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PRODUCT LIFECYCLE MANAGEMENT, KNOWLEDGE INTEGRATION AND RELIABILITY IN NEW PRODUCT CO-DEVELOPMENT: A CASE STUDY BETWEEN EUROPE AND CHINA

Gestion du cycle de vie du produit, Intégration des connaissances et fiabilité du co-développement produits : une étude de cas entre l'Europe et la Chine

Completed research paper

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Abstract:

An important question for IS researchers and practitioners is how IT can improve new product development (NPD) in an international co-development context. More precisely, this paper aims at understanding how Product Lifecycle Management (PLM) technology contributes to NPD knowledge integration and to process reliability in this environment. It is based on a longitudinal case study of a French industrial Group with design teams located in Europe, and which had greatly increased co-development work with China at the time of the study. The first author participated in PLM implementation in Asia over the course of four years. Data analyses indicate a reduction of glitches, from which we infer a positive contribution of PLM to process reliability through knowledge sharing and coordination of mature objects. Indeed, PLM use supports commissioning rather than mediating objects and close rather than open design specifications. Glitches related to knowledge transformation problems are not eliminated with PLM.

Key words: New Product Co-Development, Product Lifecycle Management Technology, Knowledge integration, Knowledge Sharing, Knowledge transformation, Coordination, Glitches, Process Reliability.

Résumé

Comment les TIC améliorent-elles le processus de développement produit ? Par une analyse longitudinale du processus de co-développement de nouveaux produits dans un groupe industriel, nous montrons que la technologie PLM contribue à favoriser le transfert de connaissances matures dans un contexte inter organisationnel distant mais ne contribue que modérément à supporter la création de nouvelles connaissances.

Introduction

Successful new product development (NPD) is critical for achieving and maintaining competitive advantage. Traditionally internal to the firm, NPD is increasingly taking place across geographic borders and continents. Outsourcing, whether partial or total, now extends beyond manufacturing, Information Technology (IT) and services, to encompass the design process itself (Dogson et al. 2006). This trend is motivated by the need to reduce costs, enhance flexibility, and search for specialized expertise (Davenport 2005). However, even within organizations, NPD is highly complex, necessitating the integration of multiple functional competencies and dynamic capabilities (Pavlou and El Sawy 2006). The co-development context adds to this the need to transfer knowledge across organizational, geographic, cultural and language barriers. But transferring and transforming knowledge across very different cultures and functions is not easy (Carlile 2002). For these reasons, co-development NPD carries a high potential for failure and consequent degree of risk. This has created demand for information technology (IT)-based tools to support this process.

The market has responded to this need and created new IT solutions for NPD, such as Product Lifecycle Management (PLM) tools. PLM tools manage product information and data using object storage and workflows, offering a structured framework for collaborative engineering based on a stage gate approach that structures the development process through milestones and predefined key tasks (Cooper and Kleinschmidt 1990). Such tools support the definition and standardisation of workflows and information objects as they are produced and used during the design process (Batenburg et al. 2004). They are designed to integrate knowledge and information across functional boundaries as they are used by multiple actors in various different functions, supporting the development phase from design to industrialization. They are also referred to as collaborative product commerce (CPC) tools (Banker, Bardhan and Asdemir, 2006; Welty and Becerra-Fernandez, 2001). However, very little IS research has been conducted on the use of these tools in organizations. Important theoretical (Nambisan 2003) and strategic (Pavlou and El Sawy 2006) contributions have been made, but new product development processes occur over significant periods of time. Therefore the most appropriate approach for understanding this phenomenon is a longitudinal one. Such an approach enables us to infer the causal mechanisms underlying the findings of previous researchers that have taken a cross-sectional approach to understanding NPD such as Pavlou and El Sawy (2006) and Banker et al. (2004). An important exception to this is the work of Andersson, Lindgren and Henfridsson (2008), although these authors focused on only the very early stages of interorganizational innovation whereas we look at the entire co-development process. Other researchers have investigated on radical innovation (Argyres 1999; Malhotra et al. 2005; Boland et al. 2007), but do not address the problem of knowledge sharing across cultural and geographic boundaries in the context of incremental co-development NPD. Barrett and Oborn (2007) have investigated this issue in IS development teams, but longitudinal research in the domain of IT for NPD lacking in Information Systems research. To address this gap in the literature, we conducted a longitudinal case study of co-development between Europe and China. Before presenting the findings of this study, we discuss the concepts of knowledge integration and process reliability as the theoretical framework for the study and basis for the developed propositions. Next we discuss the research site, characteristics of the technology, and the methodology used for the study. We then present the resultant findings with examples from the data. We conclude with an assessment of the propositions and discuss the implications of these findings.

Theoretical Background

NPD requires the integration of knowledge from R&D scientists, engineers and marketers as they work to develop and launch new products (Clark and Fujimoto 1991). Thus a central challenge of NPD is knowledge integration. Further, new product co-development (NPCD) is an inter-organizational phenomenon. During NPCD, firms may choose not to share their research regarding what is to be developed or their market orientation with suppliers, they do work with remote suppliers to exploit this knowledge and its coordination through new routines (Kogut and Zander 1996). Thus knowledge integration processes are integral to the co-development context and are an appropriate theoretical lens through which to investigate the effects of IT on NPCD. Knowledge integration refers to the integration of individuals' specialized knowledge (Grant 1996).

Okhuysen and Eisenhardt (2002, p.383) define knowledge integration as the knowledge that is created when several individuals combine their information, having first identified and communicated their uniquely held information (knowledge sharing per se). It is more difficult to integrate knowledge between actors who have different knowledge domains and cognitive schemas than between those who share the same culture and domain knowledge (Okhuysen and Eisenhardt 2002).

PLM tools have been found to improve product quality and reduce cycle time and development costs during NPCD (Banker et al., 2006), and build competitive advantage, particularly in higher levels of environmental turbulence (Pavlou and El Sawy, 2006). Similar Web-based technologies can support the creation of architectural knowledge during early phases of innovations when the inter-organizational interactions do not cross significant cultural and language differences (Andersson et al., 2008).

In order to understand ways that PLM does or does not support knowledge integration throughout the entire NPCD process when it consists of significant cultural and language differences, we utilize a theoretical model based on the concepts of knowledge transfer, translation and transformation (Carlile 2004) to distinguish three levels of knowledge integration complexity across boundaries. Based on these levels, we then define the dimensions of the objects that serve this integration, and also the characteristics of the collaborative workspace. These concepts enable us to understand how and when the use of PLM supports knowledge integration and which deep mechanisms are at play.

The NPD process: integrating knowledge across boundaries

According to the information processing view of the firm (Galbraith 1982), knowledge is external, explicit, codifiable and storable. Knowledge transfer occurs by bridging a syntactic or information processing boundary. Transfer is based on organizational routines with minor evolutions where knowledge sharing is quite easy. This perspective is the primary basis for technological approaches to knowledge integration which emphasize storage and extraction mechanisms (Davenport and Pruzak 2000). PLM tools are based on a common database and therefore enable unicity of data. A common knowledge repository between actors increases the level of dependence between actors and the level of information transparency according to conferred access rights. Transfer constraints correspond to basic problems of knowledge circulation and information access among project members. The syntactic capacity requires the development of a common lexicon for transferring domain specific knowledge.

Knowledge translation is a more complex type of knowledge sharing. This second perspective incorporates cultural aspects of horizontal integration (Adams et al. 1998; Kellogg et al. 2006) and relies on conventions between specialized actors with a common knowledge repository. A common lexicon and transfer rules are not enough. Knowledge translation has a more tacit, situated and experiential component. The high complexity of translating knowledge comes from the need to bridge semantic or interpretive boundaries. This type of knowledge integration depends on the development of routines to facilitate actors' adaptation (Sambamurthy et al. 2003), and is supported by common language definitions and experiences (Wenger et al. 1999; Kellogg et al. 2006). Knowledge translation involves sharing evolving objects that are minimally codified (Carlile, 2002), and a semantic capacity for developing common meanings and identifying novel differences and dependencies.

Knowledge transformation is the most difficult type of knowledge integration to accomplish because it encompasses pragmatic constraints (Carlile 2004; Kellogg et al. 2006). New objects are required in order to transform new or complex knowledge across multiple departments. This type of knowledge movement applies to novel knowledge and complex dependencies among actors with vague rules. Contextualization of the knowledge boundary (Star and Greisener 1989) is essential in cases of new knowledge creation or complex problem solving. Definition of routines and a common language is not sufficient for knowledge transformation (Carlile 2002).

The key role of intermediary objects

NPCD work fundamentally rests on knowledge. Because it is distributed among very different actors, it requires knowledge integration. In NPCD work, heterogeneous and diversified actors produce and communicate information artifacts. Boundary objects are a class of Intermediary Objects (IOs) (Vinck and Jeantet 1995; Boujut and Blanco, 2003). IOs are objects or documents that are created and used during collaborative design, such as schedules, minutes, functional specifications, calculation results, drafts, 2D or 3D models, prototypes, etc. They reflect intermediate states of the product as they are mediators translating and representing future states of the product (Boujut and Blanco, 2003). These IOs result from design work and also support and highlight it. IOs model the future product and also serve as communication vectors between participants in the design process. As communication vectors, intermediary objects structure the design network. However, all intermediary objects do not share the same characteristics. These characteristics depend on the properties of the

object itself and on the situated action to which it is committed. All objects do not have the same characteristics during design. Their characteristics depend on the properties of the object itself and on the situated action in which it is committed. IOs can be characterized by two dimensions: the level of prescription (open/closed) and the level of interpretation (commissioning/mediating) (Vinck and Jeantet 1995).

First, objects can vary in how open or closed they are depending on the extent that they constrain the designer (Vinck and Jeantet 1995; Blanco and Garro 1996). A closed object transmits strong constraints, whereas an open object supports ongoing negotiation. Deliverables elaborated during preliminary project phases are often open objects because they support negotiation and mutual adaptation among actors. These objects become progressively closed when actors come to agree on the object content in response to time pressure driven by the need to meet key milestones. Observations of designers in practice have shown that the uncertainty and stability of information evolves during design (Blanco et al. 2007). The overlapping of activities imposed by concurrent engineering processes modifies information flows in design teams (Loch and Terwiesch 1998) such that the role of preliminary information is increased. Under concurrent engineering, project scheduling has to include coordination strategies to avoid major rework (Terwiesch and Loch. 2002). Also, the maturity of information evolves from drafts to deliverables during the design process. Maturity management is a key issue for project coordination, communication facilitation and risk management. Preliminary information serves as a parameter that continues to evolve until its final form (Krishnan and Eppinger 1995). Immature information corresponds to such drafts, is untested and so is possibly incorrect (Hanssen 1997). Thus, during the phase of design solution elaboration, designers' reflections evolve from one workspace to another based on four workspaces: private, proximity, project and public (Blanco et al. 2007).

- First, the designer produces his initial ideas and solutions based on available information and on his own knowledge and competences. This information is arranged in draft objects which are kept in his personal (private) workspace (e.g. technical specifications that are stored on the hard disk). Drafts are not necessarily shared.
- Then the designer needs to confront his or her ideas with other actors' points of view. In this step, collaboration consists of a proximity workspace based on personal networks and loyal relationships. The actors of this ad-hoc workspace may be inside the official project team or outside of it. The proximity workspace is an ideal place for informal confrontation and advice. The role of this space is the construction of a robust and convincing discourse to argue for the solution.
- When the argumentation is coherent and when the information is considered to be enabled for use, it is then shared outside the personal network. The designer shares the information by publishing it in the project workspace. Information shared in the project workspace is not officially validated but sufficiently convincing to be published. For example, it is in this workspace that the electronic engineer places the circuit diagram in the project shared space, in order to enable the mechanical engineering designer to retrieve it.
- Finally, when the information is formally validated, it becomes public. The evolution of the information from a draft to enabled status is not linear. At any time during the design, information can evolve from draft to enabled status and vice versa (Blanco et al. 2007).

The second dimension we use to characterize IOs is the degree of interpretation they allow their users. These objects are not neutral instruments. On the contrary, there is always the possibility that they will be interpreted and used in different ways (Barrett and Oborn 2007). They provide a framework for action and suggest interpretations, acting as mediators. The level of mediation of a design process object can be evaluated along a scale where one end point is a theoretical commissioning object that transmits the whole intention of the provider without transforming it, and the other end of the scale is a mediating object which offers wide leeway for interpretation differences among users (Vinck and Jeantet 1995). Thus, the preliminary marketing specification defining target price, new product general characteristics (basic characteristics, replacing and competitors products) is considered as an open mediating object as point of departure of the project. During this exploring step, there is a wide range of possible interpretations and limitative constraints. When engineering department precise technical architecture based on marketing specifications, the corresponding object is first considered as open mediating and progressively becomes closed mediating when decisions and arbitrations are taken and so constraints are fixed. Then, finished-product technical specifications completely define technical and general characteristics of the product (motor brand and characteristics, rating plate...) with no alternative interpretations in order to detail requirements for manufacturing. Technical specifications are closed commissioning objects. We use these IO dimensions to characterize our findings in the results section.

Measuring knowledge integration and knowledge sharing through the reduction of glitches

In order to understand knowledge integration in the context of NPD we need to be able to measure it. By nature, it is hard to measure knowledge integration (Kogut and Zander 1992; Grant 1996). A good approach for analyzing the contribution of PLM to knowledge integration is to measure the reduction of glitches that occur during the NPCD process. A glitch is a gap in shared knowledge, an unsatisfactory outcome during a multi-agent project that is directly caused or allowed by a lack of cross-functional or inter-specialty knowledge about problem constraints (Hoopes and Postrel 1999). Glitches can be avoided if actors have knowledge, can understand and interpret this knowledge (Hoopes and Postrel 1999). Hoopes et Postrel (1999) defined the « glitch » in order to measure the degree of knowledge integration in the context of new product development. Knowledge integration improvement is correlated with the decrease of the number of glitches and so with errors reduction in communication between actors. Glitches can be identified by critical errors declaration directly linked with bad knowledge circulation on projects. Hoopes and Postrel (1999) have defined a typology of 4 natures of « glitches ».

- The first one is associated with synchronisation problems or non respect of communication procedures. It occurs when defined sharing rules are not respected (typically transfer in NPD according to Carlile's (2004) classification).
- The second « glitch » type is associated with situations, characterized as issue slippage, where procedures are respected in the sense that they were used, but a key constraint or issue has not been raised by an actor, whereas it directly influences other actors (typically transfer in NPD according to Carlile's (2004) classification).
- The third glitch is associated with problems that are not solved because they are incorrectly described or understood by an actor. Such problems of communication in NPD happen due to time pressure on projects, integration of several suppliers in projects, and distant design of new products. It is associated with problems of communication on non critical elements for which one party cannot imagine the difficulty another party is having trying to understand the problem. This category is characterized as one-sided sticky knowledge (Von Hippel, 1996) by Hoopes and Postrel (1999) (typically translation in NPD according to Carlile's (2004) classification).
- Finally, the fourth glitch type, characterized as two-sided sticky knowledge, corresponds to problems not solved due to high levels of problem complexity. Such glitches can be described as «sticky information» (Von Hippel, 1996), and as unsolved problems due to mutual misunderstandings between actors (typically transformation in NPD according to Carlile's (2004) classification).

PLM communication and classification capabilities are designed to solve a number of glitches which are typically due to knowledge integration problems. However, these functionalities may not solve knowledge transformation problems because these problems require richer interactions than PLM can support. Our observations suggest that this is particularly true in the co-development context studied here, which includes culturally diverse NPD teams. Moreover, PLM functionalities are likely to enable greater support of mature objects than of preliminary objects.

Proposition 1: PLM technology mainly facilitates knowledge transfer of mature objects more than knowledge transformation during preliminary design phase of new product co-development processes.

New product development process performance through process reliability

More than 75 criteria have been used to measure new product development performance (Mallick and Schroeder 2005) but NPD performance is very difficult to measure (Meyer and Utterback 1997). Here we investigate NPCD process performance, specifically the reliability of this process. Project profitability depends on delivering the finished product according to the delivery schedule and ensuring that predetermined levels of quality are met. Thus managing process leadtimes and process reliability are key components of project success. Organizational reliability is defined as the capacity to produce common objectives with a repetitively predefined minimal quality (Hannan and Freeman 1984). Reliability is based on operational constraints (Weick et al. 1999) that can be embedded in PLM tools. In the case of product development, reliability is improved when problems are detected and solved during preliminary project design phases. Problems that are identified late tend to be important and complex, which increases the costs of solving them (Brown and Eisenhardt 1995). PLM tools can improve organizational reliability by structuring routines that promote early problem identification (Hardgrave et al. 2003; Butler and Gray 2006). Structured routines are a powerful vector for ensuring reliability (Butler and Gray 2006) and reducing variations in results (Lyytinen et al. 1998). In stable environments, many reliability

problems are due to simple errors caused by poor knowledge integration. IT such as PLM can potentially increase NPCD reliability by embedding structured routines (Kogut and Zander 1992) in its processes.

However, while organizational routines are essential for improving reliability, they have their limitations. Existing organizational routines are not well suited for addressing complex new problems because they are designed to address known and predefined activities (Clarke 1993). For this reason, routines can create more problems than they solve (Orlikowski 2000). The NPCD process is highly complex and tends to surface new problems. Solving these complex problems does not involve choosing among existing solutions but on the creation of new solutions (Weick et al. 1999). Achieving reliability in this context requires that actors contextualize new problems and bring their expertise to bear on them (Weick et al. 1999). In such contexts, routines enhance reliability by increasing actor mindfulness (Butler and Gray 2006; Boland et al., 2007). At the individual level, actor mindfulness depends on the freedom space for actors to make decisions. Incentives (e.g. trainings, procedures, bonuses for knowledge codification) can motivate actors to improve NPCD process reliability. At the collective level, reliability is enhanced when decisions are based on integrated expertise (Weick et al. 1999). Collective mindfulness implies shared and decentralized approaches to problem solving, and the organizational capability for quick problem detection and solution. PLM monitoring functionalities can aid in quick problem detection, while PLM communication functionalities can aid in problem resolution. In this way PLM can enhance reliability by supporting individual and collective mindfulness.

Thus process structuring and actors mindfulness are two complementary ways that process reliability can be enhanced, both of which are supported by PLM technology:

Proposition 2: PLM increases reliability in new product co-development processes.

Figure 1 below presents the conceptual model underlying the two propositions developed above.

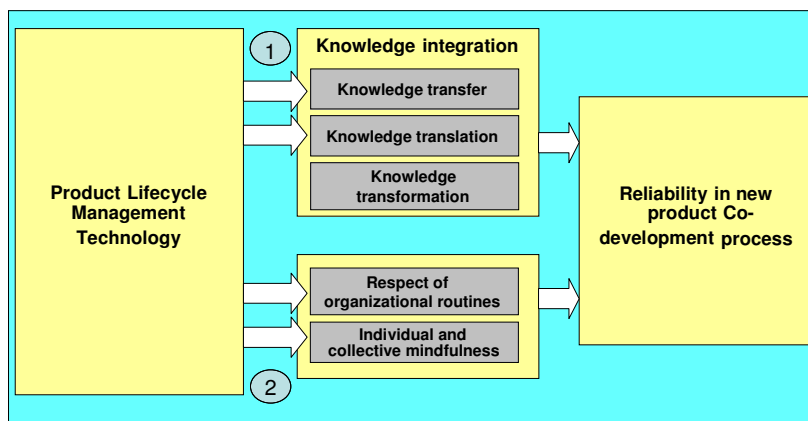


Figure 1: Conceptual model

Research site, PLM Technology, and Methodology

The design of this research is grounded in a longitudinal real-time approach (Leonard-Barton 1990; Eisenhardt and Graebner 2007) in order to deeply understand the context and the social and political interactions between actors and technology. Real-time cases employ longitudinal data collection of interviews and observations, both of which help to mitigate retrospective sensemaking and impression management. The case study method allows us to gain rich empirical insights (Yin and Campbell 2002) for understanding PLM's contribution to NPDP process reliability through a wide variety of data sources.

The first author of this paper was hired into the company studied for his PhD under a CIFRE contract (Klein and Rowe 2007). He has been working for the past three years (2005-2008) actively participating in PLM implementations in Asia and in Europe, evaluating it throughout the Group and for internal product development as well. At this time, around 350 projects are managed using PLM in this company. The findings presented below reflect a macro-level synthesis of these cases rather than cross-case comparisons.

Research site and context

The site of the case is a French industrial Group for small domestic appliances with international brands. This Group (€2,8bn turnover) has a strong tradition of external growth with multiple acquisitions. The external environment of this Group is characterized by strong competition, pressure from large retailers, and important changes in consumer behavior since the beginning of 2000. Our research context was the new product co-

development process for four product families. In these product families, more than 40% of finished product is still manufactured in Europe, but this group has had to face several constraints such as the euro/dollar exchange rate, higher manpower costs in Europe, and innovation standardization in the small domestic appliances sector. In order to manage this situation, a growing number of products are co-designed with Chinese suppliers: 40% of finished products in 2007, up from less than 10 % in 2000. For co-designed products, manufacturing is outsourced to these suppliers. New product co-development is organized around a three group structure. The first one encompasses eleven development centers with co-located members specialized by product family. These centers are geographically dispersed all over France and Germany and are relatively small (i.e. approximately fifteen people). The cultures and development processes of these centers varied widely since they were originally separate companies which were acquired for external growth. Within these centers European project teams are organized around 8 to 10 actors with specialties such as marketing, styling, technical staff, quality, standards, and logistics. The second group of actors associated with this Group's co-development efforts is based in China and ensures trading and development support functions. There, around 60 people are dedicated to identifying suppliers, participating in new product development and supporting logistic and administrative responsibilities. Within this structure, there are technical staff members in charge of project follow-up, and also quality teams in charge of implementing controls on the supplier manufacturing process and on finished products. These members are located in Hong Kong, Shenzhen, Shanghai and Nimbo. The third group of actors constituting the co-development process are suppliers. There are two kinds of suppliers: ongoing trusted suppliers and occasional suppliers. For the ongoing trusted suppliers, a dedicated resource from the Asian trading and support structure is located in the supplier's office. This actor, called outsourcing engineer, is in charge of following projects from the supplier's side. For occasional suppliers, no actors are located in supplier's offices, but the project follow up is performed by an actor sharing his time between several occasional suppliers.

	DISTANT CO DEVELOPPEMENT			
	Linen Care	Personal Care	Home Comfort	Baby Care
Range of products	Steam irons, steam station, travel irons, dry irons...	Hair dryers, lady shavers, massage, hair remover...	Fans, heaters, air conditioning, air purifier...	Baby phones, blender, thermometer, sterilizer...
Strategy	Strategic business unit with a leadership position in Europe; high volume. Most products are designed and manufactured internally. Co development is limited to basic products. No Original Equipment Manufacturer (OEM) projects.	Strategic business unit with important margins, very competitive activity. Research activity is quite important, 30% of products are developed internally, 70% are co developed with a combination of Off The Shelf (OTS) projects and OEM projects.	This business unit is quite small in comparison with Linen Care and Personal Care. 100% of products are co developed. Long tradition of outsourcing for this product family. In this business unit, there are no radical new products.	Volume of activity is limited for this business unit. Most of projects are Off The Shelf.
Nature of co development	Co developed products are mainly Off The Shelf products with: * Limited co design from the Group (CAD drawings, BOM... are created by suppliers) * Industrialization done by supplier	Diversity of co developed projects with OTS products managed as for Linen Care and OEM projects. OEM consists of: * Complex Co design shared between Group and suppliers * Industrialization ensured by supplier based on recommendations and help of Group	Most products are co developed based on existing product architecture * Co design with technical expertise from the Group (technical issues can be complex) * Industrialization by supplier	Product evolutions are based on homologation constraints * Limited co design: expertise for quality requirements respected by company * Industrialization by supplier
Organization of European SBU team	Shared resources between internal development and co development * 2 project leaders dedicated to co development * Shared resources for engineering, labs and quality (around 60 people)	Dedicated resources for co development * 4 project leaders, 3 Technical Data Administrator * 2 quality technicians, 1 for standards * 5 marketing people	Dedicated resources for co development * 3 project leaders, 1 technical data administrator * 1 for quality, 1 for standards * 2 for marketing	Dedicated resources for co development * 1 project leader * 1 for quality * 1 for marketing

Table 1: Case study description

Before PLM deployment, development teams faced several problems. Information on projects was fragmented in several IT tools depending on the department owner, so it was difficult to have a consolidated view of project objects. There were also technical difficulties due to problems interfacing these different applications. Thus, drawings were only accessible through Computer-Aided Design (CAD) tools, there were no interfaces between technical databases, and most exchanges were performed through email, resulting in problems with exchange tracking and information overload. This created redundant data collection, errors due to multiple databases, and high numbers of email exchanges on each project. In order to rationalize their co-development, the Group decided to reorganize its NPD process. Teams in China were reorganized around suppliers instead of by product family. This decision had important impacts on the objects shared during design and industrialization phases, as follows. Before this reorganization, each team in charge of a product family had its own rules and documents that they used to develop new products. The reorganization forced them to standardize and define common rules, such as project milestones and procedures, for co-development of new products with Chinese suppliers. In order to support this reorganization, the Group decided to implement a PLM tool in 2006: TeamCenter Engineering solution from Siemens. The main objective was to replace heterogeneous processes with an integrated development process based on a sharing application: PLM. The elaboration of new product technical specifications constitutes a mediating object between the internal design teams and supplier manufacturing teams. This elaboration is facilitated by PLM technology, because this application enables automatic collection

and combination of disparate information in a single final document. The new PLM application is used by all intra-organizational project members (e.g. specialists in marketing, styling, project leaders, quality, standards, and outsourcing managers). Suppliers have access to information collected in the PLM through the outsourcing engineers located in their office or plant. The decision to provide suppliers with only indirect access to project objects via the outsourcing team was based the choice of a phased PLM implementation, starting with intra-organizational teams, and also due to technical constraints with the PLM solution and in order to guarantee security and confidentiality.

The PLM Technology

PLM is a more recent variant of product data management (PDM) tools. Both PLM and PDM manage product information through object storage and workflows, and both support the management of product data. However PLM is focused on the product development process, encompassing the development and industrialization phases but not the research phase or supply chain management. This IT tool offers a structured framework for collaborative engineering based on a stage gate approach that structures the development process through milestones and predefined key tasks (Cooper and Kleinschmidt 1990). It supports the definition and standardisation of workflows and intermediary objects that are produced and used during the design process (Batenburg et al. 2004). Current PLM vendors include Dassault, IBM, SAP, PTC, EDS and Siemens.

Asynchronous communication functionalities:

- The 2D and 3D viewer: Before PLM, CAD software was required to access 2D and 3D product models, so only a limited number of project members could view product volumes and styling, for example. The viewer enables all PLM users to view the product, even those who are not CAD users (e.g. purchasers).
- Workflows facilities: These structure information flow and clarify micro processes enable task validation and diffusion between different actors.
- Automatic object generation in sharable format (pdf) to facilitate exchanges.

Object classification and storage functionalities:

- Data Organisation: PLM offers a pre defined project structure based on a template that becomes a standard for all participants of the design process.
- Unicity of data: With PLM, there is a single integrated database for projects and product artifacts that is accessible to all project members with access rights.
- Tracking functionality: object evolution is tracked with a revision index and status indicators.
- Classification of objects: objects collected in PLM are stored depending on their types (e.g. marketing, quality) which facilitates object reuse and search.
- Use cases for components: Objects are managed with links to where and when they have been used. This makes it easy to identify the products that use each component.

Project monitoring functionalities:

- Project planning: The NPD process is connected to deliverables and information management in a single work environment. However, resource allocation functionalities are quite limited in this PLM.
- Project monitoring: The coexistence of the project plan and product data on specific dashboards make it easy to follow performance indicators.
- Multicriteria search: PLM has search functionality that supports combined searches for projects with specific characteristics, or product characteristics with specific kinds of projects, for example

Data collection and analysis

In this research, we use several techniques in order to obtain saturation using different sources of data and information. The observation process was organized around three main phases: diagnostic before PLM implementation, the reorganization and implementation process, and post implementation. Data collection consisted of a combination of interviews, project documentation, observation and basic statistics from PLM. 73 interviews were conducted: 22 have been transcribed; the others have been summarized from interview notes. Interviews were conducted with actors of various profiles such as marketing, styling, engineering, quality, standards. Interviewees occupied different positions in the organization: For example, a VP of industry reflected the top management level, project leaders presented the middle management perspective, and technicians from a quality group informed us of their views. Daily observations of the PLM project were collected through field

notes. Every day, we collected some key ideas, description or sentences from participating in and observing the particular PLM implementation project. We had no restriction on documentation access. We therefore were able to collect all emails, specifications, presentations and key exchanges on the project. We also used some statistics from the PLM application in order to better understand its operational use.

Knowledge sharing is difficult to measure (Kogut et Zander, 1992; Grant, 1996). We operationalized knowledge sharing in this study in terms of ‘glitches’. Hoopes and Postrel (1999) define a “glitch” as a gap in shared knowledge. In the context of NPCD, glitches are unsatisfactory results on a multi-agent project that are directly caused or allowed by a lack of cross-functional or inter-specialty knowledge about problem constraints (Hoopes and Postrel 1999). As a knowledge sharing measure, it relies on a reverse reasoning: knowledge is not shared or integrated because there is a glitch. Thus, improvements in knowledge sharing are correlated with a decreased number of glitches, which indicates a reduction of communication errors between actors. Table 3 below lists a number of glitches we observed during data collection before and after PLM implementation. They are classified according to Hoopes and Postrel’s (1999) four categories of glitches, which are defined in the left-hand column of the table.

DATA COLLECTION		Phase of longitudinal analysis		
CO DEVELOPMENT CASE STUDY		Before PLM	During PLM implementation	Post implementation
Interviews	Collective	11	0	N/A
	Individual non recorded	20	20	N/A
	Individual recorded	N/A	N/A	22
Data collection	Secondary data	All documents concerning analysis phase: mails, specifications...	Documents such as implementation rules, procedures	Documents such as project communication, trainings...
Observation and action conducted during research	Field notes, actions Researcher presence 3 days per week	Daily field notes based on observations during diagnostic phase: needs analysis.	Field notes and participation to choices in implementation rules in PLM Perform trainings (as PLM trainer) in Europe and China	Field notes concerning post implementation support
Artefacts	Artefacts	N/A	N/A	Basic statistics from PLM: number of users, number of objects per project.....
Duration	Period	6 months From September 2005 to February 2006	6 months From March 2006 to August 2006	12 months From September 2006 to August 2007

Table 2: Data collection

We investigate our two research propositions with different data analyses. P1, PLM contribution to knowledge integration, is analyzed by identifying differences before and after PLM installation. Contribution to NPCD process performance is analyzed by looking at variances between before and after PLM launch. After PLM launch, we analyzed the operational uses of PLM and its role in error reduction, problem coordination and knowledge sharing.

RESULTS AND DISCUSSION

P1: PLM contribution to managing NPD knowledge integration

In order to understand the role of PLM in this context, we analyzed knowledge integration before and after PLM implementation. These analyses were based on interviews, observations and statistics that shed light on what types of IOs are supported by PLM or not.

The Situation before PLM implementation: knowledge integration difficulties in the co-development process

Due to the distant locations of project actors in this case of international co-development, numerous communication problems were reported before PLM implementation. Prior to PLM implementation, most communication occurred through email, resulting in very high exchange volumes. The increased numbers of co-development projects since 2000, and the numerous “artisanal” routines that evolved to manage these, explain the high number of co-development errors that occurred during this time

“Due to the number of emails exchanged during the project, it is very difficult to track modifications on requirements and so errors are quite common. It happens that evolutions in technical specifications are

not taken into account by [the] quality engineer in China” (Project leader, Personal Care, January 2006)

Some problems were clearly knowledge sharing glitches. For example, due to the lack of tracked communications some tasks were performed using incorrect document versions. Many misunderstandings were attributed to the supplier resources located in China who had limited email support. Knowledge exchanges between European and Chinese teams were also made difficult when Europeans shared knowledge directly with Chinese suppliers without including the Chinese support team. Coordination problems also plagued the Chinese support team due to the lack of effective project monitoring. Identified problems included simple knowledge transfer problems due to basic communication errors, and also complex design issues due to a lack of adequate technical competences in Chinese support teams. See table 3 for examples of these glitches.

The situation after PLM implementation: solved and remaining glitches

After the PLM implementation, we sought out residual glitches in order to distinguish them from those that seem to have been resolved with use of the PLM tool. We identified solved glitches and analysed PLM usage to identify causal mechanisms that might explain how these glitches got solved. Usage of several PLM functions can explain resolution of these glitches. Findings suggest that use of PLM forced actors to codify key project objects that were previously tacit or only partially codified. Before PLM implementation, information sharing was restricted to a limited number of co-located specialists. The circulation of IOs between the co-located specialists led to knowledge integration. However, when these IOs crossed geographical boundaries, there were significant glitches. Since not all knowledge can be codified and thus mediated by PLM, it seems that PLM mainly supports *commissioning objects* which are already standardized and mature. For example, PLM enabled standardization of the product technical sheet which served as a commissioning object, indicating all of the characteristics of the finished product. Such clear definitions reduce errors attributed to lack of information. The PLM enforced workflow and reinforced the quality of stored document information, facilitating knowledge integration among all actors involved in the process. This capacity of the PLM to generate commissioning objects seems to have reduced errors – errors in the technical requirements of finished products have decreased since the implementation of PLM.

“For a supplier, we often had different Finished Product technical sheets structures... It raised problems for quality control...With PLM, technical sheets are clear and errors of interpretations have decreased” (Outsourcing manager, Chinese support team, January 2006)

The 3D viewer functionality enabled a common representation of the finished product among diverse actors (e.g. from marketing, styling, engineering departments). This viewer is available for all actors whereas before PLM, only actors with CAD tools could visualize the design. This functionality supports knowledge translation by making it easier for actors to visualize an electronic prototype that negotiations and decisions can then center on.

Table 3 lists solved and unsolved glitches. The solved glitches correspond to knowledge transfer situations in which glitches are due to lack of procedures and uncommunicated constraints. PLM solved these simple communication problems and reduced glitches between Europe and China. Functionalities such as alerts, workflow validations, revisions and status indicators support high information quality in a central repository. Glitches that remained after PLM implementation arose mainly from complex knowledge integration situations. PLM does not appear to be helpful for these knowledge transformation situations (Carlile, 2002, Carlile and Reberich, 2003). Where it was necessary to build new knowledge and share know-how across actors, the asynchronous PLM application was not sufficient. In complex problem solving contexts, face-to-face contact or video-mediated web conference applications seem to be required. Web conference IT tools enabled actors to share and modify 3D drawings in real time. It seems that PLM is a good platform for sharing *mature* intermediary objects but does not do a good job of supporting preliminary collaborative engineering tasks during co development projects.

“PLM enables [us] to reduce simple communication errors between Germany and China but it is not sufficient to ensure project success. Cooperation and [the] technical skills of suppliers are far more important for project lead time than just document sharing and coordination of the project” (Project leader, Linen Care, June 2007)

Knowledge integration difficulties through glitches typology (Hoopes and Postrel, 1999)	Identified co development difficulties	Solved difficulties with PLM functionalities
	Description and examples of glitches	PLM functionality used to solve glitch
Knowledge transfer (glitch 1): Lack of synchronization between actors or lack of organizational routines	Problems in communication of specifications (marketing, technical, quality) between actors situated in Europe and in China. Information is exchanged with some actors but not with all of them	Single database for project and data management
	Problems occur because objects exchanged on the project cannot be found due to the use of multiple IT tools and lack of common rules for storing and managing intermediary objects	Common project structure with pre defined localization of objects
	Occurs when object evolution is not tracked. A marketing specification is an example: several modifications on preliminary specifications are conducted by marketing but seldom shared with other actors (such as the project leader) or shared without rules	Status and revision information is on all objects
	Errors on products manufactured by chinese suppliers due to the lack of definition of pre requisite informations for project or finished products. Example on finished products due to problems on Technical Sheet	Definition of a template on key project objects. Automatic generation of objects based on stored
	Lack of communication on all project actors about key decisions. An example is a project that is frozen or experiences substantial delays due to geographic dispersion of teams and only use of email	Notification and alerts functionality
	Difficulties in following relations with suppliers due to a lack of organized relationships with suppliers: An example is having different interlocutors from the company for the same supplier, which raises problems in operational project follow up	Automatic dashboards
	Problems in planning management between Europe and China. No common consolidated representations of the project such as milestones and operational tasks	Automatic dashboards
Knowledge transfer (glitch 2): Procedures are respected but a key constraint has not been communicated	Lost time due to poor synchronisation on the level of project advancement. It mainly applies to peripheral actors such as the after sales services (ASS) department, because it is not systematically included in the communication process when these exchanges are only performed via email. Actors forget to copy the ASS department on the emails	Unique project storage and alerts
	Lack of access to some technical information for some actors of the project such as 2D and 3D drawings of the product. This impedes the ability to validate technical options for design quality. This problem arises in the design validation process between the supplier and project leader when CAD tools are different.	2D and 3D viewer
	Lack of a consolidated view on projects raises problems of synchronisation in knowledge sharing. An example is delays in managing planning by the Chinese support team due to the lack of a consolidated view of the project	Automatic project dashboards
	Problems of communication in the case of mutual prescriptions because actors need to the constraints of other actors into account and cannot. An example is poor communication on quality requirements from the European quality team to the Chinese support quality engineer	Validation and diffusion of workflow for important objects
Knowledge translation (glitch 3): Complex knowledge sharing not managed by one side: often the receiver	Chinese suppliers have problems understanding anomalies detected by european teams. An example relates to quality controls performed in Europe: When problems arise, they are difficult to share with some Chinese suppliers due to linguistic and technical competency differences	Definition of templates for key boundary objects shared between company and Chinese supplier
	Difficulties in understanding mutual constraints between actors with different knowledge repositories. An example is laboratory reports which are too technical to be understood by marketing teams when these teams need a synthetic view of laboratory results. Lack of functional competence cannot be solved with PLM	No PLM functionality for solving this glitch
Knowledge transformation (glitch 4): Complex knowledge sharing not managed by transmitter and receiver	Difficulties solving complex technical problems among actors in an international context due to differences in technical competences and language differences. Most of the technical resources from panel chinese suppliers only have a basic knowledge of english. For occasional suppliers, there is a language problem combined with differences in technical competencies.	No PLM functionality for solving this glitch
	It is necessary to limit the level of know-how transfer to chinese suppliers in order to remain competitive in Europe. This creates difficulties, for example when there are leadtime constraints on projects faced with supplier manufacturing problems, and these could be easily be solved if company could explain how to deal with problem but cannot for this reason.	No PLM functionality for solving this glitch
	Difficulties managing the constraints of multiple actors, especially in the design phase. For example constraints of the supplier, the outsourcing manager and the project leader are often diverging and difficult to make explicit.	No PLM functionality for solving this glitch

Table 3: Synthetic view of co development difficulties for knowledge integration

Discussion of knowledge integration through PLM

PLM facilitates standardization of key project intermediary objects. The process of contractual co-development with suppliers is a clearly defined one. Coordination is based mainly on predefined routines and defined deliverables for each step of the process. Project monitoring is based on predefined performance indicators and specifications (Mintzberg 1998). This standardized approach corresponds to knowledge transfer situations in Carlile's (2002) typology and facilitated knowledge sharing and coordination with external suppliers. Precise key milestones and objects were defined in a commoditization process (Davenport 2005) that transformed specific processes into more generic ones in order to facilitate integration of new actors. In these ways, PLM provided good support for co-development of products in the small domestic appliance sector we studied.

PLM manages knowledge transfer well but not knowledge transformation

Our data suggest that PLM facilitates information integration rather than knowledge integration. This seemed to be because PLM only holds codified and mature knowledge and can support only a portion of complex co-development processes. Its support seemed to be particularly lacking for preliminary design phases characterized by uncertainty. Further, in the small domestic appliance sector, NPD projects are not technically complex but it is critical that evolving consumer needs be reacted to dynamically. PLM workflow management divides the development process into specific, sequential tasks with clear lines of responsibility, and this seems to be too rigid to manage the adaptation necessary in preliminary design phases. The example of the finished product qualification process in China illustrates this: In this context, PLM workflow functionality is useful because knowledge movement between Europe and China is sequential and performed through deliverables. The geographic distance, time to market constraints, and high costs of contract modifications all require clear task sequencing and prevent local adjustments. In such cases a formal validation process is strictly followed. These processes are quite different from internal development processes, which tend to be more complex and uncertain. As with IS development in cross-cultural teams (Barrett and Oborn 2007), mutual local adjustments between co-located actors are essential. In such contexts, instead of formal validation of all parts of the finished product, actors spread responsibility for qualification of the parts between design and manufacturing teams informally. This division of work is negotiated depending on the risk associated with each component, the expertise of the teams, and confidence among team members. This dynamic informal negotiation between actors is not supported by PLM. This example illustrates that PLM does not provide strong support for the operational adjustments that take place in preliminary workspaces.

PLM mainly supports mature objects of the co development process

In this study, 75% of objects collected in the PLM were in 'validated' or 'validation-in-progress' status. Thus preliminary exchanges between actors were done outside the PLM application. Intermediary objects in the PLM tended to be collected very close to the relevant milestones date. We investigated email flows to understand more about the interactions and mutual adjustments that took place in the proximity workspaces. We observed a great number of emails generated between marketing and the project leader, and between the project leader and the Chinese support team, in order to select the supplier and manage preliminary relations with him. Such preliminary exchanges concerned objects that needed mutual adjustment and annotations in order to reflect actor interactions. The use of email is intuitive and contextual, enabling object management in the proximity workspace in ways that are not supported by the PLM. Email exchanges often consisted of several pages explaining the specific problem context and potential solutions. For large files not supported by e-mail, actors used FTP or other non-PLM shared repositories. This was surprising since these actors could have used PLM functionalities for file sharing. One explanation for this is that they wanted to be sure that their early drafts wouldn't be considered as validated by other actors. Sharing in proximity workspaces is a function of confidence among actors. The PLM is considered the institutional project repository. Managing objects outside of it enables more flexibility for actors. For this reason the evolution from open to closed IO is not smooth but punctuated. For the reasons described above, results only partially corroborate Proposition 1, so we have revised it:

Proposition 1: PLM contributes to knowledge sharing of mature objects, but not to knowledge transformation.

P2. PLM contribution to New Product Development process reliability

PLM implementation led to a tangible increase in new product development process reliability. Our analysis of reliability is based on all the new product co-development processes we studied rather than on selected cases or

product families. For understanding process reliability we focused on the effects of PLM on achievement of project lead-times, adherence to defined organizational routines and reinforcement of NPD process controls, and information transparency among actors.

PLM contributions to achieving project lead-times

Our analysis utilizes two main measures of lead-time respect. The first one consists of analyses of global statistics on project delays over three years. The second one uses analysis of detailed delays on eight projects. These analyses enabled us to analyze for trends after PLM implementation. The average delay in project lead-time was nine days under PLM and thirteen days before PLM implementation. These statistics reflect the difference between budgeted and actual design validation milestones for all 2006 projects (before PLM) and on all 2007 projects (after PLM). In order to understand this reduction in delays more deeply, we focused on eight projects from our four product families. Before PLM launch, due to the heterogeneity of project coordination tools, it was quite complex to follow the operational schedule, since it was divided between three groups of actors: the SBU, trading entities and suppliers. PLM implementation enabled these groups to share most objects and to coordinate the project on a daily basis. From the point of view of these actors, this explains the contribution of PLM to reducing delays in project lead time.

“PLM doesn’t enable significantly reduced project lead times but does enable respect of lead time objectives thanks to clear processes based on milestones with key deliverables. There are less basic communication errors on projects with PLM” (Project leader, Home Comfort, June 2007)

PLM reinforces defined organizational routines through key deliverables on milestones:

As discussed above, PLM enforces structured key project milestones which correspond to the stage gate approach (Cooper and Kleinschmidt 1990; Howe et al. 2000). These key deliverables are based on common procedures and are easily assimilated in the shared knowledge repository. We conducted a statistical analysis comparing the existence of key deliverables on projects before and after PLM implementation, using the PLM database. We focused this analysis on ten key deliverables which are *commissioning objects* (e.g. marketing specifications, quality control specifications, validated bills of materials, etc.). 350 projects were available in the PLM database, 70 of which existed before PLM implementation and were uploaded into it. For projects created and managed using PLM, 95% contained these 10 commissioning objects, whereas only 75% of the projects managed outside PLM contained these elements. We believe this is due to the fact that all objects collected in PLM are tracked, and each key object is electronically validated through workflows. PLM implementation enabled structured storage of project objects and so pushed actors to mindfully respect templates of key commissioning objects.

“PLM enables us to manage the increasing number of co development projects and to increase reliability. Respect[ing the] time to market schedule is key” (Group R&D Vice President, June 2007)

In this way PLM enabled improved NPD process reliability. Indirectly it also affected the quality of finished products, as follows: Before PLM, quality inspectors used controls based on old versions of control ranges and technical sheets because they didn’t have status and revisions tracking on these documents. PLM enabled these quality inspectors, located in suppliers’ factories in China, to have easy distant access to key objects, supporting improved quality controls on finished products.

Improved reliability through increased information transparency among actors

In the cases of co-development we studied, PLM enabled improved information transparency during mature knowledge integration. This in turn improved individual and collective mindfulness on the project. For the trading entities, centralized object collection and rules regarding project milestones enabled them to have clear, objective information on the project on a daily basis. Prior to PLM, these traders had access to only a subset of the exchanges between European technical centers and suppliers. The scope of trader responsibility increased after PLM implementation since they could more easily interact with suppliers. This improved process reliability because the traders were well suited to interact with Chinese suppliers due to their common language and proximate geography. Before PLM implementation, trading companies in China had difficulties gaining a synthetic view of projects and their progress. After PLM, they had access to consolidated views by supplier and by resource.

Regarding the SBUs, less value was added due to transparency since all information was locally accessible (except for the marketing teams who were located at a distance from the technical centers). Thus improvements due to knowledge transparency mainly affected peripheral departments of NP co-development.

PLM also facilitated project monitoring and thus enhances transparency in project management. It facilitated operational monitoring, management monitoring, and particularly the daily coordination tasks of the project leader. Reliability of project figures and statistics was assumed thanks to centralized and tracked data collection. PLM also increased reliability during consolidation of project information.

However, this improved NPD process reliability was highly dependent on the level of actors' mindfulness. Trust between actors and the will to cooperate seemed to be preliminary conditions for knowledge integration and achieving the benefits of PLM support for managing this. As a tracked collaboration workspace, PLM facilitates transparency in project knowledge, ensures object storage and sharing, and tends to encourage a prescriptive NPD process. For these advantages to be realized, management involvement is necessary to encourage actors to use the application and to be as mindful as possible when doing so.

Discussion of PLM contributions to NPD process reliability

PLM seems to increase information transparency by providing a workspace for sharing mature objects. Storage of objects in a unique database with workflow functionality limits personal political games that can adversely affect knowledge sharing (Hatchuel and Weil 1996). Because routines are defined for sharing key objects, all involved actors know where to find mature objects and information. This makes it difficult for actors not to share the minimal knowledge set. However, they can still provide partial information and play political games during the complex knowledge transformation that occurs in important preliminary workspaces. Regarding knowledge transfer, actors seemed to retain information in their personal workspaces and then provide it to the public workspace immediately preceding the milestone deadline. In this way they sought to keep their objects open until the last possible moment. This behaviour was reinforced by PLM, but it did serve to increase transparency of closed mature objects.

The discussion above corroborates Proposition 2, which posited a positive contribution of PLM to new product co-development reliability. Indeed, PLM enables respect of lead-times, reinforces organizational routines and mindfulness, and supports project monitoring which increases the transparency of mature objects. By increasing reliability during co-design, PLM can reduce error risks on global projects. However, PLM does not really support preliminary design tasks which are largely informal.

Conclusions

PLM tools can improve product quality and reduce cycle time NPCD (Banker et al., 2006) and build competitive advantage (Pavlou and El Sawy, 2006). Similar Web-based technologies can support the creation of architectural knowledge during early phases of innovations (Andersson et al., 2008). But our study suggests that this is not always the case, particularly during the early phases of the process. Since the Banker et al. (2006) and Pavlou and El Sawy (2006) studies utilized cross-sectional survey methodology, and the phenomenon transpires over significant periods of time, it is possible that the glitches during knowledge transformation that we observed were not unearthed by these authors because the method they used identified positive impacts of PLM at later stages of the process that compensated for such problems earlier in the process. However, Andersson et al. (2008) used a similar longitudinal methodology to ours to investigate the early stages of NPCD and found significant positive impacts of PLM-type technologies on the creation of architectural knowledge. Since the creation of architectural knowledge depends on knowledge transformation processes, our findings are inconsistent with those of Andersson et al. (2008). We attribute this to the fact that the inter-organizational boundaries faced by the NPCD processes we studied were characterized by very high levels of cultural and language differences, in this case interacting between European and Chinese actors. The content of the Andersson et al. study was Swedish transport organizations, suggesting low levels of cultural and language differences. We believe such differences in context are likely to account for the conflicting findings between our work and prior IS researchers, although further research is needed to confirm this.

This work contributes to our understanding of information management during new product co-development. A key finding of the research is the contributions and the limitations of PLM technology to knowledge integration and reliability. PLM supports mature commissioning and mediating IOs in project and public workspaces. Like many other IT, PLM has paradoxical effects on organizational processes. PLM brings more transparency and enables more

confident actions, while at the same time increasing dependence on coordination among actors; This dependence introduced by the technology, called formal intervention (Okhuysen and Eisenhardt 2002) obviously has positive effects on reliability. PLM helps implement this structuring of knowledge flows through intermediary objects and allows actors to anticipate constraints and new needs during product development. Formal interventions in the NPD process, such as the use of PLM, are essential for improving NPD process reliability through knowledge integration, but sequential process development should be viewed as a first level in the quest to improve the NPD process. However, when the NPCD process is characterized by high cultural and language differences, other tools for managing preliminary object integration are also essential for improving efficiency and reliability in product design and industrialization.

Thanks to PLM, knowledge sharing of mature objects is greatly increased even between actors who have very different national and functional cultures. Knowledge is integrated through better coordination, but knowledge transformation is not really achieved with PLM. As an asynchronous tool, PLM improves knowledge transfer but falls short of alleviating the difficulties of knowledge transformation. We believe this is based on the underlying assumption of PLM systems that the design process is well known, predictable and quite linear. While this is partially true, research (Okhuysen and Eisenhardt 2002) and our observations indicate that the design process cannot be totally predicted and planned. This is why the contribution of PLM to improved NPD process reliability is partial and must be analyzed within the entire social context of product development.

PLM does not have a real effect on functional competencies (Pavlou and El Sawy 2006). PLM indirectly contributes to the performance of NPD in the sense that the dynamic capabilities of the firm serve as the key mediating variable between IT-leveraging competence and reliability. Dynamic capabilities are articulated around market orientation, absorptive capability, coordination capability and collective mind (Pavlou and El Sawy 2006). Our results show that coordination is greatly improved by PLM and absorptive capability through knowledge integration is partially improved by PLM. PLM improves collective mind by enabling transparency and hence knowledge sharing, but PLM has no impact on market orientation. At the same time, PLM also suffers from ergonomics limitations and rigidity, and this limits its appropriation to regular users, providing limited support for more occasional users. This limits coordination, absorptive capability, and dynamic flexibility to processes implemented with regular users.

Interesting as it is, this case has several limitations. First, it was sometimes difficult for us to distinguish between glitches that were due to language issues and those related to domain-specific issues. A comparison of PLM implementation cases based on internal development only would enable us to overcome this methodological challenge. In addition, a more in-depth comparison of projects across product families and implementation conditions might also shed light on some of our results. Finally, studies of how other technologies may help transform knowledge in similar international contexts are also needed if we are to understand better how IT can improve new product development in a globalizing environment.

Significantly, this study examined the inter-organizational NPD process in the context of very high cultural and language barriers. While previous researchers have found that PLM and similar technologies can have significant positive impacts on NPCD (Pavlou and El Sawy, 2006; Andersson et al., 2008; Banker et al., 2006), none of these studies examined the process when the inter-organizational boundaries were characterized by very high levels of cultural and language differences. In this study we investigated PLM support for Chinese-European interactions that presented significant knowledge integration challenges due to high cultural and linguistic differences. We found that this type of NPCD, PLM does not serve knowledge transformation or the creation of architectural knowledge well, particularly during early stages of development. This suggests the need for further research towards understanding how high the cultural and linguistic differences between organizations can get before the positive impacts of PLM on NPCD start to breakdown. At such a point it appears that the costs and leadtime reduction advantages of PLM may not be achieved. This also suggests opportunities for improvement in the design of PLM technologies aimed at improving support for NPCD when it occurs across organizational boundaries characterized by very high levels of cultural and language differences. Despite the challenges presented by the context studied here, PLM successfully supported numerous relationships and enabled co-development with China at a considerably higher level than previous attempts. Our findings suggest that this was primarily due to PLM's capacity for structuring the relationships and improving process reliability precisely in this context. Even if this were the only benefit of PLM in such contexts, this may have considerable indirect effects on the wealth of nations.

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