like this depend is fully to be unleashed, and if such organisations are to be able to cope with the tensions that inevitably develop within them, then there is no substitute for the development of an enriched process of dialogue, debate and learning.

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