KNOWLEDGE TRANSFER IN NPD PROJECTS: LESSONS FROM 12 GLOBAL CORPORATIONS

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ABSTRACT

This paper, which is part of a larger study, explores the issue of Knowledge Management (KM) in 12 large-sized global manufacturing companies with the objective of developing the understanding of knowledge transfer in an applied multi-project environment. Under the basic assumption that knowledge creation is embedded in NPD activities, the question of how to transfer and share that, to a large extent tacit knowledge, becomes crucial. Thus, the research focused on transfer of tacit knowledge between new development projects both within and between product lines.

The field research focused on the implementation, application, and satisfaction of different means for tacit knowledge transfer invoked in the literature, i.e., job rotation, intensive communication, and common cognitive ground. We particularly analysed the role of IT in supporting tacit knowledge transfer. Data collection relied on in-depth interviews with R&D Managers and Project Managers, on complementary interviews with Engineers, Production Managers, HR Managers and Quality Managers, and on study of internal documents.

At the level of the KM organization, the study identified three distinctive organizational structures: Central KM function, functionally located KM cells, and a project decentralized KM function. Each of them provide different conditions for effective knowledge transfer. Further, the study identified two distinctive forms of knowledge transfer: within-project vs. post-project transfer. Concerning the means for knowledge transfer, job rotation and training appeared most productive when they were practiced with the explicit goal of a knowledge-based approach to staffing new development teams. Two factors were found to play an important role for reinforcing the creation of common cognitive grounds. First, Intranets in the development organizations provide radically improved access to specialized information for all players involved. Second, a tendency in companies to extend the opportunities for people from other functional areas than project engineering to become project managers play in favour of developing shared understanding and thus facilitate tacit knowledge transfer.

Our study shows that Knowledge Management is taking root in the area of product development in large manufacturing firms. It is a top priority on the strategic agenda for product development in large manufacturing firms. As such it is also spreading quickly down the supply chain.

INTRODUCTION

The product development process is a transversal process involving a large number of internal and external players in Original Equipment Manufacturers (OEMs) and different supplier companies (Nellore *et al*, 1999). It is also a process where the related flows of information are extremely complex, and where innovation, fueled by individual and organizational learning processes, is a daily preoccupation (Adams *et al*, 1998; Kerssens-Van Drongelen *et al*, 1996). As Kerssens-Van Drongelen *et al* elucidate, a large part of the information input needed to develop products and processes will be available from within the company, stored in the minds of people, in archives, in procedures, in equipment and so on. Learning in this context concerns the increasing effectiveness of product development efforts as a result of practice, and the refinement of development/innovation skills (McKee, 1992). From here stems the importance of managing knowledge in product development.

This paper reports on the Knowledge Management (KM) part of two larger research projects involving in-depth interviews in nine global OEMs and three global system suppliers in the automotive and electronics industries. Partial findings have previously been reported in Soderquist & Nellore, (2000) and Svensén *et al*, (2000). R&D Managers, Project Leaders, Product Planning Managers, Engineering Managers, Production Managers, and Engineers in three North American, three German, three French, and three Japanese companies were interviewed over a period of one year. This enabled us to collect applied inside opinions from multiple players with an accumulated long experience and representing different perspectives and roles in product development. In all, a team of eight researchers worked in the two projects for over two years including pre- and post-interview documentary research. The overall purpose of the projects is to help medium and large size companies in the manufacturing industry to further develop strategies and practices for fast and efficient NPD through benchmarking from best practices in leading companies. The two studies concentrate on the following dimensions: NPD project and process; Early phases of the NPD process; The use of IT in the NPD process; Knowledge Management in NPD; and Goals and strategies for improvement and future evolution of NPD practices. The KM part focused on knowledge transfer, knowledge integration, communication patterns for knowledge creation and transfer, and tools and methods for improved KM in a multiple project environment.

The paper is organized as follows. Section two provides a brief overview of concepts related to Knowledge Management, and in particular knowledge transfer and communication in multiple project environments. A research framework and research questions about the practice of KM in the NPD process in large manufacturing firms are developed. Then, the results from the study are presented an analyzed, focusing on three areas: Overall organization and strategy for KM, forms of knowledge transfer, job rotation, communication and IT support for knowledge transfer and sharing. Finally we draw managerial and conceptual conclusions from the study and discuss areas for future research. The studied companies and the research methodology are presented in Appendix 1.

CONCEPTUAL FRAMEWORK FOR ANALYSING KNOWLEDGE MANAGEMENT IN THE NPD PROCESS

Based on Plato, *knowledge* has been defined in Western philosophy as "justified true belief" (c.f. e.g. Russel 1989, quoted in Nonaka & Takeushi, 1995). However, as long as there is a chance that our belief is mistaken, and as long as there is evolution of technologies, theories, practice and behaviours, this definition invites individuals and groups to constantly develop "what they think that they know" (Nonaka & Takeushi, 1995). This continuous process of *creation* of new insights and beliefs is what fuels the entire paradigm of Knowledge Management, and even constitutes the fundamental rationale for the existence of a firm. Nonaka *et al* (2000) argue that instead of merely solving problems, organizations create and define problems, develop and apply new knowledge to solve the problems, and then further develop new knowledge through the action of problem solving. In this view, the reason of being of a firm is to continuously create new knowledge through action and interaction, not to simply act as an information processing machine (Nonaka et al, 2000; Spender & Grant, 1996). This view seems particularly relevant for the product development process that could be seen as a process of solving a huge equation system (Clark & Fujimoto, 1991), starting with the creation and definition of the "problem" – the product to be developed, and consisting of detailed, numerous, and highly volatile technical and organizational questions that are long to solve and depend on compromises between a large array of demands represented by different internal and external players with different professional backgrounds and perspectives (Lawson, 1990; Lynn *et al*, 1999; Moisdon & Weil, 1992).

Under the basic assumption that knowledge is *created* more or less automatically when solving product development problems, the question of how to transfer and share this, to a large extent *tacit*, knowledge becomes crucial. The concurrency of product development activities and the need for intensive integration between staff from different functional areas and companies –subcontractors, suppliers and OEMs- put effective *knowledge transfer* at the top of the strategic agenda of R&D and Development managers as well as of CEOs of R&D intensive organizations.

At an overall level, effective Knowledge Management in the NPD process as a whole (with positive outcomes on speed, new product success, and institutionalization of learning) has been described as depending on several principles and practices (Hoopes & Postrel, 1999; Lynn *et al*, 1999; McKee, 1992):

- Explicit strategic goals for knowledge transfer, sharing and use,

- Integration of learning mechanisms in the product development process (e.g., stage-gate reviews and post project evaluations),
- Recording, reviewing and filing of information,
- Structuring of interpersonal interaction, and
- Institutionalization of KM through KM functions or task forces.

The first part of our research therefore focused on the overall strategy and organization for KM in NPD. We asked the interviewees to describe this strategy and organization with respect to the points above.

We then turned our focus to the use and functioning of mechanisms for knowledge transfer and sharing in NPD. Similarly to Dyer & Nobeoka (2000), our objective was to study mechanism that are *purposefully designed to facilitate knowledge transfer*, but across *project* boundaries within a firm rather than across *interfirm* boundaries, the latter being the focus of Dyer & Nobeoka (2000). Before reporting on the findings, we specify our research framework and questions for studying knowledge transfer/sharing in this product development context.

Research Framework and Questions for Knowledge Transfer/Sharing in Product Development

Knowledge transfer in product development concerns 1) transfer of new insights between individuals, teams, projects and organizations, and 2) capitalization on past experience –i.e., transfer of knowledge from a knowledge base into operational problem solving processes (Kerssens-Van Drongelen *et al*, 1996; Nobeoka & Cusumano, 1995).

Nobeoka & Cusumano (1995) identify three types of transfer in multi-project product development: Technology transfer, design transfer (i.e., transfer of existing engineering solutions) and knowledge transfer. In their research they show that technology and design linkages are less significant in new projects where platforms are developed primarily from scratch compared to design transfer or design modification projects. Instead, in new development projects, *knowledge transfer* is of utmost importance in order to avoid repetition of previous mistakes. For this reason we focused our study on *new design projects* (our unit of analysis), where we set out to study knowledge transfer *within* and *between* product lines. As a consequence of design and technology transfer being less important in new design projects, those "natural" tangible vehicles for transferring knowledge have to be compensated by *organizational mechanisms* that support knowledge transfer. Based on this we formulated a first research question: **What forms of knowledge transfer can be identified in multi-project development of new products within and between product lines?**

The literature indicates that the tacitness of product development related knowledge makes it particularly difficult to transfer (Dyer & Nobeoka, 2000; Lynn, 1998). This has two major impacts. First, as tacit knowledge is embedded in an individual's experience, in his or her ideals, values, and emotions (Nonaka & Takeushi, 1995), it can only develop in a professional context through the "art of the practice" (Schön, 1983), i.e., by performing the specific task(s) that the tacit knowledge mirrors. Thus, transfer and sharing of tacit knowledge would require some systems or mechanisms for sharing tasks and responsibilities, or rotating jobs. In the second research question we asked **what mechanisms are used for sharing tasks and responsibilities, and in particular, what is the role of job rotation?**

Once people have the opportunity to interact, face-to-face *communication*, enabling active real-time and task-specific exchange of information and perceptions between practitioners (Söderquist & Nellore, 2000), becomes a critical means for transfer and sharing of tacit knowledge (Nonaka & Takeushi, 1995). Moreover, formal communication (e.g., through progress review meetings) is important, but informal communication driven by the problem solving process and the development issues at hand, also plays a crucial role for product development performance (Clark & Fujimoto, 1991). We therefore wanted to explore **what role communication, both of more formal and informal nature, plays in (tacit) knowledge transfer?**

Not all communication will "do the job" of knowledge transfer effectively. Karlson (1994) argues that communication more will be of little use if people involved in the communication do not understand each other for reasons of different professional affiliations. The problem of speaking different professional languages is particularly relevant in the multifunctional tasks of NPD. Nonaka (1991) proposes positive redundancy of knowledge and the creation of a *common cognitive ground* –an intangible space of common knowledge and understanding between project participants- as ways of coping with this problem.

Further, the tacit dimension of product development knowledge has impacts for how Information Technology can be used for supporting knowledge transfer and sharing. Besides enabling storage and retrieval of information, IT systems should also provide means for communication, and support the development of common cognitive grounds. The last research question therefore concerns IT tools for managing knowledge transfer. We asked the interviewees to describe **what tools are used, how they are used, and what decides whether people actually use the available tools?**

We assume that knowledge is "automatically" created when solving product development problems, and that a large part of the information needed in this problem solving process will be available, even though not activated, in the minds of people, in archives, procedures and equipment. Our focus is on the transfer and sharing aspects, while knowledge use, the critical

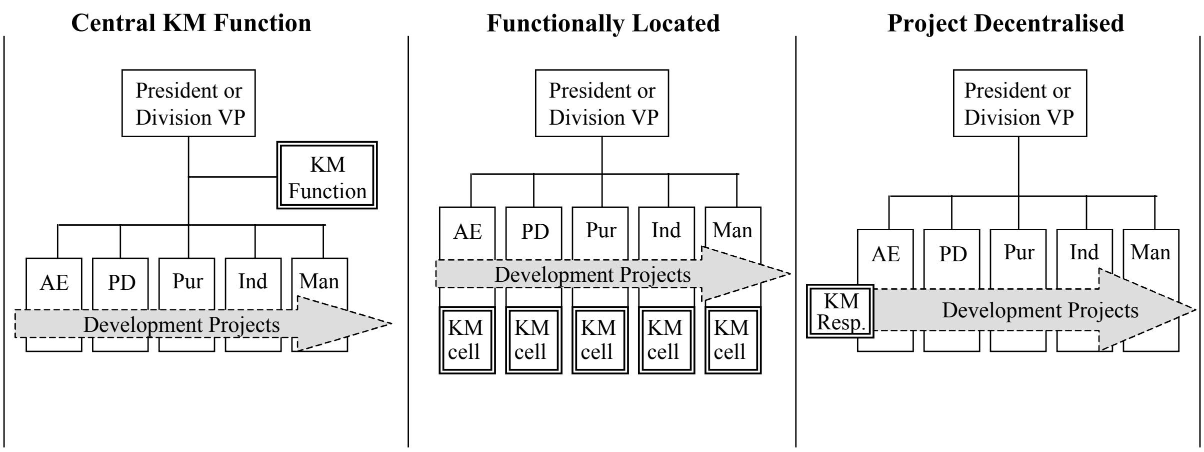
end of the KM process, depends on the successful management of the other three building blocks as well.
The following sections will present and discuss the results from the study, beginning with the overall strategy and organization for Knowledge Management, followed by a zoom on the issues identified in the research framework.

RESULTS FROM THE STUDY

Overall Strategy and Organization for Knowledge Management

The most advanced companies in terms of KM initiatives had installed a specific function for analyzing, improving and re-engineering product development procedures and activities on a continuous basis. The responsibilities of such a function include management of the *creation*, *storage*, *transfer*, and *usage* of development related knowledge. Under names such as "Projects Efficiency" or "Internal Consulting Department", these functions were staffed with former management consultants and people with long operational experience from within the company. The latter's profound knowledge of a company's development history, patent base and core engineering capabilities, and the formers' analysis and assessment skills, that additionally were said to be less culturally biased, proved to be a productive combination of skills for this function.

In companies where no such formal department existed, the responsibilities for KM could fall under the R&D Director, the Quality Director or a Directorship for Product Planning with a project manager assigned to lead the initiative. A third organizational structure was the dissemination of KM activities to the project management level. Figure 1 shows these three type organizations for KM identified in the 12 companies together with an identification of their major pros and cons as described by our interviewees. All types of organization were found in Europe. In Japan, the companies had a pure project decentralized or a combination of a project decentralized and functionally located structure. The US companies had not yet finalized a formal structure for KM, but indicated a preference for combining a central and a project decentralized structure.



Legend: The following operative functions are illustrated in the organizational charts: AE - Advanced Engineering, PD - Product Development, Ind - Industrial/Process Engineering, Pur - Purchasing, Man - Manufacturing

Figure 1. Three different organizational structures for KM in the new product development function.

In companies that disposed of a central KM function the R&D Managers reported high satisfaction with the strategic importance given to Knowledge Management. They found strong support for KM initiatives, as KM was a central goal in these companies. Conversely, project managers and engineers felt that the approach to Knowledge Management could be too distanced from operational development work and problem solving. The quote in table 1 comes from one of the European OEMs and illustrates this potential conflict between KM as a support function and the operational reality.

The functionally located organization was quoted as very strong for knowledge creation. This seems natural as KM cells within each function can focus on highly specialized state-of-the-art knowledge. While a KM cell in product development was efficient for transferring engineering knowledge between product families, this organization could not efficiently contribute to inter-functional knowledge sharing. In one of the American OEMs an R&D Manager said "It is of course nice to know that they (manufacturing) dispose of the latest and most advanced know-how, but it would be even nicer if we could share that knowledge between them and us (product development) so that we improve our design for manufacturing performance".

The project decentralized organization, finally, provided the strongest process orientation and therefore was quoted as most efficient for interfunctional knowledge sharing. However, once a project is finalized, this structure provides few incentives for transfer between projects and product families.

From the above, it seems that different approaches are complementary in the sense that what is gained in one is somewhat lost in another, indicating that a combination of the central approach, the functional approach and the project approach would be an optimal solution. Such an integration was not fully deployed in any of the companies at the time of our interviews.

In companies where KM was an explicit part of product development and corporate strategy, essentially those operating a central or functionally located KM function, it was closely related to the overall strategic planning through an integrative approach between Knowledge Management, Technology Planning and Human Resources Development Planning. Technology development plans were commonly used in all companies in order to forecast what technologies will be necessary to develop over the coming three to five years based on anticipated evolution of technologies, markets and customer needs. The integration of KM in these plans consisted of the majority of the European companies developing and explicitly integrating databases where the skills and competencies of all individuals engaged in product development were carefully recorded and analysed. Technical skills, as well as leadership, organizational and negotiation skills were listed for optimized project staffing and skill development. By combining technology forecasting and skill analysis, a continuous comparison between a *current state of knowledge* with *future anticipated needs for knowledge* based on technological evolution was operationalized. R&D and HRM managers with a few years of experience from this practice prized the improved relevance and efficiency of training and recruitment plans that it had led to. "This is a KM initiative that really pays off" said the HR Director in EuroSupplier1. "It seems so evident once practised, but before introducing this integrated analysis, we spent huge amounts on unplanned external recruitment in order to bridge urgent knowledge gaps as technology and market needs no longer matched what people internally were good at", he continued. The technology development plans were revised on a yearly basis and during these revisions, the assessment of the state of knowledge was also revised. The revisions consisted of rectifying forecasts and adapt training and recruitment strategies.

Forms of Knowledge Transfer

Transfer of product development knowledge took place in several forms. An overall distinction can be made between initiatives to transfer knowledge *after* project completion, and transfer on a *continuous* basis. Not surprisingly, the European and American companies emphasized the first activity, while the second was put forward by the Japanese interviewees. This finding corroborates perfectly what Nonaka & Takeushi (1994, p. 28) say about the vision of time in Japan vs. in the West: "The Japanese see time as a continuous flow of a permanently updated "present". […] In contrast, Westerners have a sequential view of time and grasp the present and forecast the future in a historical retrospection of the past".

Concerning transfer on a continuous basis, the three Japanese and six of the Western companies explicitly mentioned what they called, certainly inspired by Toyota, "lesson learned books" (c.f., Ward *et al*, 1995). One Japanese company used the metaphor "Negative List" for this kind of database containing information about mistakes, problems and, most importantly, the solutions employed to come to terms with the difficulties encountered. Another Japanese company used check lists of operational steps, work methods, and functional and quality performance. These lists were based on as much as 10-15 years of engineering experience. A third Japanese company emphasizes apprenticeship and continuous transfer of knowledge through specialist groups within the engineering sections. Those groups move from team to team and from project to project providing ad-hoc expertise in daily product development activities. More than dealing with complex technical issues, these "nomad expert groups" consisting of two or three "authority engineers", shared their experience in design for manufacturing, supplier integration, and product architecturing – areas where the tacit dimension of knowledge is predominant.

Considering initiatives to transfer knowledge *after* project completion, companies from all regions had organized a specific "post-project" or "project closure" phase with the explicit objective of evaluating product and process performance as well project management efficiency. Besides reviewing traditional performance metrics such as R&D expenditures, development lead-time and engineering hours, these companies looked into KM related evaluation criteria such as effectiveness in staffing and the efficiency of knowledge and technology transfer from previous projects into that being evaluated. The project closure phase contributed to within team and inter-functional learning. To the extent that suppliers and customers were integrated into the evaluation (three European companies) it also enabled inter-organizational learning between the NPD teams working on common projects.

Cross-team learning between different projects was generally perceived as more difficult to achieve. A majority of the companies emphasized the transfer from one project to another of *people possessing valuable knowledge*, rather than the transfer of *valuable knowledge between people* after project completion and evaluation. The main reasons evoked were two. First there are serious limits in the willingness to share knowledge between individuals for cultural or behavioural reasons (our research clearly showed that knowledge still is power, in spite of all the talk about sharing…). Second, the importance of tacit knowledge in the complex product development activities make it difficult and time-consuming to grasp an individual's knowledge, encode it and then transfer it to other individuals. For a product development manager it might be "safer" to rely on the presence of people with the right experience and tacit knowledge than to put faith in an uncertain outcome of knowledge sharing activities where much of the tacit knowledge might be overlooked.

However, rotating people between projects comprises a trade-off between a *wish to keep experienced people as long as possible in a project* so that they can participate in pre-series and ramp-up production, and the *need for them in new projects*. The best compromise that some companies had come up with was to optimize the staffing of new project teams in terms of the balance between key people from previous projects and less experienced people. The efficiency of this staffing strategy had been seriously improved in those companies that had developed competence databanks and specific HR planning software. In the staffing decisions, such IT tools enable to match people with different skills and different skill levels in specific areas (see exhibit How EuroSupplier 1 staff its teams).

How EuroSupplier1 Staffs Its Teams

The product development knowledge database developed over a period of three years, and still undergoing evolution at the time of our study, provides a mapping of the skills of all project participants, starting with the engineering staff. The database was organized in three pools: project experience, technical experience, and other relevant experience (particular knowledge or experience about suppliers, customers or other internal functions). Based on auto-evaluation, people are classified in three categories: knowledgeable but not independent - training need can be defined; knowledgeable and independent - no specific instant training need; and expert - able to train colleagues in a particular area.

The strategic objective with the database was to share a common platform of knowledge within the development teams, and to identify the specific areas where the need for enhanced knowledge is important. Then, the company can proceed to training, recruitment or specific initiatives for knowledge development such as job rotation or spontaneous on-the-job-training by making people with complementary training needs work together. The operational objective was to optimise human resource allocation in projects through a better knowledge of the competence levels of different employees. In stead of simply saying "this project needs five people, let's put these five", teams will be staffed based on the specific needs of the project in terms of competencies. The databank comprised *competence reference sheets* developed by the R&D managers who had defined, for each job position, a list of competencies required in order to be efficient on the job.

Exhibit 1. How Euro Supplier 1 Staffs Its Teams.

Job Rotation as a Means for Knowledge Transfer

If we look at "a piece of newly created knowledge" -such as the knowledge of how a new combination of plastics behave in multi-layer moulding, created by a product engineer in a late night laboratory experiment- it will, in conformance with received wisdom in Knowledge Management Theory, be partly *explicit* (the engineer writes down part of his or her observations) and partly *tacit* (he/she is not able to write down or even explain the exact process that led to the new knowledge). In this specific case, observed in one of the European supplier firms, the same promising results that had been obtained that particular night were impossible to reproduce until several months later. The engineer himself advanced three explanations. First he had been all alone in the lab that evening, he had not shared his activities with anyone, and no one had observed what he actually had been doing (adjustment of the moulding machine, exact mix of the plastic ingredients, time for preheating the ingredients, and so on). Second, he did not have enough knowledge about the moulding technology that had been developed in the process engineering department together with an equipment supplier. Hi simply did not know how the equipment would behave as a result of different adjustments he might have made. Third, he did not have enough knowledge about the raw material –the plastic ingredients- to understand what might have led to the succesful outcome of the moulding experience. The plastic raw material was defined in the chemical laboratory together with a raw material supplier, and purchased by a specialized purchasing agent in the procurement department. No engineering product staff member had any involvement in these activities.

This "classical" and daily problem in technology based innovation and development perfectly illustrates the extent to which "glitches" in knowledge (c.f., Hoopes & Postrel, 1999), in this case about material and process technology, reduce the efficiency of the product development process. The "incident" described above led the engineer to ask for a formal job rotation period, that was accepted and took place for two months in the process engineering section where moulding equipment was developed. It allowed the engineer to acquire both explicit and tacit knowledge not only about moulding processes as such, but about they way in which process engineers and equipment suppliers think and work in their problem-solving/knowledge-creating processes. Once back in the plastic component development team, the engineer transferred this knowledge to his colleagues both explicitly, by explaining particular technical parameters, and implicitly by the fact that he changed some of his work routines. In particular, he started to systematically meet with process equipment suppliers in the early stages of new development projects. At the level of development engineers this example also illustrates the concept of common cognitive ground. The development engineer was able to bridge an important gap in his understanding of process technology and process technology development.

Job rotation was also successfully practised at the level of project managers. A basic requirement of a project leader, as the R&D manager in one of the US OEMs expressed it, is "to be everywhere, know everything and communicate with everyone". Several US and European companies had started to extend the opportunities for people from other functional areas than project engineering to become project managers. They had already successfully used project managers with a functional belonging in Purchasing or Marketing. One of the US companies emphasized, in parallel, the importance of having the right man in the right place. "If you do a project very heavily tuned to body design, you need a project leader from body engineering – he will have the best network. If you try to create a low-cost product, it is best to use a project leader that is experienced in cutting costs", said an R&D executive in this company. Again, the driving force behind this greater sharing of the project manager role is the need for reinforcing the common cognitive ground in the multi-functional context of development.

Managed by the VP for R&D in some cases, by the HR department in others, there were examples both of formalized job rotation schemes as a part of training programmes, and of more ad-hoc initiatives based on dynamic project needs, such as the example analysed above. While some companies practised job rotation essentially within the operational development teams, i.e., between product engineering, process engineering, purchasing and marketing, others emphasized the importance of sending product engineers to production, to the dealer structure, to dealer outlets and even to abroad dealer organizations in order to get a direct impression of the differences in market conditions and customer requirements at an international or even global level. In a car company, an anecdotal example of the importance of market understanding concerned the cup-holder in a prestige segment car. In Europe no one would like a cup-holder, so the engineers ignored this US requirement. Not until engineers had been sent to the US, and realized that also prestige car customers are drinking sodas in their cars, the cupholder was integrated…

The Japanese companies did not practice any formal job rotation schemes. However, some of them referred to an engineer exchange system between research laboratories and business units. When a new technology has been developed and reaches the stage of commercialization, researchers responsible for its development might transfer to the concerned development departments in order to support and monitor the development program that uses the new technology.

Concerning the practical aspects of job rotation, most companies offered a lot of possibilities of job rotation in the development work. There could be possibilities of moving both between different professions within the same division, and between different divisions, either continuing in the same profession or changing job. Most often the decision to move was made by management (functional and project) after that the employee has expressed a wish to rotate. Management, mainly in the European companies, frequently pushed people to move as a competence development incentive. After a longer period of job rotation, six to twelve months, engineers in one of the French companies could integrate either the department of origin normally at a more qualified job, or stay in new department where they went for the rotation. Thus, this was also a method for career evolution.

Communication for Effective Knowledge Transfer

As discussed in the conceptual introduction, communication plays an important role as a tool for managing knowledge transfer and knowledge integration. However, let us first mention another important role of communication, namely that of motivating people. Several companies insisted on communication's role in treating people fairly. This generally related to the use of communication for transmitting corporate information and the importance of preparing employees for shifts in priorities such as the increased importance of knowledge transfer and sharing in all phases of product development. As previously discussed, communication can play an important role also for changing corporate culture in favour of knowledge sharing.

We now turn to discussion communications role, first internal communication, then external communication including supplier involvement.

Informal Communication

Communication basically occurs in the context of teamwork. It seems useful from the interviews to make a distinction between informal and formal teamwork and communication in development projects. To begin with informal group work and communication, it was found to occur whenever it was natural according to the work situation, but it also depended on each individual's professional behaviour and on structural supports for collaboration. Several R&D Executives insisted on the importance of creating an environment where informal networks easily can be established. Informal groupwork and communication occurred for example:

- During idea generation when an individual turns to colleagues for advice on how to solve a specific design problem;
- During applied development work in front of the CAD system, whenever there is a need for real-time advice during application;
- In the testing and observation phases, when design solutions and functional performance data are presented to colleagues for their comments and reactions; and finally

- In the final evaluation phase where outcomes are analysed on a more abstract level focusing on causal links between the outcome and the way of getting there.

Support structures for informal communication were found to have an important impact on its frequency and intensity. In some companies, all design engineers working on a specific project, or even on different projects, had been regrouped in a common office allowing for spontaneous joint problem solving, idea exchange, and exchange of advice. When asked the very straightforward question whether integration and cooperation between design technicians was beneficial for design productivity, the unanimous answer was *yes*. Both project managers and engineers expressed great satisfaction with such an organization. It had much facilitated problem solving in collaboration with colleagues and thus individual and collective learning. Moreover, it had reduced product development lead-time with as much as 20% in average in the best company having introduced this structure and measured its benefits.

Several interviewees stressed that when engineers work in small groups on a specific design problem, and when the joint problem solving occur in real time (directly upon the discovery of the problem), the chances of finding relevant solutions are multiplied. This statement can be supported by theory (c.f., e.g., Bucciarelli, 1988; Kim, 1993, Kerssens-Van Drongelen *et al*, 1996) arguing that when colleagues are informed about each other's problems, they will more or less unconsciously, i.e., tacitly, process these problems mentally while working on their own respective design problems. Suddenly an idea for a solution springs out while solving another design problem.

Formal Communication

A formal team is "created by the formal authority of an organization to transform resource input (such as ideas, materials, and objects) into product outputs (such as a report, decision, service or commodity)" (Schermerhorn *et al*, 1991). Such teams were much quoted in the interviews, especially in the form of regular design reviews where the following objectives were more or less explicitly stated:

- Assess the state of advancement of the project both quantitatively and qualitatively;
- Inform about and discuss lessons learned and future directions;
- Determine priorities between different tasks within the project;
- Inform about and discuss any kind of problems experienced in the projects.

Formal team meetings, most often led by the project manager, did, however, not seem to represent an optimal use of time in many cases. One reason evoked by the interviewees was that formal meetings were too oriented towards the project managers' issuing of directives.

Operational people principally waited for new instructions concerning project priorities and did not see opportunities to draw much useful information concerning operational problems. Another difficulty was that most companies lacked what only one company claimed to have successfully installed, namely what they called "broad-band feed-back structures" - a registration of *all* that is discussed during a group session and where participants afterwards have the possibility to make comments and observations concerning the evolution of different points during the time between two different meetings. In the absence of such a support device, participants did not pay much attention to what was said by another participant, they did not express themselves very vividly, and seemed to be mostly preoccupied with their own problems.

Improvement objectives for design review meetings can be summarized in two points. First, meetings should be seen as vehicles for materializing a continuous improvement effort by searching for the causes behind all kinds of problems, discuss them and propose possible actions. Second, they could be vehicles for promoting knowledge sharing by integrating experience of problem solving, design solutions, and market imperatives from each individual's work into the common knowledge base.

While design engineers fully recognized the usefulness of collaboration and communication, project managers seemed to share this opinion to a lesser extent. When analysing the work of project managers more in depth, three reasons for this emerged. First, their *work tasks* are much more heterogeneous than those of engineers are. This, of course, is due to a much wider spectrum of activities. Therefore, their preoccupations could be quite different at a given moment (such as at the time of a product development assessment or improvement meeting), leading to a lack of interest in each other's discourses. Second, their personal *work methods* were found to be more heterogeneous than those of engineers. Some of the interviewed project managers were oriented towards a rigorous planning of every single project activity and preferred to manage their work to a large extent from their desk in an analytical, almost scientific way using different project planning tools and software. Others were more relational-oriented and practised a management-by-walking-around approach[1]. In other words, there were some problems of compatibility between the management methods of project managers and this made their incentives to learn from each other weaker compared to the situation of development engineers. Third, a certain *career competition* between project managers was identified. This was not a very apparent or significant problem, but for this reason, project managers seemed less open to each other in comparison to engineers.

[1] Both approaches have their pros and cons. The best way is probably a combination of the two. This is also what is proposed by the project management literature (c.f., Clark & Fujimoto, 1991; Bowen *et al*, 1994). No judgement in favour of either of the two is made here. The research did not include measurements making it possible to recommend one method rather than the other.

Creating more of collective dynamism in formal group work requires a long-term cultural change that needs structural support. A first step could be to analyse meeting and group work efficiency with respect to their roles as vehicles for knowledge sharing and enhanced problem-solving capabilities.

Tools for Managing Knowledge Transfer

All R&D Managers in the studied companies shared a similar philosophy towards Knowledge Management, expressed in the following way by the R&D Director in Euro OEM 2: "Knowledge Management is a matter of culture. The tools are only ten percent or less, ninety percent is culture". The most advanced companies in terms of cultural achievements for KM – the Japanese and one European company- where sharing of information already had become integrated in operational behaviour, were now heavily investing both money and time in IT based tools such as databases, knowledge mapping software, Intranets or other network solutions. They strongly emphasized the importance of getting culture and organization right before implementing KM tools. A project manager in Japan OEM 2 said "Tools are used once the right people in terms of skills, culture and behaviour are selected. Then it becomes crucial to share information between these people in an effective and efficient way".

Interviewees in those companies expressed consensus that several IT tools are instrumental in managing the acquisition, transfer, sharing and use of knowledge in new product development. "No engineering company, how small it might be, would today consider developing products without using a CAD (Computer Aided Design) system", one Chief Engineer said. "I think that very soon, the same will hold true for managing project efficiency: no one will imagine to manage multi-project development without software for communication, sharing and transfer of information and knowledge", she continued.

In fact, product development engineers are using CAD systems for problem solving, and EDI systems for transmission of technical data between teams, suppliers and OEMs since more than 20 years. Internal design data bases of patents, design studies and already commercialized products are other well-known tools, while groupware and Intranets are more recent developments in the engineering environment. As knowledge intensity increases, mainly because of the growing technical complexity of component systems (read, an ever increasing degree of electronics content), a general problem encountered in the large organizations studied was that many of the more traditional IT tools lacked relevant dissemination and sharing functions. Moreover, they could be extremely fragmented, i.e., different data-bases did not always exist in an integrated form, and they could be laborious to use outside the narrow circle of some specialists familiar with the tricks necessary to import and export data from these "knowledge repositories". As a result, these supposed support structures acted merely as storage devices separated from the logic of inter-firm and inter-functional project collaboration.

To cope with this growing problem, project-specific or inter-project product development Intranets had been successfully introduced in the majority of the companies in order to provide a platform for knowledge integration and sharing. Table 1 lists the most frequently held information on the company's product development Intranets.

• Listing of quality problems with continuous updating of their evolution/solving • References to quality manuals and quality procedures • Specifications and drawings with continuous updating • Qualification plans for technology • Testing and simulation results	• Reporting from achievements and gateways of different steps in the project phases • Reporting about production constraints • Cost models • Project schedules • Competitive benchmarking data, sometimes with photos and detailed analysis of competitors' products

Table 1. Most frequently held information on product development Intranets

The enabling of close to real time reaction to information, and a "coffee-room" style discussion of ideas and opinions, that also can be stored and made available to consult in the future, were put forward as the major advantages for knowledge transfer and sharing (see exhibit 2). This complements the access to quantitative data and information in CAD systems and databanks.

Intranets: Competence Repositories and Tools for Sharing

One of the European OEMs had set up computer-based "yellow pages" of development competencies. This ongoing project had started with engineers, but the company wanted to extend the "competence pages" to sales, service, controlling, and marketing. The database and associated search engine operate by domains and topics, for example acoustics (domain); interior or exterior acoustics (topics). A major advantage of this system was the opportunity it offered for forming informal problem solving networks based on operational and timely needs in day-to-day development activities. These could be initiated by virtual connection through the Intranet and evolve to also include face-to-face collaboration. Moreover, by mapping search patterns and resulting communication networks, ideas for reorganization and alternative team staffing could be developed. Also, expert profiles from the yellow pages could be set up on the Intranet.

Exhibit 2. Intranets: Competence Repositories and Tools for Sharing.

It also became clear that the more *global* the development projects were in terms of involving teams with participants located in different countries or even continents and tapping into world-wide supplier bases, the more the need for formal tools for KM was obvious. Companies engaged in this kind of global development projects considered the existence of a project specific bi- or multi-lingual Intranet as a key success factor for making the development project at all possible (see Exhibit 3).

The Global Peep-Hole

One of the American OEMs had developed an advanced Intranet application for prototype check. In their R&D department for plastic design, a camera controlled by a joystick moves all over and inside the product prototype, enabling team members to check whether a specific design would interface appropriately with the component in question. In this research center, a hub for the company's global research on plastics, photos can be made and spread through the Intranet as a basis for discussion in the local development divisions spread over the world. Literally, technology enables engineers in France, Korea and Brazil to look inside the plastic shape in real-time.

Exhibit 3. The Global Peep-Hole

A potentially important "hidden" advantage from the use of Intranets was identified in EuroOEM1 and 2. The Intranets could be an excellent vehicle for developing a common cognitive ground in teams. In fact, when navigating in the vast Intranet areas (a frequent late-evening or lunch activity of many engineers and other project members), people are faced with an extraordinary opportunity to explore what others are working on, how they work, how they transmit information, and so on. The learning effect from this was discovered both at the managerial level and at the operational one, and was qualitatively valued (no formal indicators had yet been collected) as having an important impact on product innovation, on the speeding up of problem solving and for developing a better systemic understanding of one another's tasks. This learning effect, a Project Manager expressed it, could be seen as a "silent victory of the recognition of the importance of knowledge sharing". However, as an engineer in the same company said, referring to a large multinational project: "note that this is hidden knowledge sharing, the people I learn from have no idea what I am able to learn from them!".

The IT based efforts for integrating development work with suppliers included shared databases for component systems identifying all project participants (e.g., who is capable of doing what), and groupware or component system based Intranets allowing for a dynamic access to both quantitative and qualitative data, and to "lessons learned" during the development project. Such systems also allowed for electronic message exchange between OEMs and suppliers and between different suppliers working on a common system. Finally a few companies were experimenting with shared CAD software for virtual design and prototyping, as exemplified in exhibit 3.

Concerning communication with end customers, several companies were starting to emphaize this often neglected area. Euro OEM 3 and 4 (automotive manufacturers) systematically send engineers to dealerships in its global markets. Euro OEM 2 emphasized the importance of letting engineers and customers come together during their regularly organized product shows where target customers (identified through market research) are introduced to new concepts and prototypes. In the rest of the companies management put faith in collecting customer inputs through marketing and product planning departments. Internet, basically through the opportunities of mass communication and data collection that it offers, was expected to revolutionize the role of end customers in the development process. All automotive firms that were studied had this issue on their strategic agenda for product development process improvements.

Making People Use the Tools

Reporting on IT tools in product development would be incomplete without a brief discussion of how to make people use these tools. A first basic premise for frequent and productive use is that the systems reflect basic user needs and the operational working practice in development teams (c.f., e.g., Söderquist & Nellore, 2000). It must be "effort-less" to use the tools as a routine in daily work. This is also important in order to avoid that "too much of tools hamper creativity" as one R&D manager expressed it.

As discussed previously, the productive use of tools require a solid base in terms of a culture for communication and knowledge sharing. If "teaching" of a sharing culture, or if visionary leadership and alignment of systems to operational user needs in not enough, a Japanese company suggested to make engineers use databanks and Intranets by force! If an engineer has developed a component and something goes wrong because he or she didn't check the database, the engineer is held responsible in this company. Also, when adding or updating a drawing in a CAD program, the engineer must go to the "lessons learned" area and deposit an explanation in order to be able to approve the new drawing in the system.

There could also be different incentives to motivate people to share knowledge. In EuroSupplier 1 who were operating a product development knowledge database (discussed in exhibit 1), knowledge and competence development was part of the yearly evaluation procedure. It focused on each individual's contribution to the knowledge base project itself and on initiatives for self-assessment and training.

MANAGERIAL IMPLICATIONS AND FUTURE RESEARCH

The overall question that companies struggle with as far as Knowledge Management in new product development is concerned is to develop procedures for *what kind* of knowledge and experience that will be productive to transfer between projects, *how* this will be done, and what kind of *support systems* might be used. The data confirmed the basic assumptions in the research framework, i.e., that new knowledge is continuously created when solving development projects, that a large part of the information input needed in the NPD process is stored in the minds of people, in archives, procedures and equipment, that the application of knowledge for business value depends on the efficiency of creation, storage, transfer and sharing, and the better use of knowledge itself contributes to knowledge creation.

Concerning the overall strategy and organization for KM, three distinctive organizational forms were identified; a central, a functionally located, and a project decentralised structure. The exclusive use of either of these forms was found to lead to specific advantages and disadvantages, indicating that a combination of at least two structures, as practised in the Japanese companies and as planned in the US firms, could be an optimal solution. For top management, the understanding of the pros and cons of different structures for KM in product development is an important input for decision-making. Knowledge Management as a "function" is relatively new making it even more important to learn from the experiences of early adopters. Further empirical survey research would be needed to specify in more detail the three identified organizational forms, search for and specify other possible forms, and relate organizational forms to performance outcomes in terms of the effectiveness of KM efforts. This could lead to the development of a contingency dependent typology of KM organizations in NPD.

In most of the companies, there was a strong integration of Knowledge Management in strategic planning, technology planning, and human resources planning. Moreover, all of the supplier companies had defined routines for capturing and sharing knowledge with customers during joint product development. All OEMs, except for the two US firms and one of the European, also had such routines for capturing and sharing knowledge with their suppliers. This holistic approach to Knowledge Management is an important finding. From a managerial perspective it is essential to understand that KM can not be superposed as an "extra" requirement at certain points in the development process. It certainly requires specific routines, systems and methods, but needs to be integrated with other management systems and imperatives of strategic, technology and human nature. In world-class product development, Knowledge Management needs to be as well integrated as are already product engineering, process engineering and purchasing.

The ideal approach to KM as discussed above was practised in Japan and in one of the European companies. The other firms had well understood the strategic integration of KM in planning, but had not yet reached a very advanced level of operational integration of KM. Even though initiatives such as lesson-learned book existed, the Western companies put more emphasis on post project than on continuous knowledge transfer, and they preferred to rely on transfer of people with relevant knowledge, rather than on transferring knowledge between people. The reasons invoked were the difficulty of transferring tacit knowledge and the reluctance to knowledge sharing still persisting in many situations. Relying on this "individual centred" knowledge transfer can be risky in the long run, however. People can "walk", and knowledge that is not organisationally embedded remains extremely volatile. In future research it would be important to study the efficiency of within-project vs. post-project knowledge transfer, as well as specifying these types more specifically and develop a model for integrated knowledge transfer.

Job rotation was confirmed as a powerful, but time consuming way of transferring tacit knowledge. There were examples of both systematic and more ad-hoc approaches to job rotation. In the former case, however, it often seemed to be part of a career advancement plan rather than a means for transferring tacit knowledge. An important finding was the tendency of designing people from other functional belongings than product engineering as project managers. In future research it would be interesting to qualitatively analyse how development is affected by the difference of functional belonging of the project manager, and to quantitatively relate such differences to development performance.

The role of communication in transfer of tacit knowledge was analysed both in terms of formal and informal communication. The latter has a particularly strong positive influence on tacit knowledge transfer. Companies try to maximize the opportunities for informal communication during problem solving, for example by locating teams together and using software that enables real-time communication. Concerning formal communication, most interviewees stated that meetings, even such meetings explicitly devoted to the issue of knowledge transfer, often fail in giving support for knowledge sharing. There seem to be cultural barriers, expressed essentially in Europe and the US, against an open discussion between team members and project managers. At the theoretical level, this might be explained by the fact that project managers and operational engineers do not always have a shared purpose (c.f., Dyer & Nobeoka, 2000). Our study showed that project managers mainly work against cost and time targets, while engineers work against quality and technical performance targets. The study thus indicates that we might witness an emerging gap between these players in the product development process in terms of professional objectives. This is not only negative for knowledge sharing, but can jeopardize the entire development process performance. Some interviewees suggested that the ever increasing number of new product call-backs, especially in the auto industry, can be tracked back to this split in the necessary balance between cost, time, quality and technical performance.

Concerning IT-based tools for KM, these, and especially Intranets, knowledge mapping tools, and common data bases were found to be instrumental for the efficiency of knowledge sharing as soon as sharing of information had become a part of the culture in the product development organization. Further, a basic premise for frequent and productive use of IT tools is that the systems reflect basic user needs and the working practice in development teams. It must be "effort-less" to use the tools as a routine in daily work. The research illustrated "hidden" effects for knowledge transfer through the use of Intranets. Future research could try to measure the effects of these phenomena on product development efficiency.

Our study has shown that Knowledge Management is taking root in the area of product development in large manufacturing firms. It is a top priority on the strategic agenda for product development in large manufacturing firms. As such it is also spreading quickly down the supply chain.

The exploratory nature of the research and the focus on practical issues do not allow for any definitive conclusions to be made. However, as discussed above, the study identifies several phenomena that open up avenues for future empirical research.

Acknowledgements

The authors wish to thank the companies that agreed to participate in the study and the sponsors of parts of the project: The Swedish Office of Science and Technology - STATT (Stockholm, Detroit, Paris, Berlin, Tokyo) and The Research School ENDREA, represented by The Royal Institute of Technology in Stockholm. Special thanks to Rajesh Nellore for inspiring discussions in the process of the research projects.

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THE INTERVIEW COMPANIES

ID no	Company	Sector	Division
1	US OEM1	Household Appliances	Central R&D
2	US OEM2	Vehicles	R&D Automobile
3	US Supplier	Automotive Components	R&D Automotive Systems
4	EuroOEM1	Electrical Equipment and Appliances	R&D Low voltage products
5	EuroOEM2	Household Appliances	Central R&D
6	EuroOEM3	Vehicles	R&D Automobile
7	EuroOEM4	Vehicles	R&D Automobile
8	EuroSupplier1	Automotive & Industrial Components	R&D Cables & Wires
9	EuroSupplier2	Automotive Components	R&D Electronics
10	JapanOEM1	Motor Cycles	Central R&D
11	JapanOEM2	Home Electronics	Central R&D
12	JapanOEM3	Electronics and Telecommunications	R&D Consumer products

RESEARCH METHODOLOGY

The companies were selected following a criterion sample strategy, meaning that they should fulfil a certain number of criteria, in this case they were:

- Being a large multinational manufacturing firm,
- Pertaining to the automotive, electronics, electrical or household appliances industry,
- Consider new product development as a major key to competitive advantage,
- Be in the frontline of innovation and improvement of the product development process,
- Be located in the US, Germany, France, or Japan.

The choice of companies then largely depended on access and disposability of companies in each country. Participating in a study that would mobilize considerable employee time required some persuasion and explanation of the potential benefits. After extensive search, and thanks to valuable help of STATT representatives in the different countries, four companies in the US, three companies in Germany, France and Japan agreed to participate (the time-frame for searching companies was limited to four months).

The research relies primarily on in-depth, semi-structured interviews. In each of the 12 companies, the following people were interviewed: Product Development Manager, R&D Managers, Project Managers, Design Engineers, and Production Managers. These interviews were completed by interviews with Human Resource Managers, Quality Managers, and Marketing Managers.

The majority of the interviews were tape recorded (a few interviewees refused recording), and during interviews the following guidelines developed in methodology literature were respected:

- First, semi structured interviews with open-ended questions are the most appropriate when the opinions and meanings of the interviewees are looked for; the objective being to gather an 'authentic' understanding of people's experiences.
- Second, some specific techniques for animating the discussion were used. A too passive attitude from the interviewer, that might create a problem for the interviewee about what is relevant or force him/her to talk only to fill up a silence, was avoided. The questionnaire served as a tool for conducting the interviews. Moreover, if the interviewee hesitated or gave imprecise answers questions like 'Could you tell me more about this?' 'Could you specify further'? or 'What are you thinking about in particular'? were used. It is important in such cases not to give any suggestions to interviewees.
- Third, the critical incident technique was useful to start out the interviews or enter into new subjects. This approach is efficient when managers have difficulties in articulating answers to specific questions. It consists of asking the interviewee to describe specific events that have had a critical impact on the way a specific question or domain has been managed.

Interviews were complemented by documentary analysis of project documents, quality procedures, and extensive company documentation.

An comprehensive literature review preceded the generation of the questionnaire. Three of the researchers that worked in the project had very recently completed their literature surveys in the process of their doctoral research focused on product development. This provided invaluable help to the design of the questionnaire. Draft questionnaires were extensively benchmarked with as well leading international academics as company representatives in some of the studied, and other multinational manufacturing companies.

Data analysis followed the open coding technique (Strauss & Corbin, 1990). When using this technique data are first broken down by taking apart an observation, a sentence, a paragraph and giving each separate idea or event a name. Data are then regrouped in categories that pull together around them groups of ideas and events that become sub categories. The following step in the method - axial coding - aims at regrouping and linking categories to each other in a rational manner. The objective of axial coding is to identify main categories - phenomena, and make connections between them and their sub-categories leading to the development of a series of propositions clarifying context and causal conditions to phenomena.