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# HOW SHOULD "KNOWLEDGE BASES" BE ORGANISED IN MULTI-TECHNOLOGY CORPORATIONS?

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This paper addresses a key interest in Keith Pavitt's later work; the organisational arrangements for co-ordinating technological knowledge. It also concurs with Pavitt's insistence on the constraints on managerial agency and his nihilistic amusement at frustrated plans. The paper considers Pavitt's conceptualisation of knowledge bases as technical disciplines and argues that there is an inconspicuous sub-level of specialised knowledge base associated with tools, products, project experience and requirements that may hamper the intents of higher-level organisation design.

Two contrasting case studies are analysed of organisations attempting to manage transitions that are aimed at improving co-ordination processes. The first has moved from organisation around functional disciplines to product-based, cross-functional teams, while the second has done the reverse. The paper reviews the effects of these opposing organisational solutions on the processes of knowledge integration within the firms, the effects on communities of practice and the ways in which the systems have developed and adapted in response to the reorganisations. The paper challenges some of the simplistic prescriptions offered in the literature and provides further fuel for the debates over organisation design and the knowledge integration task.

*Keywords*: Organisational knowledge; knowledge bases; cross-functional teams; matrix organisation; organisation design.

## Introduction

Keith Pavitt in his later work had a healthy interest in the organisational arrangements for co-ordinating technological knowledge (Pavitt, 1998, 2002). With Ove Granstrand and Pari Patel he showed empirically the increasing range of knowledge bases and specialisations required to produce contemporary products and systems (Granstrand *et al*., 1997; Patel and Pavitt, 1997). Taking issue with the vogue for "core competences" they argued in favour of "distributed competences" in Multi-Technology Corporations (MTCs). But it was an intriguing puzzle how organisations might co-ordinate all these specialisms. Pavitt was clear that not all knowledge could be outsourced and was critical of firms that allowed their technological activities to be run down. His nihilistic streak enjoyed high-profile failures when carefully designed plans were frustrated. He was sceptical of many of the fashionable prescriptions for organisational solutions to the problem of complex knowledge requirements.

With Stefano Brusoni and Andrea Prencipe he challenged the view that modular product architecture should be matched by a corresponding organisation design. Brusoni *et al.* (2001) argued that the knowledge bases of firms reach far beyond the boundaries of their production activities. Through their analysis of patenting activities they showed that firms typically retain knowledge associated with those modules that are routinely outsourced. It was a typically Pavittesque sceptical approach to investigate empirically an intuitively appealing but simplistic recipe, albeit at a comfortable distance (!)

This paper explores the issue of how technical disciplines might and should be organised in the firm. It attempts to draw together the Pavitt-eye view of knowledge bases and organisations with the management literature. Rather than technical subfields as observed through patenting, the concept of "knowledge bases" is operationalised at the level of the team and how the individual engineers that work therein share their knowledge.

It is a commonly found proposition in the management literature that cross-functional teams or matrix style organisation is associated with better knowledge sharing and, consequently, better performance than pure functional forms (for example, Eisenhardt and Tabrizi, 1995; and most recently Cummings, 2004). In general a high frequency of knowledge sharing outside of the group has long been established as positively related to performance, as gatekeeper individuals pick up and import vital signals and understanding (Allen, 1984; Brown and Utterback, 1985 Ancona and Caldwell, 1992). In particular, cross-functional composition in teams is argued to permit access to disciplinary knowledge bases outside (Keller, 2001; Sapsed *et al*., 2002). Given the necessary range of knowledge bases in MTCs, should organisations be arranged in cross-functional teams? Does this make productive knowledge sharing more or less likely? What are the effects on technical advancement in the disciplines?

However, the paper is not a deductive study testing the proposition of cross-functional knowledge sharing associating with performance. Rather, it takes a step back to examine the first part of the proposition; it asks what quality of knowledge sharing is effected by cross-functional or functional teamworking organisation. It takes an inductive approach to uncover the motivations, tools, effects and managerial issues involved with reorganisation to cross-functional teams.

The paper analyses two case studies of organisations attempting to manage transitions aimed at improved co-ordination processes. These are similar firms in high-tech, multi-technology, knowledge-intensive businesses. Both are project-based, in the same geographical region and about the same size, yet they have taken their organisations in contrary directions. The first has moved from organisation around functional disciplines to product-based, cross-functional teams, while the second has done the reverse. The paper reviews the effects of these different organisational solutions on the processes of knowledge integration within the firms, the effects on communities of practice and the ways in which the systems have developed and adapted in response to the reorganisations. In keeping with a Pavitt approach it challenges many of the simplistic prescriptions offered in the literature and provides further fuel for the debates over corporate initiatives and the knowledge integration task.

The next section in the paper reviews the literature on cross-functional teamworking pointing out the controversy over its purported advantages. It shows that there are tensions generated by cross-functional team structures. The third section addresses these tensions by looking at the received theory on social identification and the more recent work on communities of practice. The fourth section outlines the method for the study; an inductive approach based on grounded theory procedures that attempt to guard against tautological research. The fifth section outlines five categories that were common across the two companies: organisational change; knowledge integration; loss effects and problems; deployment of expertise and evolution. The conclusions then end the paper.

## Cross-Functional Teamworking

The distinction between functional and project-oriented organisation was well described by Sapolsky in 1972, in a military context:

> A functionally specialized organization is responsible for a particular organizational process or skill, e.g. aeronautical engineering, accounting, or typing, irrespective of the purposes to which

> those processes or skills are applied. A project-type organization is responsible for a particular organizational purpose, e.g. strategic retaliation, conventional warfare, or counterinsurgency, and thus ties together all the process and skills necessary to accomplish that purpose (1972, p. 62).

This shows that discussion of functional organisation versus cross-functional organisation is not new. Indeed, Sapolsky himself referred to "the classical statement" on the distinction by Luther Gulick in 1937 *(ibid.)*. While the lineage goes back some time, in recent years cross-functional project teamworking has emerged as an important imperative for organisations and the subject of considerable managerial and scholarly attention. Empirical research suggests that most New Product Development (NPD) activity uses the cross-functional form (Griffin, 1997). Gobeli and Larson (1987) present data for a sample of 1634 project managers in NPD, construction and new services and processes where less than 50 percent of managers used a pure functional structure, while 85 percent used some form of cross-functional matrix structure. As regards performance, Holland *et al.*'s (2000) review shows that inter-functional communication and transparency was correlated or associated with successful NPD projects.

Cross-functionality is only one type of diversity that is said to benefit teamworking outcomes, alongside age, gender, ethnicity, personal background, etc. Roberts (1987) asserts that diversity of technical background, age and values appears to heighten project team performance, as well as maintaining tension and challenge in the team. Too much similarity, comfort and familiarity reduces productivity and tends against the refreshment of technical knowledge through external contacts. Leonard and Sensiper (1998) argue that although diversity entails the management of divergent viewpoints, this "creative abrasion" can generate discussion and thought resulting in new ideas. Leonard and Sensiper suggest "…intellectually heterogeneous groups are more innovative than homogeneous ones" (1998, p. 118).

However, research on diverse teams also shows that group members tend to have lower job satisfaction, higher turnover and stress (Keller, 2001). By contrast to traditional functional silos, in terms of knowledge management there is a problem to co-ordinate a diverse set of areas of expertise (Denison *et al.*, 1996). While various authors argue that for systemic tasks like NPD, Cross-Functional Teams (CFTs) are more effective, Roberts (1987) and Allen (1984) claim functional organisations show best *technical performance*. This is contested by Gobeli and Larson's (1987) study, which shows that project managers generally felt that dedicated Cross-functional project teams and project matrix type structures were judged most effective on criteria of technical performance, costs and schedule. More functional configurations were considered ineffective.

Roberts (1987) warns of the erosion of technical skills if a cross-functional project team is maintained over time. Engineers are removed from the disciplinary structure of their functions, and while matrix organisation is a noble ideal, usually one interest dominates. There is often tension and conflict. Members of cross-functional teams, which are typically temporary, working groups, often act as champions of their respective functions (Denison *et al.*, 1996). Donnellon (1993) refers to team members withholding their functional knowledge from the CFT as a means of defending functional territory. As a practical solution Donnellon suggests shifting the role of the functional manager away from *controlling* the resources that are "made available" to CFTs, in favour of a "supplier" role; teams themselves should be responsible for delivery. This generally supports Gobeli and Larson's position above that recommends the balance of responsibility in favour of project team managers.

## Teamworking, Identity and Communities of Practice

These tensions could simply be interpreted as the group-serving bias observed in behavioural decision-making research, which is shown to have an even greater effect than self-serving biases (Taylor and Doria, 1981). However, individual and group identity is another notion fraught with problems and factorial issues. Social identification theory suggests that the immediate group is often more salient for the individual, than an abstract, secondary organisation, as the immediate group is where interpersonal proximity and task interdependence is greatest (Ashforth and Mael, 1989). The immediate group can be a functional discipline or project team, but typically individuals have multiple, conflicting identities in the organisation. These are usually unresolved and are managed separately; "compartmentalised", sometimes giving rise to hypocrisy and "selective forgetting" (Ashforth and Mael, 1989, p. 35).

For the ethnomethodology field — the study of sense making in everyday life — the team context is not so much imposed by the external functions of the collected team members, as *negotiated* and *achieved* through the individuals' interactions in the team setting (Sharrock, 1974; Housley, 2000). Work on individual and group productivity bears this out. Roberts (1987) observes that in the innovation literature the nature of the immediate work group in terms of composition and supervision matter greatly to productivity among technical professionals, in addition to exogenous factors like the individuals' job maturity.

This somewhat dated debate becomes relevant again with the current interest in "communities of practice", as described by Lave and Wenger (1991) and Brown and Duguid (1991) — "These groups of interdependent participants provide the work context within which members construct both shared identities and the social context that helps those identities to be shared" (Brown and Duguid, 2001, p. 202). These communities naturally emerge around local work practice and so tend to reinforce "balkanisation" around functions or occupation, but also extend to wider, dispersed networks of similar practitioners (van Maanen and Barley, 1984; Constant, 1987). Brown and Duguid's solution is "intercommunal negotiation" of differently practising individuals, challenging and stretching each other's assumptions about ways of working. Cross-functional teamworking is an organisational setting that promotes this kind of intercommunal negotiation.

But the real value of cross-functional teamworking appears to be the channels it opens to the bodies of knowledge that are exogenous to the team. This is confirmed by recent research by Keller (2001), which shows that there is an important mediating variable between cross-functional diversity in a team and performance: external communications. By itself functional diversity had a strong, negative direct effect on budget performance, and no direct effect on schedules, but the presence of external communications effects improvement to technical quality, schedule and budget performance, but reduces group cohesiveness.

From this discussion several threads of research point to a view that cross-functional teamworking may be regarded as an organisational means of promoting the exchange of knowledge and practice across disciplines and communities. The literature suggests that this benefits creative activities such as new product development but there are associated penalties with regard to technical performance and professional career development. The picture that emerges is one of teamworking as organisational design (Galbraith, 1994; Mohrman *et al.*, 1995) to promote the objectives of knowledge sharing, as well as the accustomed objective of efficiency in manufacturing operations (Tranfield *et al.*, 2000).

## Method

The empirical research presented here consists of two case studies of companies attempting to design and implement contrary organisational designs to manage essentially the same sorts of problems that arise in project-based, complex task environments. The two case study organisations, LandTraining Simulations and Visual Displays,[1] both operate in high-tech project-based businesses in related sectors and provide differentiated products to many of the same customers. The products and solutions they develop require integrated contributions from several diverse knowledge fields and technical disciplines. Both development facilities are located within

[1] These names are used instead of the actual companies' for reasons of confidentiality.

a mile of each other in the UK, although they have corporate affiliations in North America.

For these similarities the organisations make comparable case studies for comparison. Although one, LandTraining, is a division of a much larger organisation and the other, Visual Displays, is independent, LandTraining is quite autonomous in terms of its organisational operations and management. The two face similar structural constraints from country, region and industry, have similarly sized workforces with similar skill sets and need to cope with the same problems of knowledge integration and uncertain, discontinuous business conditions. What is particularly intriguing for research purposes with these two case studies is that despite the resemblance, each has designed and implemented organisational changes that move in contrary directions. LandTraining Simulations has moved from project-based, cross-functional teams to a predominantly functional organisation, while Visual Displays has done the reverse.

The research was aimed at exploring and understanding the teamworking and knowledge dynamics and the effects of the reorganisations. The research process was influenced by the procedures and thinking of grounded theory (Glaser and Strauss, 1967; Strauss and Corbin, 1990). Grounded theory is an inductive approach to research that is concerned with avoiding preconceptions and the tautological confirmation of them. It is useful for research aiming at deep contextual understanding where labelling and analysis is tightly coupled to observed or recorded phenomena. In LandTraining Simulations the author conducted 15 face-to-face interviews with Software Team Leaders, Project Managers, Managers for Systems Engineering and Purchasing, a Systems Architect and a Director for Engineering and Software. In Visual Displays, 13 interviews were conducted with product team managers, technical development managers, programme managers, directors of sales and marketing, product strategy, operations and corporate organisation. The interviews had a modal length of 1 hour each.

Company documentation was also collected and analysed, including organisational diagrams, internal presentations used to support the initiatives and process and procedure documents such as work breakdown structures. The interviews were semi-structured but diversions from the “script” were also explored and recorded as respondents occasionally raised important issues that were unanticipated. The interviews were taped, transcribed and the data were systematically coded according to categories, properties and dimensional scales (Strauss and Corbin, 1990). For example, the following quote from one project manager:

> …if you’re designing a switch box then the electrical guys are designing all the wiring and the circuit, and the mechanical guy [is] designing the box to put it in and where on a particular piece

> of equipment this box is going to fit, so they work very closely together. And that has been a problem in the past; that the electrical guys go off and do their thing, the mechanical guys go off and do their thing and when you come to actually put this unit together it doesn't fit… that's improved now, it only happens once and its improved it, it is just a matter of banging heads together.

was coded as follows:

Category: Team Knowledge Requirement
Property: Product integration
Dimensional Scale: Cross-Discipline Interaction–No Interaction.

All interviews were systematically coded in this way, building up a table of variables for each organisation. Relationships between these variables were then mapped, which allowed the subsuming of many of them, revealing five categories that were common to both organisations: Organisational Change; Effects on Knowledge Integration; Loss Effects and Problems; Deployment of Expertise and Evolution.

Such grounded theory procedures intrinsically involve subjective interpretation but efforts are made to leave an audit trail and to validate the constructs with others to check for empirical reliability. The results were verified with the practitioners from the firms through interactive workshops and written reports, as well as academic colleagues. Finally, follow-up interviews were conducted approximately 1 year after the initial interviews in order to check that the results were robust over time and not unduly affected by the "snapshot" approach. In fact, this revealed what had subsequently occurred in the firms and resulted in the fifth factor, evolution. The two firms are compared under each of the five key factors below.

## The Case Studies

### Organisational change and the role of boundary objects

The first category relates to the transitions in the two organisations: the motivations for them and the artefacts and tools — so-called *boundary objects* — that were developed to facilitate the changes.

#### *LandTraining Simulations*

LandTraining Simulations' organisation structure was previously oriented around project-based, cross-functional teams, in which engineers worked for "heavyweight" project managers. This has changed to a functional system organised

**LandTraining Simulations**

LandTraining Simulations is a provider of customised simulators and training solutions to military and civilian markets. It is based in a cluster of simulation firms in the U.K. but is a division of a 5000-employee international business headquartered in North America. Because of volatility in the defence industry and the project-based nature of the business, the division's workforce fluctuates from year to year from 60 to 200 staff. Its products support training of land-based military applications such as for air defence, artillery and tanks, and battle command and control simulation. Civilian applications include simulators to train airline pilots. The products are typically high-value, highly customised or one-off units. They are complex products to develop, requiring the integration of various engineering disciplines; software, design, databases, production, electro-mechanical and electronic. In addition-specialist knowledge of the applications is required, such as image generation or user-end knowledge such as the behaviour of artillery in the field.

Increasingly LandTraining Simulations has had to recruit and build capability in a new and different product area, microcomputer-based training (CBT), which is proving to be an effective and low-cost alternative to high-end customised simulators. In response, LandTraining Simulations has been trying to effect a shift in thinking away from technology and equipment to training needs and solutions.

**Visual Displays**

Visual Displays is a supplier of high-end screen displays and structures for a wide range of visualisation applications. These include corporate presentation and broadcasting, training devices and a growing range of applications in virtual reality for education and engineering, as well in entertainment. Visual was created in 1984 to take advantage of the trend towards outsourcing of subsystems in simulators. While the firm is developing markets for the newer applications its core customer base remains that of simulators in the same way as their neighbour LandTraining, for whom they have supplied screen modules. The firm is organised around three core cross-functional teams that specialise in specific product lines. Although this permits a degree of standardisation, the workflow is project based and involves high degrees of customisation for each client. The production of these display systems requires the integration of knowledge bases in electronics, mechanical engineering, software and structural design as well as specific know-how in optics, projectors and mirrors. Increasingly, Liquid Crystal Displays are being introduced to this product market.

The firm has been growing at a steady rate of around 20 percent for 10 years and is entering a stage of consolidation and maturity, as distinct from its early period as an entrepreneurial start-up. It currently has 170 employees, most of whom are at the firm base in the same simulation cluster as LandTraining Simulations. Visual Displays also has sales and marketing branches and a spin-off Virtual Reality company in North America.

Fig. 1. Company profiles.

around technical disciplines called "resource groups", with project managers procuring pieces of work as deliverables from the functional managers. Groups from each discipline are assigned to the project with one engineer designated as the group leader for that project.

It has been argued that this form of organisation effectively relegates functional managers to the position of *suppliers of resources*, which tends to encourage their co-operation from a project management viewpoint (Donnellon, 1993). The reorganisation was motivated by two concerns; firstly management were aware that under the prior system an engineer with a particular skill may have been required on one project and "owned" by another team. The change was intended to make engineering resources more widely accessible and allocated more suitably. Secondly,

Table 1. Key factors in the case study organisations.

| | Organisation design | Knowledge integration | Loss effects | Deployment of expertise | Evolution |
|---|---|---|---|---|---|
| LandTraining Simulations | From CF project teams to functional groups | Regular reviewing and integration of project pieces | Project manager loses control | Niche experts and generalist systems architects | Project teams for novel projects |
| Visual Displays | From functional groups to CF product teams | Improved product lines. Inter-team knowledge breakdown | Engineers losing community and skills breadth | Generalists deployed on R&D | Functions co-locating. Middle tier emerging in teams |

engineers had been dissatisfied with the old project-based system because they were frequently working in isolation from their technical peers. The transition to functional groups was attempting to re-establish closer ties *within* the disciplines. The engineers took advantage of a move to a new building with large, open-plan space and set up their workspaces in functional tribal settlements.

To support the changes representatives of all functions were involved in the creation of graphical process maps, showing linkages between the key players and groups in the new project process. These maps were devised by a cross-functional working group, effectively serving as boundary objects (Star and Griesemer, 1989), artefacts that embody and symbolise negotiated agreement between the different communities (Brown and Duguid, 2001; Carlile, 2002). By contrast, Key Performance Indicators (KPIs) for the measurement of overheads, project completions, overspend, etc., were developed at engineering development meetings and implemented within the functions. While the interfaces between communities are agreed at the boundaries and embodied in the process maps, the KPIs enable measurement within the functional communities.

### *Visual Displays*

Visual Displays' reorganisation was antithetical to LandTraining Simulations'. Visual moved from a functional system into three cross-functional teams that specialise on three product lines; firstly, wide "panorama" style screens; second, wraparound, spherical screens with several projectors blending to generate the image; and third, special customised products with a rear-mounted projector. Each

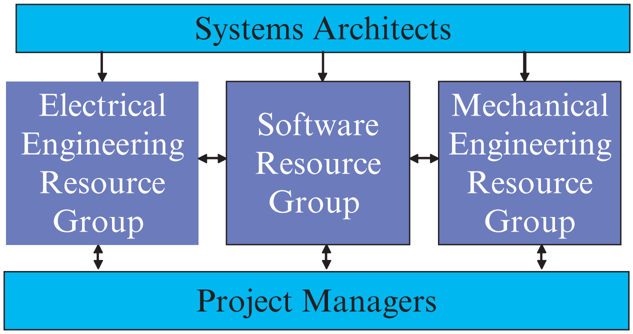


Fig. 2. LandTraining Simulations team.

team has between 10 and 20 projects ongoing within the product line. Bids, sales and marketing and R&D functions were located outside of the product teams. Project managers were combined together with electronic, mechanical and commissioning engineers in the multidisciplinary teams, in order to achieve a greater customer focus and relationship. There was also a desire to promote learning across disciplines, as the firm's corporate organisation director explained "Ideally a display engineer is multidisciplinary, he is an expert in one technology but knows something about all of them. The idea of the teams was that engineers would pick up skills from the other disciplines".

To compensate for breaking up the functional disciplines, a new management role was introduced, the Technical Development Manager (TDM). TDMs were appointed for electronic design, mechanical design and programme management and were intended to provide leadership for the functional discipline. Although "owned" by an individual team, the idea was that they would lead their functional communities across the organisation. This is a quasi-matrix device often recommended for project-based organisations (e.g., Hobday, 2000).

Visual Displays' reorganisation was a much more planned and deliberate strategy than LandTraining Simulations'. The perceived need for a more formal organisation design to improve communications came about because of the firm's growth of 30 percent per annum. The directors wanted to mix up disciplines, which they felt had become large enough to become too entrenched and internally focused. Similarly to LandTraining, this was an effect of the previous building that encouraged "groupishness" through its architecture of several small rooms, each of which housed a co-located functional group. The reorganisation preceded a move to a new building, which permitted large, open plan spaces.

There was a 12-month process of design, advocacy and planning during which all disciplines were consulted. The initiative was managed by a cross-functional working group involving strategic retreats, regular presentations on the new organisation structure, with consultation on details like job designs. The initiative was supported by internal publicity including a countdown poster campaign and T-shirts. A definite "D-Day" date was set when people would move desks and took up their new roles.

This long period of consultation served to span boundaries between the disciplinary communities, so that the new organisation design was built on a base of consensual legitimacy. Similarly to the process maps in LandTraining, an important boundary object developed in Visual Displays was a cross-team Work Breakdown Structure (WBS). This was intended to give an operational focus to complement the product focus achieved by the reorganisation. Previously projects and functions had their own spreadsheets, databases and time-reporting cost. The introduction of the WBS meant that they could now plan and measure against the same codes, and could begin using enterprise management tools. The WBS was based on a Product Structure, a hierarchical architecture of product subassemblies and components, negotiated jointly between engineers of all the disciplines.

The WBS is an effective boundary object, framed at a high enough level to allow discretion over the activities reported within the codes, but allowing for monitoring of overspending. Code categories include, for instance, technical investigation, performance characteristics review, system testing and so on. This is an example of the distinction between the *framing* and *content* of complex management problems and solutions, as shown by Fiol (1994). Consensus is achieved with the framing of the problem; the need for accounting and accountability; the cash flow pressures of a project-based organisation; the need for common approaches to project management for better integration; but leaving sufficient scope for the inescapable *content* discrepancies and divergences within the agreed structure. In both companies boundary objects played an important role in facilitating the reorganisations through providing informational support and symbolising agreement between the communities.

## Effects on knowledge integration

The second category refers to the task of integrating the diverse knowledge bases in the development and installation of products. This involves teamworking through consulting colleagues, reviewing, verifying and final integration both within and between the newly created teams.

### *LandTraining Simulations*

The integration of knowledge resources is stressed as a key capability for turning the ownership of those resources into competitive advantage (Grant, 1991, 1996a, b). For both LandTraining and Visual, the major problems of projects arise with integrating the pieces of the project together. These problems tend to occur late on in the

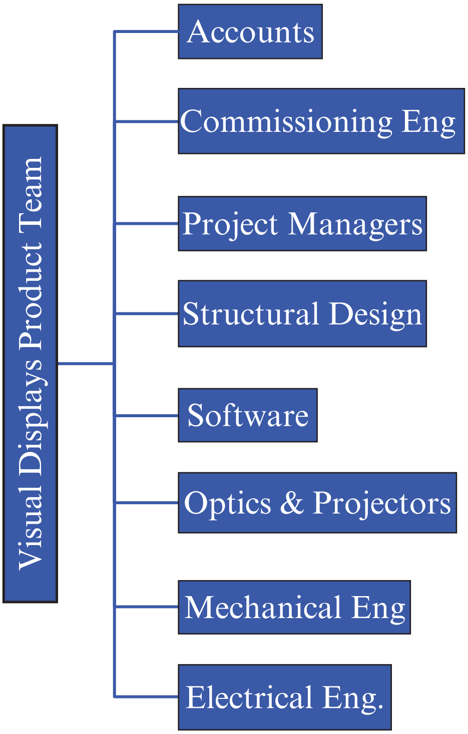


Fig. 3. Visual Displays product team.

production phase. Integration is complex and all about teamworking. But "teamworking" in this task environment is generally a matter of individuals independently completing their project pieces and validating these with others prior to the pieces being integrated "…most people can work largely in isolation, they are following their schedules that are laid down on the Gantt charts, but they're generally doing fairly individual things…"[2] or more bluntly "…people don't tend to talk to other people, they just sit and code their chunk".[3]

However, communication becomes critical at the integration stage, as explained by this Software Team Leader:

> …you can still break it down into bits, and they go off and do their bit and then come back and say, "I have finished". And it's at that point that you've got to fit all the bits together and hopefully, they talked to each other whilst it has been going on, and then fitting

[2]Author's interview with Software Team Leader A, LandTraining Simulations.
[3]Author's interview with Software Team Leader C, LandTraining Simulations.

> all the bits together is a lot easier...in the end, if people have been speaking then it all comes together much more smoothly, it wastes a lot less time in trying to iron out problems.[4]

So, although the teamworking in the company is not *interdependent* on a task level in the short term, in the sense that one team member cannot proceed without a colleague's actions, a high degree of communication is important in integrating the quite different knowledge bases together. Problems occur if validation and cross-checking has been insufficient and these problems are exacerbated if engineers are part-time players on a project. However, in general, managers in LandTraining reported a preference for the new functional system shortly after the change was made. They found that engineers were less tied-up than in the prior project-teamworking system.

*Visual Displays*

Meanwhile, combining technical disciplines in product teams had improved integration processes in Visual Displays. The firm had previously had problems that would only appear at the final stage of installation at the customer's site. Design and production engineers would only learn that their systems were not fitting together when the problem reached crisis-point. Following the reorganisation, commissioning engineers' feedback on integration problems is communicated directly to the designers and engineers in the product teams at an early stage. Engineers have a greater sense of the "big picture", understanding the issues and problems of their colleagues in other disciplines.

However, in spite of the improvement in knowledge integration in the product development teams, breakdowns in knowledge transfer continued to occur between the teams and the external services and functions. The non-technical bids and business development functions are dependent on the product teams engineering knowledge, and frequently need to interrupt their workflow. There are similar problems between R&D and the product teams where new product prototypes are passed over to the product teams at a stage they consider too early. These are typical problems that arise in complex organisations where knowledge integration is an inter-team, as much as an intra-team organisational problem (Grant, 1996a, b, 2001; Sapsed *et al.*, 2002).

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[4] Author's interview with Software Team Leader B, LandTraining Simulations.

## Loss effects and problems

The third common category was associated with various perceptions of loss and dispossession resulting from the reorganisations.

*LandTraining Simulations*

One objective of the change to functional organisation was to satisfy engineers' needs for exposure and organisational proximity to their disciplinary community.

> … one of the problems that the guys found in the project teams and they were always moaning because … you might have three, four software engineers on a project where there were thirty or forty in the company and they got isolated over in their project group and they were always talking to the 'leccies [electrical engineers] and the clankies [mechanical engineers] and they never got to talk to their colleagues [laughs] so they always felt a bit sort of isolated from their colleagues and felt they were missing out on the engineering chit-chat that goes on and the cross-fertilisation and in a way I think they felt a lack of technical leadership.[5]

Organisation into functional groups has effectively addressed this desire for regular contact with disciplinary peers. But there is a corresponding denuding of the project manager. Some complained of the loss of their previous pastoral role, where the project manager was responsible for all the team members' appraisals and personal development. Another frustration is the shift in authority between the project manager and the resource group manager:

> I've got no-one in this company that works for me so I have not only got to manage people who are working for my project, I have also got to manage the management because I am dependent on them as well. I'm dependent on them to release the resources — the resources that I want at the time I want them.[6]

This belies the view that this form of organisation relegates functional managers to mere "supplier" status as described by Donnellon (1993). The experience in LandTraining Simulations suggests commitment to release resources can be difficult to attain and that the balance of power favours the functional manager.

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[5] Author's interview, Project Manager A, LandTraining Simulations.
[6] Author's interview, Project Manager A, LandTraining Simulations.

*Visual Displays*

Visual's shift from functional teams to cross-functional teams brought the equal and opposite effects to LandTraining's reversion to functions. One director commented "I think we've lost some things. I think we've lost technical specialisms. When all the designers worked together, they learned a lot from each other."[7] Lack of regular exposure to technical peers has the effects of eroding the currentness of the individual engineers' skill sets and losing the benefits of disciplinary communities of practice. One Product Team manager explained

> … as a company although we're quite small, we've got quite a cross section of engineering skills, when you look at all three teams. When you look at them [the engineers] individually unfortunately, it tends to narrow them down a bit. That's not just my view … we're aware that their skill levels are very directed towards their own team, and really couldn't jump straight into another team and start working effectively. That would not happen.[8]

Although gaining a sense of the "big picture" for their team's product, the engineers lose the overall viewpoint of the organisation. A corollary of team specialisation on products is a tendency towards balkanisation on product lines rather than functions "… it has almost set up three different companies", one Technical Development Manager observed. The TDM role of maintaining technical community across the teams has proved difficult to achieve as the pressures of current projects in the product team take priority:

> … unfortunately you're up against team leaders who control their own teams and they're not going to really want their staff to spend a lot of time doing for example, learning about another product, spending time with another team. If for example, Panorama is stuck for one design engineer, they need one from another team, that is their first port of call that's what they've got to say, "well, I need another person, can these other teams supply him" and they'll immediately go on the defensive saying "Oh no, we can't let anyone go" [laughs] I'm not suggesting that is the case but sometimes maybe it is. You may end up employing some contractor, get round it some other way. So that side of it is not so flexible, [if] we had all the design engineers in one group, it's just a case of moving work around between them, because the team environment was not an

[7] Author's interview, Director A, Visual Displays.

[8] Author's interview, Technical Development Manager A, Visual Displays.

> issue. It does tend to put up walls, there's no doubt about that. It's got its pluses and its minuses, if you ask my opinion it's got more pluses than minuses.[9]

This shows that in some respects knowledge sharing and teamworking was actually damaged as a result of introducing cross-functional team structure. In both cases there were significant loss effects as a result of the re-orientations of teams.

## Deployment of expertise

The fourth category relates to expertise; how it develops and becomes specialised, the implications of this specialisation for the organisation and how experts and gurus are deployed.

### *LandTraining Simulations*

The software and engineering teams in LandTraining contain a diversity of specialised knowledge bases. Individuals within teams tend to develop specific know-how, for instance, in image generation or user interfaces, and are then deployed on tasks in subsequent projects that draw on this same knowledge. Over time they accumulate an expertise and this specialisation is reinforced on successive projects. The downside of this is that this knowledge is uneven across the teams and the organisation. The one or two experts on a key technology or tool are not always available when their expertise is demanded, presenting a major resource-loading problem. This specialism may be in a particular engineering field, for example, all three software teams call upon an engineer with expertise in sound. Specific product knowledge is also rare and valuable. One software manager describes the dilemma associated with one engineer's rare knowledge of the DEC PDP product family[10] as well as the specific application:

> … this particular guy who's been here a long time, and he has got excellent experience in a number of areas, and the thing is he is a major player on one of the current projects, and if we get this Skyfire [project] we will need him very badly for that one because he used to work on Skyfire many, many years ago and its an old PDP product. Most of us don't have any knowledge of PDPs now; none of us know really how that product used to work apart from him … Generally our products now are PC-based, this one's in the

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[9] Author's interview, Technical Development Manager A, Visual Displays.

[10] The DEC PDP was a line of minicomputers in the 1960s, which later evolved into micro or super-micro computers in the 1970s and 1980s.

> days of PDP. So he's currently allocated … But he is really needed on Skyfire as well, so if we win Skyfire, what the hell do we do? He's allocated up to his eyeballs so we are almost just hoping that he can finish that before we go on Skyfire, and I don't know how the hell you'd ever train up someone to pick up Skyfire. Yes, you might get someone who knows PDP and who knows Assembler and things like that, but they won't know the product.[11]

From a project-completion viewpoint, it makes more sense to deploy the specialists on tasks rather than the less-experienced:

> Most engineers are capable of doing all the tasks, it's just how efficient they will do those tasks … you know that if you can get someone else to do it, but it's going to take twelve weeks, as opposed to someone who can do it in two weeks. You know, because they have got to be trained for eight weeks and then they make loads of mistakes and then that's got to be redone, and they have got to have all the training there and so on. So people are very much in their own little area and I don't think it is a bad thing I think that really does focus people's skills most of the time, and I think it does mean we get a much better product in my view …[12]

However, there is also the recognition that this reinforcement of expertise tends to promote a teamworking structure around knowledge specialisms, which undermines the firm's organisational strategy:

> … What we don't want in the company of course is an I[mage] G[eneration] team and a GUI [Graphical User Interface] team and a core services team. That's not the way the company has been structured, but effectively it is because we have one or two people who do GUIs, some of them do IGs and so on, and we keep those people in those areas of work. … I just think these people are in those specialist areas, so you almost have two levels of teams, in some respects.[13]

This admission illustrates how there are levels of "knowledge base" within an organisational structure. At a high, abstract level there are the technical disciplines (within which patenting activity can be observed and measured). Yet, below this is a level

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[11] Author's interview with Software Team Leader A, LandTraining Simulations.
[12] Author's interview with Software Team Leader C, LandTraining Simulations.
[13] Author's interview with Software Team Leader C, LandTraining Simulations.

of specialisation that relates to particular products, processes and tasks that is not so easily identifiable. Typically, senior management organises at the first level, while project managers, engineering and resource managers find themselves organising at the second. The two levels may be, and frequently are in conflict from a knowledge sharing and development perspective. Often people are assigned to organisational units reflecting their broad profession, but in terms of how they allocate their time and attention they serve the pressing requirements of operations. Their "specialised expertise" is in knowing how to efficiently achieve results in a set of activities with high entry barriers of learning, rather than in a particular subfield of their engineering discipline.

In LandTraining, specialist experts do not appear to be affected by the reorganisation in terms of their everyday activities. However, LandTraining also has a small group of generalist experts. These are the "Throbbing Heads", gurus who possess rare knowledge bases combining know-how from all the engineering domains that go into producing simulators, albeit uneven. This expertise has accumulated over years of experience in the industry, and is complemented by insights into the idiosyncrasies of the business process, and the dynamics of competition.

LandTraining's management have deployed these experts as "systems architects" focusing their attention largely on the bid stage of the process. This design was attempting to provide an overview to more accurately cost bids and assess the feasibility of prospects. The functional teams could be seen to have a fragmented and "localised" perspective on bids and the systems architect role was introduced to provide overview, which is seen as critical to bid work. Previously, there was a perceived discontinuity from bid team to project team, which were typically entirely different sets of people. Under the new system the Systems Architects work intensively on the bid, defining the engineering solution and cost framework. Following contract award their involvement tapers off, but is still available as a resource for consultation.

### *Visual Displays*

Visual Displays also has a small number of highly experienced engineers named the "display gurus". One director explains:

> There are a handful of people in the company that you can identify as a display guru. We can't go to the universities and take graduates who've taken a course in display systems, because of course those courses don't exist, so we've got to breed them ourselves, develop them and train them. They are very much a multi-disciplinary

> person — its electronics expertise, mechanical, design, optical, software; it's a mixture of all those things.[14]

But unlike LandTraining Simulations these experts are deployed as a Research and Development (R&D) team, working on a variety of internal projects that address the applications that the market will want in years to come. This is consistent with the Visual organisation design in which the "erudite overview" should be less critical than in LandTraining, because of the compensating influence of the Technical Development Managers and the cross-fertilisation in the teams. In practice, the interface between the R&D team, bids and the product teams is problematic, the point at which prototypes are passed on to the more commercially oriented teams is ambiguous. In addition, the accumulated expertise of the display gurus is not easily accessible to the product engineers since they are organisationally and philosophically separate. R&D engineers nevertheless find themselves distracted from their R&D projects by bid work, in effect enacting the Systems Architects role in LandTraining. Both organisations find their specialists are deployed more or less on the same tasks as before the changes, while their generalists' time is spread thinly on support activities.

## Evolution

This fifth category, evolution, was added following validation research visits 1 year after the initial fieldwork was conducted. It captures the subsequent adaptation to the new system, which to some extent might also be interpreted as "slippage" into the original state.

### *LandTraining Simulations*

LandTraining's organisational structure has changed significantly since implementation of the changes. The previous section referred to the "teams within teams" that exist within LandTraining Simulations as an effect of knowledge specialisations. Subsequent to the reorganisation, the large software team of 25 people has been formally divided into three small teams, focusing on projects requiring three distinctive software competences, as well as some "floaters" who will work in all areas. To some degree then, project-based team structure has re-emerged, which reintroduces the concern among engineers that they will become too embedded in one area of application. One software team leader put it "…I think people are a little bit unsure

[14] Author's interview with Director A, Visual Displays.

and unhappy about [it] because not everyone likes the category they're currently working on and the…thing is 'well, am I going to get stuck in this one?' "[15]

In addition, some cross-functional teamworking has been reintroduced. For projects that involve a high degree of novelty for the firm, project managers have asserted the need for a dedicated team of people drawn on a full-time basis from the resource groups. The resulting organisation is rationalised as CFTs for new, novel projects, functional organisation for familiar, "business as usual" work.

*Visual Displays*

Similarly, some of the old order is re-emerging in Visual Displays. Physical layout now resembles the previous structure, as team members of the same discipline have all moved their desks together. This is professedly because of the differing preferences for lighting and noise levels between the functions, but may also be interpreted as the tribal instinct returning.

Again similar to LandTraining, another management layer has formed in all three product teams. The original design was attempting to maintain as flat a hierarchy as possible, but the size of the teams was too large for one team leader to handle. In fact, the senior management of Visual is considering another reorganisation to address some of the deficiencies of the current system. These include the inter-team breakdowns of knowledge transfer noted above, e.g., making the product teams more responsible for bids work and trying to better integrate product team engineers and R&D engineers working on new product development.

Although the development from the original designs is categorised as evolution, correcting and adapting the system after intervention, it is interesting that both organisations have reverted to previous practice to some extent. This could also be viewed as the attraction to homeostasis, as described in Schon's (1971) "Stable State". Certainly this applies as regards the reaction of the disenfranchised elements; project managers needing to direct a dedicated team for a difficult project; the impulse for engineers to colocate with their peers. These issues are discussed more generally in the conclusions.

## Conclusions

The paper has outlined the recent literature debating the best way of organising technical disciplines in MTCs. It has shown how this discussion is long-standing and echoes debates in the past. The research presented followed a grounded theory approach to two case studies of firms re-organising in contrary directions. As such

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[15] Author's interview with Software Team Leader A, LandTraining Simulations.

the research is subjective in its interpretation and limited in how the results may be generalised. As regards the first weakness the author has collected data from multiple sources and attempted to validate the analysis with the practitioners from the firms involved and with academic colleagues to check that it was accurate. As for the second weakness, a follow-up stage was conducted a year after the initial research to mitigate the time-specificity of the reorganisation. However, the population of MTCs is extremely numerous and diverse and there would be a huge variety of outcomes from a range of reorganisations. The two cases here serve as powerful contrasting illustrations of cross-functional and functional organisational design. Bearing in mind the caveats we can make the following conclusions.

## The antinomy of cross-functional diversity and specialisation

The contrasting experience of the two cases shows how the benefits of specialisation bring the converse disadvantages. While cross-functional teamworking brings some benefits from a product viewpoint, there is a corresponding loss in disciplinary collegiality. Organisation on functional lines tends to the antithetical problems of disempowered project managers and challenges the integrity of projects. This suggests there is no single "best practice" for teamworking organisation in complex task environments. Rather there appears to be an antinomy, a contradiction of equally valid principles between the advantages and drawbacks of cross-functional teamworking organisation. One seasoned project manager from LandTraining Simulations suggested the organisation design should be influenced by the external conditions prevailing at the time; if engineers are in demand then accommodate them in a favourable structure, whereas in lean times for the firm, deploy them for organisational benefit:

> As long as I've been in the industry, it's never been resolved, there's always this movement, we've always been going backwards and forwards between one way or the other . . . I don't think there is an answer, if there is someone would have had it. We're stuck with it, the fact that we are always changing, people can recalibrate it. And again the priorities change you see, if the job market is tight [for] your project engineers you've got to be a bit more careful as to how you look after engineers, and how you feed their aspirations. If you're in a situation where, there's a shortage of people out there, or recessionary times, and also you haven't got much work you've got to do, got financial pressures, then perhaps you give less priority

> to that, you worry about other issues, just getting the job done, and again it's a lot of external influences that could factor in.[16]

From the other side a Visual Displays Director concurs on the pros and cons of functional versus cross-functional structures:

> We have achieved a good part of what we wanted to achieve, we certainly have removed a lot of the barriers that we had, the internal walls, where problems were thrown over walls, what you do find is, you almost can't win in some respects, you knock down some walls and others emerge in other places. The issue is more one of wherever the walls pop up, trying to squash them down again, it's a constant battle. I don't believe there is any perfect ideal structures, the nature of our business is we're full of matrix structures in our organisation, and its not just one simple matrix, it's a number of multidimensional matrices going on. The challenge is trying to identify where the walls are happening and trying to do things to minimise them.[17]

Both firms were quite sensitive to the positive and negative effects of their team-working designs. Various mechanisms and techniques were employed to mitigate the unfavourable consequences. Boundary spanning activities and objects were used and were important in promoting intercommunal negotiation, such as the process maps, Work Breakdown Structure and working groups. These helped to gain agreement and understanding of the new organisations.

Less successful were the attempts to compensate for the loss effects of the new structures, such as the Technical Development Managers in Visual. The technical leadership role was not fulfilled as the same individuals were also assigned to specific product teams. This role may be more successful in better-resourced companies without the pressures of project-based workflow. Yet, accounts of large technical organisations show a remarkably similar pattern. For example, Jack Morton's book on the management of Bell Labs — perhaps the best resourced and most successful technical organisation of the 20th century.

Morton, writing in 1971 about the previous three decades, shows that the concern over knowledge sharing and the co-ordination of specialisation is not a new one. He recounts the various organisational and spatial bonds that were introduced to couple Bell Labs and Western Electric, as well as AT&T and the operating companies. These bonds, such as relocation of personnel or assigning a common manager

[16] Author's interview, Project Manager B, LandTraining Simulations.
[17] Author's interview with Director A, Visual Displays.

to separate units, were designed to balance the isolating effects of earlier separations. However barriers are sometimes desired to avoid domination and protect creativity in research and it is the job of the manager to adjust the system with bonds or barriers as is appropriate to the current situation. This recalibration, as our project manager above put it seems to be an endless task, as Morton says "…the job never ends" (1971, p. 63). We can see then that even in large technical organisations the antimony between diversity and specialisation is not easily remedied by organisational devices.

## Organisation design and knowledge bases

Organisation design is a popular topic for theoretical literature and prescriptions for practitioners. The paper outlined some often-cited ideas on designing for teamworking and for complexity. Galbraith (1972,1994), for example, stresses the design of complex organisations. Wageman (2001) provides evidence to suggest that team design affects team performance significantly more than any subsequent coaching. The two cases here show some of the limitations of design, as an *ex ante* means of predictable control. In both cases the outcomes were quite different to the intended plan. Both showed some "slippage" to new hybrid forms. Similar to Mintzberg's (1994, 1996) observations of emergent corporate strategies, it may be that organisation designs are rarely implemented as they are conceived. They evolve and adapt and in a short space of time look quite different to the design. As illustrated by the two cases, they may exhibit self-organising properties as studied by work on complex open systems (for example, the Organisation Science special issue on this topic, see Lewin, 1999, and others).

The cases show how natural "self-organisation" occurs and that received knowledge profiles and prior structures have a continuing influence. LandTraining Simulations' teams are actually more organised around specialised knowledge and skill sets than technical functions, as noted by one of the software team leaders, in spite of the pronounced reorganisation. While reorganisations tend to revolve around knowledge bases at the higher level of professional disciplines and functions, for convenience and efficiency engineers often find themselves deployed according to a lower level of specialisation, related to product knowledge, specific tools or non-codified ways of getting work done. The Pavitt-eye view of knowledge bases as observed through classes and subclasses of patenting activity would pick up on the first level, but probably not the second. Yet, it is an important factor in why organisation design tends to have undesired effects, or no effect at all.

In real terms, the necessary organisation emerges and the scope for organisational engineering may be more limited than some of the management literature suggests. The cases give a flavour of organisational design on the ground, showing not a straight managerial choice between static archetypal designs, but a messy imperfect process of change and resistance to it because of competing motivations. There are likely to be loss effects, and the choice of whether the benefits outweigh the losses is primarily a matter of managerial choice, rather than scientific calculation. This author believes Keith Pavitt would agree with that. He might argue this is what managers are paid for, "presumably" (2002, p. 117).

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