Developing Systems to Support Organisational Learning in Product Development Organisations

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Abstract: There are aspects of New Product Development (NPD) business processes that pose particularly difficult challenges to Organizational Learning systems. Short product and process life cycles compress the available time window for recouping the expenses associated with product development. Cross-functional collaboration in product development organizations requires the merging of knowledge from diverse disciplinary and personal skills-based perspectives. Cross-institutional collaboration leads a requirement for knowledge to be combined from participants across multiple collaborating organizations. Transient existence in teams and high turnover results in a reduction in organizational knowledge unless there is a repository for knowledge rather than a dependence on knowledge which is situated in the minds of individuals.

High rates of change in turbulent industries, such as electronics, motivates participants in NPD processes to effectively overcome these Organizational Learning challenges. The potential payoff includes time saved by not repeating mistakes and reuse of knowledge that leads to successful products and processes. IS research has paid little attention to NPD processes despite the fact that some IS appears to have the potential to have an impact in that area.

Recent research completed by these researchers in Analog Devices Inc identified Organizational Learning challenges encountered by engineering teams in product development. This paper will report on these challenges and will describe how systems were developed to support organizational learning to support the product development process.

Keywords: Organizational Learning, New Product Development, Knowledge Management, Knowledge Management Systems

1. Introduction

There are aspects of New Product Development (NPD) business processes that pose particularly difficult challenges to Knowledge Management Systems (KMS). Short product and process life cycles compress the available time window for learning lessons associated with product development. Cross-functional collaboration in product development organizations requires the merging of knowledge from diverse disciplinary and personal skills-based perspectives. Cross-institutional collaboration leads to a requirement for knowledge to be combined from participants across multiple collaborating organizations. Transient participation in teams and high turnover results in a reduction in organizational knowledge unless there is a repository for knowledge rather than a dependence on knowledge which is situated in the minds of individuals.

When these challenges are not overcome they result in inefficiencies in NPD business processes. The inefficiencies may have several negative influences on the performance of NPD organizations. There can be a lack of shared understanding among the NPD team members. There may be an over-reliance on transmitting explicit rather than tacit design information that can, in turn, lead to repeated mistakes or a re-invention of solutions during product evolution. Skills that had been developed due to collaboration may be also lost thereafter because of the inability to transfer existing knowledge into other parts of the organization. Inefficiencies also arise from inconsistencies in multiple versions of information located in different locations.

High rates of change in turbulent industries, such as electronics, motivates participants in NPD processes to effectively overcome these KM challenges. The potential payoff includes time saved by not repeating mistakes and reuse of knowledge that leads to successful products and processes.

IS research has paid little attention to NPD processes despite the fact that some IS appears to have the potential to have an impact in that area. Recent research completed by the authors of this paper in Analog Devices Inc. (ADI)[1] identified KM problems encountered by engineering teams in product development. These challenges pointed to the need to adopt a dual approach to knowledge management. The approach demands (a) a supporting infrastructure of IS applications and (b) management initiatives to promote appropriate behavioural patterns that help create a one-company culture.

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[1] Analog Devices Inc. is a world leader in the design, manufacture, and marketing of integrated circuits (ICs) used in signal processing applications. Founded in 1965, ADI employs approximately 8,500 worldwide.

This paper will report on the KMS challenges faced by engineering teams engaged in NPD and will outline the balanced approach to KM adopted by ADI that incorporates both technical and socio-technical systems to support the product development process. The paper is structured as follows:

Table 1: Structure of this Paper

Section	Topic
1	Introduction
2	New Product Development and Knowledge Management Systems
3	KM Challenges posed by NPD Processes
4	ADI's Response to KMS Challenges
5	Summary, Conclusions

2. New product development and knowledge management systems

This section will review current thinking on KM in the context of NPD and will describe some of the KMS models proposed for organizations engaged in NPD

2.1 Knowledge management and new product development

Seminal contributions to research into the role of knowledge in competition have come from Drucker and Grant. Drucker was one of the first to herald a knowledge-based economy by illustrating that knowledge was eclipsing traditional factors of production (i.e. land, labour and capital) as a primary resource. He was credited with coining the term "knowledge worker" and in (Drucker 1993) stated, "knowledge had become the basic economic resource". Support for Drucker's viewpoint came throughout the 1990's as a more general view of the pervasive role of knowledge in business activities evolved from a number of management writers and practitioners. For example, (Quinn 1992) provides statistical support for the information and knowledge-based view of the economy (e.g. services sector accounts for 74% of value-added in the U.S. economy, estimating that 65-75% of those engaged in manufacturing employment are actually engaged in services). Similarly, (Stewart 1997) supports this assertion that information and knowledge are the economy's primary resource with numerous statistics and examples in both his book's foreword and first chapter.

Grant proposed a "resource-based" view of the firm. This view emphasizes the importance of a firm's resources, including intellectual capital, as its source of sustainable competitive advantage. In (Grant 2000) he states "what distinguishes the Knowledge Economy from previous economies is the sheer accumulation of knowledge by society, the rapid pace of innovation and, most important, the advent of digital technologies that have had far-reaching implications for the sources of value in the modern economy". He identifies four aspects of management practice which are impacted by the dynamics of the emergent Knowledge Economy:

a) Property rights in knowledge
Recognition of the value of proprietary knowledge has increased the amount of intellectual property legislation by legislatures and judicial systems over the past two decades. The enforcement of intellectual property in the form of patents, copyrights, and trademarks has become a central asset-management activity (Grindley and Teece 1997).

b) Accelerating knowledge creation and application
Companies engaged in new product development have struggled to shorten their product development cycles. For example, the fundamental force behind Intel's sustained success is its "time pacing" - the time pacing of product development though continual minor innovation with periodic "mid-life kickers", together with nine-month fabrication cycle (Brown and Eisenhardt 1998).

c) Converting tacit into explicit knowledge
Kogut and Zander coined the term "paradox of replication" to describe where the codification of knowledge required for internal replication may also facilitate replication of that knowledge by other firms (Kogut and Zander 1992). The challenge facing KM practitioners appears to be how to build barriers to external replication through linking internal systems to knowledge that cannot be replicated by outsiders (Schultze 1998).

d) Competing for standards
Over the last two decades, there has been a change in attitude towards the role of industry standards. Firms are now more willing to sacrifice short-term financial gains for long-term benefits derived from standardization processes. These strategies can imply that firms have to form collaborative projects with customers, competitors and government agencies to

achieve a standardization goal. These types of projects, by their nature, place a lot of emphasis on KM capabilities.

2.2 Knowledge management systems and new product development

There are three common applications of IS to KM initiatives: (1) the coding and sharing of best practices, (2) the creation of corporate knowledge directories, and (3) the creation of knowledge networks. There is much debate on the effectiveness of these IS contributions in supporting KM initiatives. Some argue that capturing knowledge in a KMS can inhibit learning and results in the same knowledge being applied to different situations even when it might not be appropriate (Cole 1998). Other researchers contend that the application of IS can create an infrastructure and environment for strengthening and accelerating KM initiatives by actualizing, supporting, augmenting and reinforcing knowledge processes by enhancing their underlying dynamics, scope, timing and synergy (Vance and Enyon 1998), (Hendriks and Vriens 1999). Research in KMS has paid little attention to NPD processes despite the fact that KMS technology appears to have the potential to have an impact in that area. Ramesh and Tiwana analysed the NPD process for a Personal Digital Assistant operating system, and went on to develop a prototype system to support collaborative NPD (Ramesh and Tiwana 1999).

Court, Culley et al. investigated the use of information in NPD teams and reported on the use of information technology to support the product development process (Court, Culley et al. 1997). They analyzed the methods by which the NPD team members retrieve, apply and subsequently transfer their information. A significant finding was that even though team members have access to IS tools and services, they still preferred to use manual and verbal methods of communication and information retrieval. These preferred formats may suggest that computer information accessing and storage is still at the infancy stage and therefore used with some reluctance by design teams. A key challenge appeared to the researchers to be the extensive use of personal information stores and the absence of easy-to-use indexing systems.

Scott proposed a framework that decomposed the NPD process into three phases and then classified the types of knowledge and IS appropriate for each phase (Scott 1996) (see Table 2). The first phase is the pre-product phase and the knowledge requirements at this phase are related to what has been learned about these types of products in the past and how that learning can be applied to the planned project. Groupware and intranets are seen as IS support systems that can help this phase. The second phase is concerned with the actual product design activity and focuses on the design decisions that are made and the IS that can provide decision support. The third and final phase focuses on production issues that arise after design. Product data management IS are seen are relevant at this stage, as well as Video Conferencing to help coordinate production planning.

Table 2: Knowledge in New Product Development (Scott 1996)

	Pre-product Design	Product Design	Post-product Design
Knowledge	Lessons learned Projects history Links to Experts Customer needs Supplier competence Market intelligence	Product design rationale Process design rationale Causes for problems and failures in product testing	Manufacturability Product testing Root causes for Engineering Changes
IS	Groupware Intranets	Simulations Prototypes Prod. Data Mgmt. Syst. Videoconferencing	Prod. Data Mgmt Syst. Video Conferencing

The same author used Nonaka's SECI model, in combination with a model for cross-department coordination (Adler 1995) to develop a framework to describe IS support for New Product Development in the electronics industry. The framework is depicted in Figure 1.

Nonaka's "socialization" knowledge creation mode and Adler's "teams"- type coordination mechanism requires face-to-face interaction for the transfer of tacit knowledge that is difficult to articulate, communicate, formalize and encode ((Nonaka 1991), (Adler 1995) (Winter 1987), (von Hippel 1994)). Software models of the product under development

enhance the "externalization" knowledge creation mode by making tacit understandings of specifications explicit. The prototype becomes a source of discussion for "mutual adjustment" coordination mechanisms (Adler 1995) and prevents misunderstandings from perpetuating. The "internalization" knowledge creation mode depends on experimentation with multiple "plans". Computer simulations help engineers convert explicit knowledge (originating across boundaries) to tacit knowledge with many iterations of "what if" scenarios. Engineers vary parameters and test performance creating new knowledge without the need to build physical models. In the "combination" mode of knowledge creation, Product Data Management Systems (PDMS) represent explicit knowledge, which is objective and easy to encode, and enables its transformation to further explicit knowledge using Adler's "standards" type of coordination mechanism.

Some empirical work has been done on analyzing knowledge management in new product development processes. Anderson et al. look at the design activity in Rank Xerox and illustrate how collaborative, inter-actional, and organizational ordering are not addressed by the information technology infrastructure in the Design Dept. at Rank Xerox (Anderson, Button et al. 1993). Adler et al. argue for a process-oriented approach to new product development and use a case study of a fictitious company, which represented a composite of a number of companies studied by Adler (Adler, Mandelbaum et al. 1996). He claims that the process oriented approach, which had cross-functional teams as a central element, led to the creation of best practice templates which in turn led to greater efficiencies in product development. Van de Ven and Polley empirically demonstrate how the early stages of product development projects can be accounted for by using principles drawn from chaos theory – providing potential future insight into the front end of new product development efforts that traditionally have proven elusive (van de Ven and Polley 1992).

	Socialization	Externalisation	Internalisation	Combination	
Teams	Video-Conferencing				Tacit Knowledge
Mutual Adjustment		Prototypes			
Plans			Simulations		
Standards				Product Data Management Systems	Explicit Knowledge
	Tacit to Tacit	Tacit to Explicit	Explicit to Tacit	Explicit to Explicit	

Figure 1: IS to support New Product Development (Scott 1996)

The next section will identify and describe some of the KMS challenges encountered by organizations engaged in New Product Development.

3. The KMS challenges faced by NPD processes

Todays NPD activities pose interesting challenges for KMS initiatives. This section will describe some of those challenges.

3.1 Demands for increased productivity in new product development

NPD processes may have short product and process life cycles. These cycles are getting shorter and they are compressing the available time window for recouping the expenses associated with product development. This places a premium on the ability to effectively capture knowledge created during the process so that it can be re-used in the next generation of products to reduce development time. This capture-reuse cycle is a key enabler for productivity improvements in the design phase of product development.
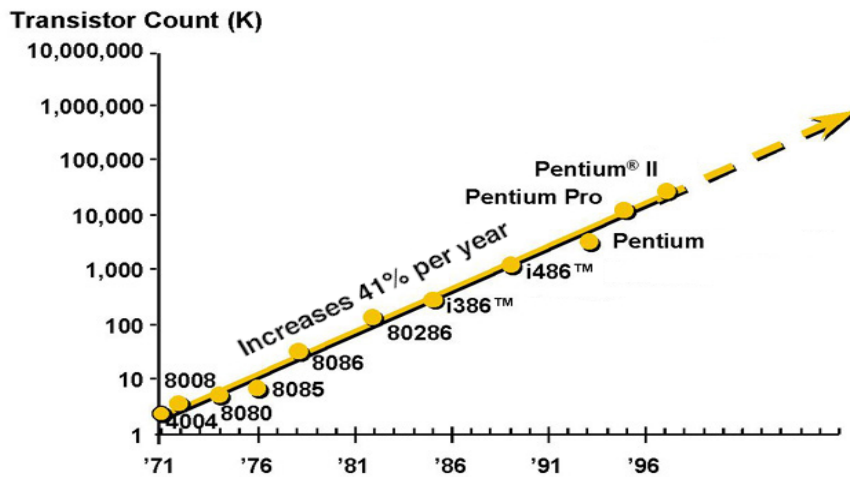
Figure 2: Rate of Product Development in Electronics (Moore's Law)

Figure 2 shows that the number of transistors per chip doubles every 18 - 24 months. However it has been estimated that productivity[2] among electronic design engineers doubles every 36 months (Collett 1998). The competitive pressure to improve productivity and thereby reduce the product development cycle time is huge. Since the challenges associated with capturing and reusing knowledge are, by their nature, knowledge management challenges – this is one of the key KM challenges being posed by NPD. KMS responses to this challenge range from the application of knowledge "codification" systems to knowledge "personalization" systems [Hansen, 1999 #1262].

3.2   Internal knowledge transfer

Today's NPD organizations need to facilitate knowledge transfer across internal organizational boundaries. The drive to enable this knowledge transfer may stem from any one of a number of factors: the existence of "virtual teams" that are geographically dispersed, the re-organization of NPD activities from a linear to a concurrent model or the need for stronger communication flow between organizational units that had been disconnected heretofore e.g. sales and manufacturing.

3.2.1   *Virtual product development teams*

NPD organizations can be distributed across geographical boundaries. In the case of ADI, there are product development centers in the USA, Ireland, India, and China. The product

development activity that spans these centers requires the teams to share their knowledge across team boundaries. It also creates a need for KMS infrastructure to support and promote knowledge sharing. The challenges posed by distributed teams may arise from cultural differences. The appreciation of cultural differences across geographically dispersed teams may be a key factor in the success of those teams. There are at least four ways in which culture influences the behaviours central to knowledge management in virtual product development teams:

a) Culture shapes assumptions about what knowledge is and which knowledge is worth managing. Sackman empirically demonstrated four different kinds of cultural knowledge: "dictionary" knowledge, "directory" knowledge, "recipe" knowledge and "axiomatic" knowledge (Sackmann 1992). Hedlund and Nonaka contrasts U.S. and Japanese practices of managing knowledge (Hedlund and Nonaka 1993). The basis for the contrast is the cultural difference between U.S. and Japanese firms.

b) Culture defines the relationships between individual and organizational knowledge, determining who is expected to control specific knowledge, as well as who must share it and who can hoard it. This relationship is influenced by what some researchers refer to as the presence of an atmosphere of "care" in a company. "Care" can be characterized by an active empathy, access to help and lenience in judgement. Organizations can foster helping behaviour in their workers by training them in pedagogical skills and intervention techniques. Help can become an element of their performance appraisals

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[2]   Productivity = Dollar Value-add per Unit of Engineering Effort in the U.S. Semiconductor Industry 1986 – 1995. Source: U.S. Census and Bureau of Labor and Statistics

and talk about how people are helping each other can be encouraged. Von Krogh and Roos stress that knowledge nurturing and creating organizations should be caring organizations (von Krogh and Roos 1996). They are characterized for having a propensity to help, as well as lenience or a capacity to accept errors and for being reciprocal. Altogether, these characteristics give rise to a trustworthy, empathetic and helpful organization culture in which knowledge is the basic aspect. Culture can also promote unique attitudes toward communication and information, which in extreme cases can restrict knowledge transfer to the point of organizational demise as demonstrated by (Brown and Starkey 1994).

c) Culture creates the context for social interaction that determines how knowledge will be shared in particular situations. Knowledge that is introduced to an organization is often purchased with cash, but for knowledge that is generated internally, the currency is reciprocity. Davenport and Prusak describe three different roles that workers assume in an organization's knowledge market economy (Davenport and Prusak 1997):

- Buyers in the market are seeking information to solve a complex problem. Buyers will look to people with knowledge and who are willing to share it and will also seek sellers who have exchanged knowledge with them in the past.

- Sellers in the market have the information about a product or service that will benefit the buyers. In a market where hoarding knowledge is rewarded, the price for buying knowledge is too high because sellers are unwilling to sell.

- Knowledge brokers spend a lot of time gathering their information through various means and channels.

Reducing harsh bureaucratic structures and increasing informal communication may empower creativity and innovation by promoting spontaneity, experimentation and freedom of expression (Graham and Pizzo 1996). This culture entails an almost total removal of many of the values that underpinned the reengineering and "right sizing" management culture of the early 1990's. For example, knowledge cultures value a "fat" middle management layer for professional support and a tolerance for the functional inefficiency that a messy, chaotic creative process implies (Baskerville and Pries-Heje 1998).

Culture shapes the processes by which the new knowledge with its accompanying uncertainties is created, legitimated, and distributed in organizations. In this context Hayduck developed a framework of organizational practices to foster knowledge sharing that is based on sensitivities to the national culture in which a firm finds itself located (Hayduk 1998). She referenced Hofstede's work and asserts that his work could be used to identify the dimensions of management that influence the success or failure of knowledge management initiatives. In particular, she referred to Hofstede's identification of masculinity and individualism as the predominant "dimensions of management" endemic to American culture and describes how these cultural traits place a strong emphasis on the need to fulfill obligations of self-interest and self-actualization. She went on to describe a program of organizational practices - systems, structures and processes, which would help overcome cultural barriers to knowledge management.

3.2.2 Cross-functional collaboration

Many NPD projects require cross-functional collaboration. The nature and importance of this collaboration is described by Wheelwright and Clark as follows:

"Outstanding product development requires effective action from all of the major functions in the business. From engineering one needs good designs, well-executed tests, and high quality-proto-types; from marketing, thoughtful product positioning, solid customer analysis, and well-thought-out product plans; from manufacturing, capable processes, precise cost estimates and skilful pilot production and ramp-up. Great products and processes are achieved when all of these activities fit well together. The firm must develop the capability to achieve integration across the functions in a timely and effective way." p.165 (Wheelwright and Clark 1992)*

The patterns of communication are described in Table 3. The ends of the spectra represent opposites in integration. On the left is a communication pattern that is sparse, infrequent, one-way, and late. One the right, the communication is rich, frequent, reciprocal, and early. This is the preferred mode of communication for NPD organizations because collaborating engineers meet face to face with their colleagues early in the design process

and share preliminary ideas with sketches, models, and notes.

Table 3: Communication between Functional Groups in NPD (Wheelwright and Clark 1992)

Dimension of Communication	Range of Choice	
Richness of Media	Sparse: documents, computer networks	Rich: face-to-face, models
Frequency	Low: One-shot, batch	High: piece-by-piece, on-line, intensive
Directions	One-way: monologue	Two-way: dialogue
Timing	Late: completed work, ends the process	Early: preliminary, begins the process

3.3   External knowledge transfer

3.3.1   Cross-institutional collaboration

Cross-institutional collaboration is also becoming quite common in NPD processes. The need for this type of collaboration arises when organizations seek to collaborate with sources of knowledge, which are external to it. For instance a firm may want to work with an internationally recognized centre-of-excellence in an academic institution with which it has no formal relationship. Cases where NPD teams want to work closely with external standards organizations are also becoming more prevalent. In such cases knowledge has to be combined from participants across multiple collaborating organizations.

3.4   Transient team membership

NPD teams are staffed with people who may possess much sought-after skills and expertise. Consequently there can be high turnover rates in NPD organizations, as firms compete for staff with highly rated R&D experience. The resulting transient existence of teams results in a reduction in organizational knowledge unless there is a repository for knowledge rather than a dependence on knowledge that is solely situated in the minds of individuals.

There is also a requirement, however, that *some* staff turnover should exist for product development teams to be effective. The rate of movement of staff members across organizational boundaries has been shown to have an effect on NPD team output. Katz explored the relationship among the mean tenure of product development teams, the degree of external communication, and performance (Katz 1982). In his study of 50 product development teams in a large American corporation, he found that initially group performance increased with increasing mean tenure of the group, but this relationship reversed and performance dropped off after five years. The decline in performance was significantly correlated with a decline in external communication and a growth in so-called Not-Invented-Here (NIH) behavior (Brown and Eisenhardt 1995).

3.5   Knowledge to support NPD stage gate processes

A stage-gate process is a conceptual and operational road map for moving a new-product project from idea to launch (Cooper 1994). What differentiates stage-gate NPD processes from other NPD processes is that decision-making events follow each stage. Gates are meetings where the project undergoes a thorough examination and after which executive management decides whether to incur more R&D expense in the project or not. NPD teams complete a prescribed set of related cross-functional tasks in each stage before obtaining management approval to proceed to the next stage of product development. The gates represent control points where teams' plans are repeatedly re-assessed in the light of the additional information that emerges during the life-cycle of the project. Researchers who have recognized that different phases of the NPD process may demand different KMS requirements include (Adler, Mandelbaum et al. 1996), (Scott 1996), and (Yang and Yu 2002). The diagram in Figure 3 describes a typical NPD stage-gate process and indicates the critical decisions made at the different stages.
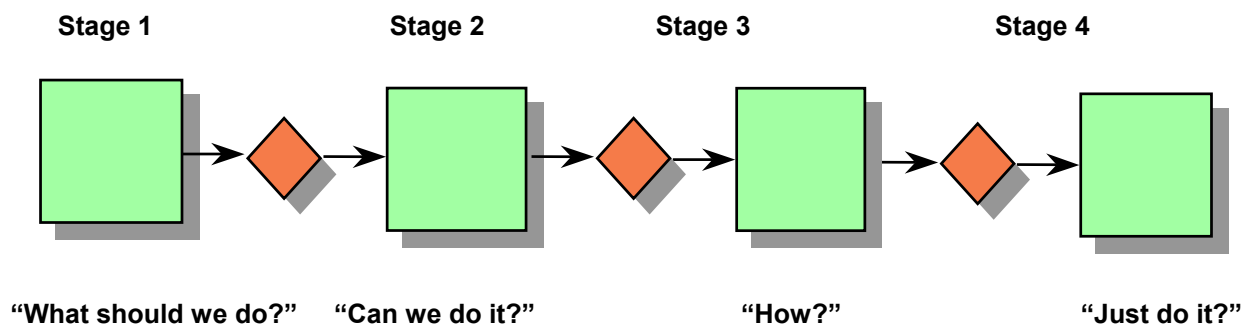
Stage 1   **Stage 2**   **Stage 3**   **Stage 4**

"What should we do?"   **"Can we do it?"**   **"How?"**   **"Just do it?"**

Figure 3: NPD Stage-Gate Process (adapted from (Shake 1999))

There has been some attention paid by researchers to the identification of the types of knowledge required by a new product development activity. Table 4 lists the main contributors and their categorization of NPD knowledge types.

Table 4: Knowledge needed in NPD Processes

Researcher	Types of NPD Knowledge
(Eder 1989)	Prescriptive (know-how), Descriptive (know-that)
(Nonaka 1991)	Explicit and Tacit with four knowledge conversion processes: socialization, externalization, combination and internalization.
(Orlikowski 2000)	Knowing the organization, Knowing the players in the game, Knowing how to coordinate across time and space, Knowing how to develop capabilities, Knowing how to innovate
(Rodgers and Clarkson 1998)	Tacit, Explicit, Operative, Substantive, Heuristic, Algorithmic, Deep, Shallow
(Scott 1996)	Pre-project, product and process design, manufacturing
(Rajagopalan and Subramani 2002)	Agents, Actions, Agency, Context, Purpose, Lessons for the Future
(Ullman 1992)	General, Domain Specific, Procedural
(Vincenti 1990)	Fundamental Design Concepts, Criteria/Specifications, Theoretical tools, Quantitative/Physical data, Practicalities

The KMS challenge for NPD organizations is to recognize that different types of knowledge are appropriate for different phases of an NPD process. Once this realization has been achieved, the next challenge is concerned with ensuring that the sources of that knowledge are available to the NPD teams at the appropriate milestones in the stage gate process.

4. ADI's response to KMS challenges in NPD

4.1 A portfolio of KMS applications to address different KM challenges

There are two common applications of IS to support codification and personalization in product development – the use of "codified" design libraries (codification) and the creation of corporate knowledge networks or "yellow pages" (personalization). These approaches are shown in Figure 4. The diagram shows three dimensions. The "explicitness" dimension shows the degree of tacitness vs. explicitness of the knowledge being addressed by a KMS.

The "reach" dimension shows the range of effectiveness of the knowledge transfer mechanism. The "KMS" dimension shows the scope of the KMS application, ranging from personalization to codification. "Yellow Pages" are shown as spanning the communication space from individuals to groups in an organization. Such systems are not exported outside an organization because of the threat of loss of key individual contributors to competitors. The systems are positioned close to the tacit dimension because they enable people-to-people (tacit) knowledge transfer. "Design libraries" are shown at the other extremes of the diagram. The libraries span the communication space between groups and other organizations because they may be packaged in a format suitable to delivery as intellectual property to either internal groups or external groups (or both). They are close to the explicit dimension because they represent an attempt to codify the knowledge associated with a product i.e. a people-to-documents approach.

"Meta-knowledge" is located between the two extremes and is focused on intermediation. Intermediation refers to the connection of people to people. It is the brokerage function of bringing together those who seek a certain piece of knowledge with those who are able to provide that piece of knowledge. It is interpersonal focus positions intermediation primarily within the realm of tacit knowledge transfer. It occupies the communication space between individuals and groups in an organization and lies between the tacit and explicit dimensions. Through the use of meta-knowledge, the documents become more like databases where search, retrieval, and reuse of text elements (explicit knowledge) are promoted while also giving the reader the opportunity to contact the source of the knowledge so that they may have a dialogue to

enable tacit knowledge transfer (Braa and Sandahl 2000).

A conceptual framework showing the relative contribution spaces of EnCore and docK is shown in Figure 4.. The vertical axis describes "knowledge" as it ranges from tacit, at one extremity, through metaknowledge, to explicit knowledge at the other extreme. The horizontal axis describes organizational "reach", ranging from the individual, at one extremity, through group, organization and ultimately to other organizations. In this context, "reach" is intended to convey the range of applicability of different KMS. The Z-axis describes the spectrum of types of KMS, from personalization through harvesting to codification. The three KMS applications are mapped onto the framework in Figure 4.
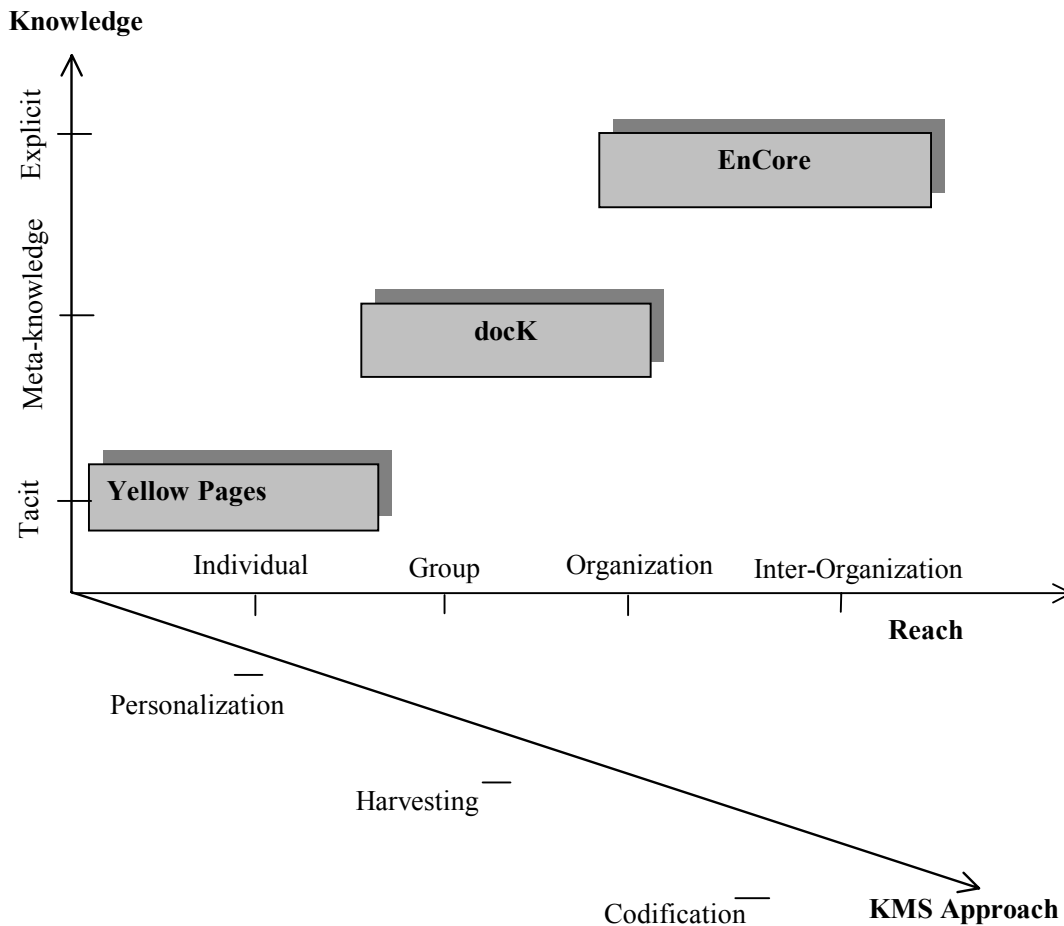
The KMS shown in Figure 4 are:
a) "Yellow Pages" are WWW-based systems used to locate employees in an organization based on attributes such as knowledge, affiliations, education, or interests (Carrozza 2000). Where these

systems are used, staff profiles are created (either by the staff themselves or by a facilitator). These profiles are structured in a manner that renders them easily searchable and retrievable across the organization. The central goal of the

systems is to enable staff members to easily identify other staff members who share common interests. These types of systems are located close to the "tacit" and "personalization" extremes of the conceptual framework because they are concerned with enabling direct human-to-human knowledge exchange.

b) "EnCore" is a repository for reusable product development IP. In Figure 4, it is located close to the "codification" and "explicit" values on the KMS and knowledge axes respectively because it is concerned with codified, explicit IP elements. These elements are capable of being reused across the organization or even exported to other organizations (hence its position on the "reach" axis).

c) "docK" is a KMS designed to locate and retrieve metaknowledge. It is a catalog with entries describing knowledge creation events in ADI. In Figure 4 it is located close to the "harvesting" and

"metaknowledge" values on the KMS and knowledge axes respectively. The system may be most effectively used to create opportunities for knowledge flow across internal organization units and hence its location on the "reach" axis.

4.2 Peer reviews as "Knowledge Events" in NPD stage-gate processes

Each of the "gates" in an NPD process represents a peer review with a "go" or "no go" outcome. Since the majority of costs are incurred in the latter stages of a project, and since companies do not want to "spend good money on a bad idea", the process should include a pause for reviewing all learnings after each stage. The outcome of each gate is a critical decision to either continue or abort the process. This citical decision is illustrated in Figure 5.
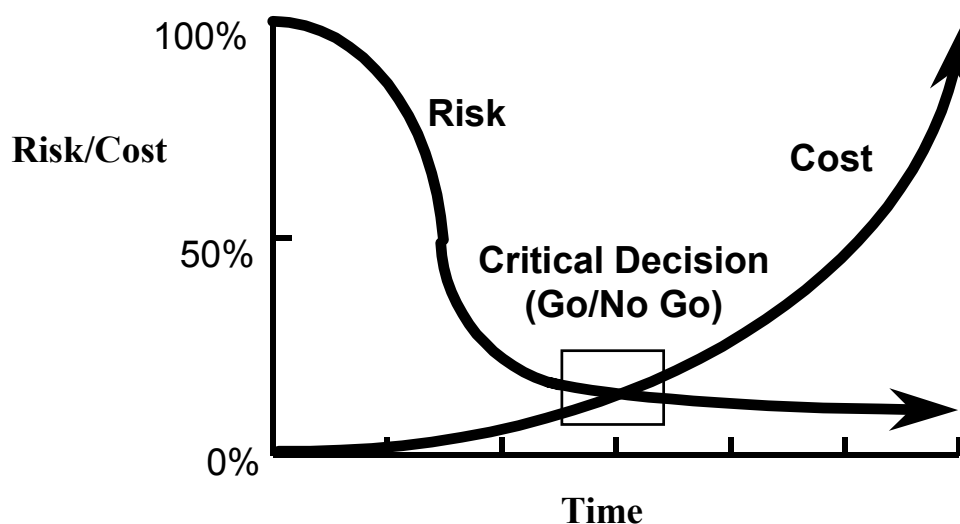

Figure 5: Decisions in a Stage Gate Process (adapted from (Shake 1999))

Bergquist, Ljungberg and Snis draw attention to the potential offered by peer reviews as a mechanism for knowledge dissemination (Bergquist, Ljungberg et al. 2001). In particular, they conclude from their analysis of peer reviews in a pharmaceutical company, that the reviews "play an important coordination role in workers' daily knowledge activities". Furthermore, the collaborative effort involved in peer reviews has the effect of legitimizing new knowledge by "organizationally sanctioning it and thereby creating a platform for collective sense-making."

4.3 Summary and conclusions

The challenges listed above have a significant effect on key NPD performance metrics and researchers (e.g. (Ramesh and Tiwana 1999), (Macintosh 1997)) are starting to identify the detrimental effects of poor knowledge management on NPD organization performance. Their research concludes that sub-optimum knowledge management in NPD teams can lead to situations where highly-paid workers spend too much time looking for needed information because essential know-how is available only in the hands of a few employees or else is buried in piles of documents and data. To make matters worse,

costly NPD errors are repeated due to disregard of previous experiences. Generally, there is an over-reliance on transmitting explicit rather than tacit design knowledge, leading to a lack of shared understanding and constant re-invention of solutions during product evolution. Skills that are developed due to collaboration may be lost after project completion because of an inability to transfer existing knowledge into other parts of the organization. The end result is that there is a gradual loss of tacit knowledge to the firm.

APPENDIX A – KMS Infrastructure Requirements for Virtual Teams

a) Distributed Systems Administration:
- Information Integrity: Site level backup and restore facilities such that each site can be individually backed up and restored.
- Usage Statistics: Ability to generate site statistics for usage and detect inactive sections of the site.
- Site Storage Quotas: Ability to set quotas for site storage size and generate automatic notifications for the site owner when a site reaches a certain limit.

b) Ease of Use:
- User Interface: Web-based admin interface, easy to use and post data so that users can maintain access and post content with minimal effort and training
- Customization: Ability to create personalized views from a pre-defined list of web parts that provide specific functionality.

c) Functionality:
- News: eMail notification to team members when new content has been added or changed.
- Document Revision Control: Ability to enable version control such that documents under control must be "check-out" and "checked-in" as part of the modification process. Also need to be able to disable this capability by team/project.
- Issues Tracking: Ability to post and track issues relevant to project team (assignment, priority, description, priority…etc).
- Check-in/Check-out: Enable users to lock a file while editing, to prevent others from overwriting or editing the file inadvertently.
- Search: Ability to initiate a structured search on documents, issues, lists and other site content respecting security rights.
- Templates: Ability to use pre-defined templates/themes to organize team site, maintain consistent look, feel and style
- Document Workflow: Ability to require route documents through a workflow for electronic approval.
- Discussion Boards: Users can create threaded discussions specific to the site or specific to a document or piece of content.

- Content Organization: Provide the ability to create folders and subfolders in a document library to organize content.
- Versioning: Create a backup copy of a file whenever it is checked in or modified.
- Mgmt Rollups: Ability to rollup & consolidate subteam issues/tasks into higher level consolidated summary.
- Surveys: Ability to create team specific surveys and automatically collect the results in a structured and organized manner
- Multi-language support: Ability to communicate in preferred language with international customers
- Announcements: Ability to post global announcements for individual team sites.
- Minutes: Ability to create & post minutes for individual projects.

d) Integration
- Address Book Integration: Ability to browse enterprise address book to select users or groups that can access site.
- Calendaring: Integrate team site events with a common calendar

e) Security
- Access Level Control: Ability to control who can access which information (down to the individual team/project level) So that customers, based on their identity, can view selected or customized NDA level content. Needs to be controls in place so that errors can't be made here!
- Role based security and Distributed Administration: Project Team areas are self administered with at least Administrator, Read-Only and Contributor Roles.
- Ability for both customers and firm to post/exchange information: Two-way Collaboration via portal with customers, suppliers or other business partners in a secure way over the Internet.
- Security standards compliance: Portal need to comply with ADI security issues, without giving up ease of access

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