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HOW PLM INFLUENCES KNOWLEDGE INTEGRATION IN NEW PRODUCT DEVELOPMENT:

A SET-THEORETIC APPROACH FOR CAUSAL ANALYSIS

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Abstract

This paper evaluates the effects of the use of Product Lifecycle Management and its three sub-systems - Organizational Memory, Project and Resource Management and Cooperative Work systems - on three components of knowledge integration in New Product Development: knowledge transfer, translation and transformation. A second aim of this paper is to explicate and discuss the use of the crisp set version of Qualitative Comparative Analysis to explain the three components of knowledge integration. It does so in an international inter-organizational context of a moderately turbulent industry. In addition to the PLM sub-systems, this configurational analysis focuses on the level of supplier relationships as characterized by two conditions: the boundary spanner participation and supplier integration. Results show that different types of sub-systems impact various types of knowledge integration, and that the level of supplier relationship conditions is important to ensure knowledge translation and transformation.

Keywords: QCA, New Product Development, Knowledge Integration, Supplier Integration, Boundary Spanner

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1   Introduction

PLM promises to provide product information and knowledge to numerous functions in the firm in addition to R&D itself, such as logistics, marketing, manufacturing and accounting (Batenburg et al. 2004). In sum, PLM integrates product design knowledge in a single logical database, and similar to an ERP, allows its use by several functions of the firm. More recent than ERP systems and dealing with a more complex type of information and knowledge, PLM use has been drastically neglected compared to other enterprise systems in IS research. There is a strong need to understand better what PLM actually supports and which kind of features or sub-systems incorporated into PLM are helpful for knowledge integration. This need is all the more important, given that knowledge integration seems to be a major vector for the new product development process reliability when R&D projects are co-developed with countries such as Brazil, China or India (Merminod et al., 2008). In turn, this implies analyzing those elements at an appropriate level of granularity, and examining their influence on various dimensions of knowledge integration. Pavlou and El Sawy (2010) distinguish between three sub-systems: Organizational memory systems (OMS), Project/Resource Management Systems (PRMS) and Cooperative Work Systems (CWS) which, as we explain below, are all PLM sub-systems. Based on a similar distinction, this paper offers an original approach for identifying which PLM sub-systems use can contribute to knowledge integration in the context of the home appliances industry. This paper pursues this first goal by analyzing 42 projects embedded in a case study. In addition, it aims at illustrating and discussing one of the first uses of Qualitative Comparative Analysis (QCA) in Information Systems. This set theoretical method has been advocated (Fichman, 2004; El Sawy et al., 2010), but not really used yet in Information Systems. It precisely allows distinguishing of modalities of a variable as necessary conditions that can make a difference. It further presents sufficient conditions for an outcome articulated as a set of necessary conditions combined with other conditions, thus responding to one of the major challenges for IS research in innovation (Fichman, 2004). By focusing on configurations encountered in each project in a specific way, QCA enables paying attention to patterns of multiple causation and produces explanation that account for every different combination of conditions, thus overcoming the limitations of the findings of previous quantitative researchers who have taken a co-variance approach. Indeed, classically, the treatment of these configurations is based on statistical methods (Doty et al., 1993), which do not preserve the unique combination of each case in their analysis.

Naturally we recognize that organizational characteristics also play a role in explaining PLM use related outcomes. Because QCA imposes certain constraints that we will discuss, we follow Fichman's recommendation to avoid selecting variables whose impact is evident, such as top management support, and restrict the analysis to two types of project conditions characterizing the relationship (level of supplier integration and level of participation of boundary spanner). As exposed below, these two dimensions are critical in inter-organizational and international new product development.

Hence, this paper responds to the following research question: Which combinations of PLM sub-systems' use and types of relationships ensure knowledge integration in international inter-organizational new product development projects?

We begin with a literature review presenting components used in PLM, and justify the conditions we have chosen to analyze, before developing a methodological section explicating the use of QCA in this context. We then present the results and discuss them, with special emphasis placed on the benefits of the methodology and its implications.

2   Conceptual framework

2.1   PLM sub-systems

Pavlou and El Sawy (2010) define "IT leveraging capability as the ability to effectively use IT functionalities to support IT-enabled NPD activities." They view it as a three dimensional construct that captures how IT functionalities are leveraged (or effectively used) comprising Organizational memory systems (OMS), Project/Resource Management Systems (PRMS) and Cooperative Work Systems (CWS) which are all PLM sub-systems. PLM, depending on versions or options, may include

them all (Batenburg et al., 2004).

Hence, PLM use enhances the ability of NPD work units to sense the environment, enhance learning, integrate resources and coordinate activities (Pavlou et El Sawy, 2006). In their first important work on the topic, Pavlou and El Sawy (2006) did not distinguish the effects of each of the components of IT leveraging capability, that is, they examined only their aggregate effect in NPD work on dynamic capabilities and competitive advantage. Recently, they have disaggregated the analysis of the effects by type of systems, but in their conceptual development, they present it, essentially, with respect to improvisational capabilities (id., 2010). One of the aims of this paper is to further their work on IT-enabled NPD activities by focusing on the effects of OMS, PRMS, CWS and their variants, on knowledge integration with a very different methodology and in a more specific context of PLM use: that of a firm in the consumer goods industry in its relationships with Chinese suppliers.

Organizational Memory Systems (OMS) support the processing and sharing of information, management activities in NPD and especially knowledge directories. They offer knowledge coding and sharing functionality to store and retrieve product components as well as best practices from prior projects. OMS enhance the learning capability of NPD work units. Among OMS, we distinguish between the basic storing and codifying functionalities, and the more advanced visual product representations that they convey. The latter functionalities were not included in OMS by Pavlou and El Sawy; however, we believe they should be, since they fundamentally enrich our cognition of objects, and they do not resort to CWS, although it may seem to be the case. In fact, these functionalities are used by single users, and not necessarily for simultaneous communication with others. The core of PLM systems, whatever they encompass, has all the features of these OMS (cf. Table 1).

Coding and Storage: Object and data storage and codification are key elements of PLM technology. Regarding unicity of data, with PLM, there is a unique database for projects and product creation that is accessible to all project members. The predefined folder 'arborescence' allows for quicker search and retrieval.

Global Product Visualization: The digital representation of the product and components in various forms borrows from the techniques of mechanical engineering, and allows for visualization features of the global product that are certainly very important in the appropriation of PLM tools. These features can also be seen as the natural products of the Product Lifecycle Concept (Grieves, 2006) and the idea of expanding the design views of the objects beyond the designers themselves with integration points into CAD systems. This enables viewing CAD elements for all PLM users, even those who are not CAD practitioners as purchasers, for instance.

Project & Resource Management Systems (PRMS) enhance the coordination capability and the ability to manage project and processes. They mainly help *Scheduling and Monitoring* resources and tasks. In fact, project planning forecasts deliverables and tasks management in a single work environment. In addition, the project can be monitored, since the coexistence of Project plan and Product data enables following performance indicators through specific dashboards.

Cooperative Work Systems (CWS) enable *real time collaborative* work by supporting group communication across time and space with web conferencing. They are based on conveyance functionality, such as CAD viewer for knowledge sharing, on convergence functionality in order to elicit tacit knowledge and clarify assumptions on presentation functionality to sort and structure individual contributions into a collective design. It is best supported when, in addition to the web conferencing solution, users share their desktops remotely making simultaneous changes on a specific object, such as a three dimension plan.

2.2 Level of Relationships in NPD projects

Knowledge integration depend on the degree of task standardization, geographic dispersion, size of organization, etc. (Fong Boh, 2006). We do not take all these characteristics into account, as they do not apply at the project level, being at a higher level (organization) or at a lower level (task). We also want to focus on a limited number of critical conditions for methodological reasons. Inter-individual behaviors develop in a set of relationships that are structured, depending on organizational and project relationships where roles are more or less mandated and developed. We consider that two of these types of relationships have been under-researched, even though they are relevant when product development is not internal to the firm. The first, the type of supplier integration (Petersen et al.,

2005), describes a type of relationship integration that is specific to new product development. The second, the level of participation of the boundary spanner, has proved to be critical in international Inter Organizational NPD (Merminod and Rowe, 2010), but it has not yet been used in a comparative analysis at the project level, and thus is not yet established as a term of causal mechanisms.

Level of supplier integration: Many researchers (Handfield, 1999; Petersen et al., 2005; Koufteros et al., 2007) have defined categorizations of supplier integration in the product development process (Petersen et al., 2005). Most of their categorizations are based on the supplier responsibility in the product development process, and are conceptualized on four levels of supplier integration in NPD projects:

- In black box configuration, the supplier is commonly in charge of the development of an outsourced complex system (from preliminary design to manufacturing phases) on the basis of a customer's needs specifications. The lack of skills from the customer and the high level of development risk require considerable communication with the supplier.
- In gray box configuration, the supplier contributes to the functional specifications' definition, which is integrated at the product design stage. There is joint development with daily interactions between supplier and customer actors.
- In the white box configuration, the customer makes all design and specification decisions. The design is ensured by the customer, and the supplier prescriptions are limited to the product industrialization and manufacturing.
- Make to print configuration is typically a situation of sub-contracting with high prescriptions from the customer. The supplier is chosen to execute client constraints with no real input on the product design or industrialization.

Level of participation of boundary spanners: Boundary spanners (Baskerville et al., 2006), also named gatekeepers (Tushman and Katz, 1980) are "individuals in the communication network who are capable of understanding and translating contrasting coding schemes" (Tushman and Katz, 1980, p. 1073). Boundary spanners are vital individuals who facilitate the sharing of expertise by linking two or more groups of people separated by location, hierarchy or function (Levina and Vaast, 2005). Their function is to ensure adequate circulation and diffusion of cross boundaries knowledge (id.). In the Inter Organizational NPD context, the challenge is to manage more complex knowledge boundaries because functional boundaries are combined with cultural and organizational boundaries. Typically, boundary spanners play several roles in the everyday relation in NPD projects: (1) bridge lexicon gaps, (2) reconcile interpretive differences by creating shared meanings, and (3) facilitate means through which individuals can jointly transform their local knowledge (Kellogg et al, 2006).

2.3 Knowledge transfer, translation and transformation

In order to understand knowledge integration throughout the entire NPD 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 dimensions of knowledge integration complexity across boundaries. These dimensions enable us to explain how the use of PLM supports knowledge integration, and which level of relationships mechanisms are at play (cf.Figure 1).

Knowledge transfer occurs by bridging a syntactic or information processing boundary (Carlile, 2004). This is consistent with the information processing view of the firm (Galbraith, 1982), for which knowledge is external, explicit, codifiable and storable. The syntactic capacity requires the development of a common lexicon for transferring domain specific knowledge. This perspective is the primary basis for technological approaches to knowledge integration (Davenport, 2005). A common knowledge repository between actors increases their level of interdependence 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. Managing common knowledge is more difficult in inter-organizational development because of differences in organizational and functional expertise due to actors' specializations, such that they belong to different cognitive environments (Hoopes and Postrel, 1999; Carlile, 2004). The definition of a common lexicon between these actors becomes crucial.

Knowledge translation is a more complex dimension of knowledge integration, as it incorporates

cultural aspects (Adams et al., 1998; Kellogg et al., 2006). The creation of a common meaning is a way to address semantic and interpretative differences across boundaries (Dougherty, 1992, Nonaka and Takeuchi,1995). The complexity of translating knowledge comes from the need to bridge semantic or interpretive boundaries. This type of knowledge integration is supported by common language definitions and experiences (Kellogg *et al.*, 2006; Wenger *et al.*, 1999).

Knowledge transformation is the most difficult dimension of knowledge integration to accomplish because it encompasses pragmatic constraints (Carlile, 2004; Kellogg, Orlikowski 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. Definition of routines and a common language is not sufficient for knowledge transformation (Carlile, 2004). Thus, transforming knowledge can be associated with creative work, which is substantially different from a routine problem solving situation (Majchrzak, et al., 2005). Managing knowledge transformation in International Inter Organizational New Product Development necessitates using a virtual real time environment for knowledge combination in real time, including tacit knowledge (Nonaka and Takeuchi, 1995; Brown and Duguid, 2001). Thus, knowledge creation comes from bridging people gaps while enacting negotiating practices (Brown and Duguid, 2001).
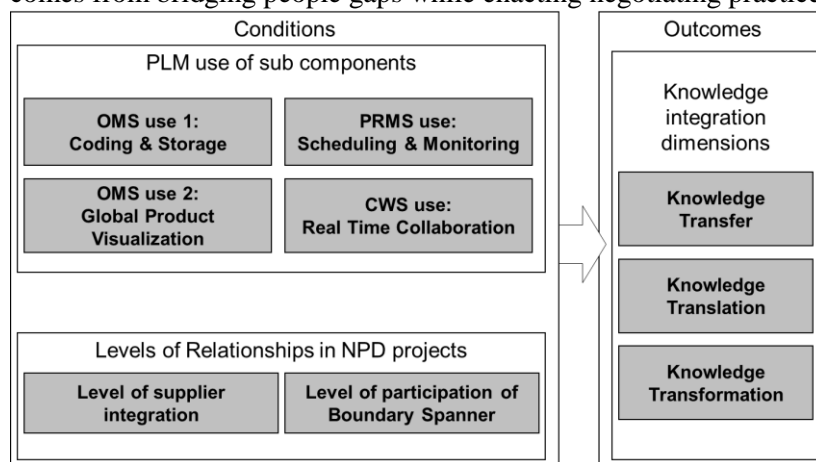

Figure 1. Conceptual framework

3   Methodology

In this paper, we analyze knowledge integration outcomes at the project level. These projects have been launched by the same European group in relationship with different Chinese suppliers. This embedded case study can be considered appropriate to shed new light on how different project conditions explain a complex phenomenon such as knowledge integration in international inter organizational context. Indeed, whereas the context and the general problems encountered at the group level have been described elsewhere (Merminod and Rowe, 2010), there can be important variations at the project level which need to be better understood. Again, we do not focus on each possible managerial type of action, but on PLM subsystems and on relationships. To explain, i.e., to identify the causal mechanisms that systematically produce an outcome, we need to envision all the combinations under which this may occur. Therefore, consistently with the case method (Yin, 2003), we conceptualize cases as combinations of attributes along the configuration dimensions, emphasizing that it is these combinations that preserve the empirical character of the case. Set theoretical methods are suitable for configuration theories because they treat cases as unique combinations of related attributes, instead of breaking cases into instantiations of independent variables in order to investigate their statistical co-variations. In their treatment of cases, set-theoretic methods are compatible with the researcher assumption that there is underlying social system cohesion that can be conceptualized as configurations of strong holistically constrained components (Meyer et al., 1993).

3.1   Study design: Qualitative Comparative Analysis (QCA) research

A limited number of papers have been dedicated to QCA methodology in the context of Information Systems research. Developed first by Charles Ragin (1987), a sociologist, QCA has been mainly

explicated and used in political science and sociology (Rihoux and Ragin, 2009). Only recently have we seen empirical works published in management, more precisely, in Organizational Theory and Methods (Fiss, 2010; Greckhamer et al., 2010). In the IS discipline, Fichman (2004) points out some conditions that are important to mobilize QCA methodology rigorously in order to benefit from its specific advantages, while El Sawy et al. (2010) advocate the use of the method and reinterpret some of their former results. However, these IS works do not explicate the method, nor use it in a demonstrative way. Therefore, it is useful to describe the application of critical aspects of the method for the IS audience.

QCA uses the logic of Boolean algebra to determine the most parsimonious sets of inter related conditions that explain the outcomes observed among a given set of case examples (Fichman, 2004). Explanations may be understood in terms of necessity and sufficiency (Ragin, 1987), which describe the ability to generalize from a limited set of cases to larger populations.

With respect to necessity, "the basic idea is that a phenomenon or a change emerges from the intersection of appropriate pre-conditions: the right ingredients for change. In the absence of any one of the essential ingredients, the phenomenon does not emerge. This conjunctural or combinatorial nature is a key feature of causal complexity" (Ragin, 1987, p.25). Following QCA, a necessary condition is a situation where the outcome can be attained only if the attribute in question is present.

However, with QCA, the main goal is to find which specific combinations of attributes are collectively sufficient to produce a particular outcome (Fichman, 2004, Ragin, 2000). A sufficient condition is a situation where the outcome will always be obtained if the attributes in question are present. This strong causal view is supported by QCA methodology.

After developing the theoretical framework for the study and deciding which variables best measure the dimensions of the configurations, the data which can be verbal statements or discrete or ordinal variables, are coded into binary sets of 0 or 1. The data are then presented in a truth table. Once the data have been coded into "crisps" sets, they are analyzed using QCA (Boolean algebra) analysis with software packages, such as Tosmana. QCA facilitates a constant dialogue between in depth analysis of cases and ideas expressed as variables in terms of conditions and outcomes. All through the research process, progress in literature allows refining the analysis of cases that orient the literature review. Whereas statistical techniques focus on a main explanation supported by a majority of cases, QCA forces researchers to treat deviant cases not as an exception to their theory, but as an unsuspected phenomenon for which an explanation must be given. Correlational statements cannot account for necessity and sufficiency. To analyze which different configurations of organizational characteristics may cause a certain outcome, a researcher using a set theoretic approach first constructs a truth table that lists the possible configurations of characteristics, as well as whether these configurations lead to the outcome in question. In our case, with six conditions, we obtain 2^6, i.e., 64 potential configurations. All possible configurations are not always possible to be observed. Hence, a limited diversity corresponding to the number of configurations actually observed in comparison with all potential possibilities (Ragin, 2000). In order to obtain a more comprehensive and explicit result, QCA enables optimizing the level of parsimony of the sufficient conditions by reducing the number of combinations of conditions, thanks to Boolean algebra techniques. To get a parsimonious set of sufficient conditions, it is then necessary to validate the analysis of non-observed combinations which lead to simplifying assumptions, whether they are "observed" elsewhere or not (i.e., empirically observed or validated by a theoretical reasoning). The limited diversity of the selected sample forces the researcher to complete non-observed configurations, either by building hypotheses which must be justified theoretically or by her knowledge of empirical phenomenon. Indeed, even if the selected set of observed configurations is limited, the researcher may have observed other configurations that were not selected. Measuring coverage enables seeing the relative importance and unique contribution of different causal combinations.

3.2 Data collection and research site

Data collection consisted of a combination of interviews, project documentation, observation and basic statistics from PLM. From September 2006 to August 2007, daily observations of PLM use and outcomes were collected through field notes, resulting in a collection of key ideas and descriptions from participating in and observing the particular PLM Asia implementation project. We had no

restriction on documentation access, and were thus 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. There were 54 interviews conducted for projects developed with external suppliers, of which 22 were transcribed; the others were summarized from interview notes.

A total of 42 projects were selected based on the diversity of project configurations. Thus, the diversity in NPD project characteristics is based on the level of supplier integration in NPD project, the level of Boundary Spanners participation in NPD project and the diversity in the family of products analyzed (Linen Care, Beverage Preparation, Cookware, etc.). The diversity of projects is also based on the use of PLM subsystems such as the level of knowledge storage use, scheduling and monitoring use, visual representation and real time collaboration use.

The site of the case is a French industrial Group for small domestic appliances with international brands. New product development is organized around a three-group structure. The first encompasses 11 development centers with co-located members specialized by product family. These centers are geographically dispersed all over France and Germany. The second group of actors associated with this Group's co-development efforts is based in China and ensures trading and development support functions. They are dedicated to identifying suppliers, participating in new product development, supporting logistic and administrative responsibilities, and acting as boundary spanners with Chinese suppliers. The third group of actors is two types of suppliers: ongoing trusted suppliers (32 in 2007) and occasional suppliers (61 in 2007). In order to manage projects with suppliers, a dedicated resource from the Asian trading and support structure is part-time, located in the supplier's office. This actor, called outsourcing engineer, is in charge of following projects from the supplier's side.

The PLM application, TeamCenter from Siemens, was implemented in 2006.

3.3   Data coding and analysis

Two types of set-theoretic methods, also known as Qualitative Comparative Analysis (QCA), may be used for our problem: crisp sets and fuzzy sets of coded data (Ragin, 2000). We have chosen the Crisp sets method which is based on binary values on each attribute. This crisp sets approach forces researcher to clearly identify and analyze observed phenomenon while justifying membership or no membership for each attribute. Our conditions and outcomes were codified depending on the data coding matrix with our variables and the measure of each variable (cf.Appendix 1).

4   Results

Conditions are given for three outcomes: knowledge transfer (step-by-step process explained), knowledge translation and knowledge transformation (only direct results due to space limitations).

4.1   QCA results for Knowledge Transfer

The QCA methodology is based on 3 major steps. The first consists of determining the level of limited diversity by identifying the coverage of observed configurations in comparison to potential possibilities. The process then consists of identifying the necessary conditions for the outcome. Finally, the objective is to determine the ultimately best level of parsimony for sufficient conditions while justifying the "non-observed" configurations corresponding to the simplifying assumptions.

Limited diversity of the phenomenon

The truth table presents all configurations observed among our 42 projects. The observed configurations correspond to a part of all possible configurations in order to observe the outcome. This corresponds to the phenomenon of limited diversity defined by Ragin (1987). Thus, from our 42 projects, we have 33 different configurations of conditions. The truth table enables identifying existing configurations with empirical observations. Here, 33 configurations are observed on 64 possibilities (2^6), which indicates that the coverage is about 51,5%.

Necessary conditions

Necessary conditions correspond to the situations where whenever one sees the outcome, the necessary condition can also be seen. In order to identify if there were necessary conditions for high

knowledge transfer, we analyzed the truth table, which suggests that for all projects where the level of knowledge transfer is high, High knowledge Coding & Storage condition exists.

Sufficient conditions

The sufficient conditions correspond to the situation where, whenever one sees the sufficient condition, the outcome can also be seen; in other words, when a condition is observed, the outcome is also observed. In order to identify the sufficient conditions for high knowledge transfer, we used Tosmana solution which enables automatically determining sufficient conditions, depending on the different combination of conditions and outcomes observed. This analysis shows that four combinations of conditions are sufficient in order to note a high knowledge transfer in projects. These four combinations of conditions are:

- High use of coding & storage, High use of Global Product Visualization, Low use of Real Time Collaboration solution and High participation of boundary spanners
- High use of coding & storage, Low use of scheduling & monitoring, high participation of Boundary Spanner and High level of Supplier Integration
- High use of coding & storage, High use of Scheduling & Monitoring, High use of Real Time Collaboration and High participation of Boundary Spanner
- High use of coding & storage, High use of Global Product Visualization, Low use of Scheduling & Monitoring, Low level of Supplier Integration and Low participation of Boundary Spanner

Identifying the best level of sufficient conditions

The Boolean reduction consists of taking into account all configurations of conditions which lead to the outcome. The Boolean reduction aims at minimizing the combinations in order to reach a good level of parsimony, thanks to logical Boolean operations. This consists of listing all configurations which are associated to an outcome and seeing if some combinations can be simplified in order to better understand the phenomenon.

The Boolean reduction is generated by the Tosmana solution based on observed configurations and on non-observed configurations (called simplifying assumptions) in order to optimize the parsimony. Thus, the Boolean reduction process integrates the limited diversity forcing the researcher to validate non observed configurations leading to the outcome (hypothesis), due to a justification of the configuration of non-observed conditions (simplifying assumptions) based on theoretical or empirical demonstration.

The Boolean reduction for high knowledge transfer shows that there are potentially two sufficient combinations of conditions which are associated to high knowledge transfer:

- High use of coding & Storage, High use of Global Product Visualization
- High use of Coding & Storage, High participation of Boundary Spanner

In order to validate this simplification of sufficient conditions, we have to explain and justify 6 "non observed" configurations (simplifying assumptions) listed by Tosmana. Due to space limitations we will show them during the paper presentation. It should be clear therefore that the "non observed" configuration in the studied sample can have been observed elsewhere.

Justifying the non-observed configurations (simplifying assumptions)

After the identification of simplifying assumptions, the researcher has to analyze the 6 simplifying assumptions in order to demonstrate, empirically or theoretically, the positive outcome which has not been observed with the 42 retained projects. In order to validate the 6 simplifying assumptions, we had to search the 6 non-observed configurations among the 182 existing New Product Development projects within the company. Our work consisted of finding the missing configurations among the 182 projects, and after having found these configurations, verifying the performance of knowledge transfer: high or low. The association between non-observed configurations (simplifying assumptions) and projects from the company has been validated by the R&D process manager from the company. This analysis enables us to empirically validate the simplifying assumptions proposed by Tosmana, and thus to validate the Boolean reduction proposed for sufficient conditions in order to observe high knowledge transfer. The table listing the projects associated with the simplifying assumptions from the company will be presented at the conference.

As the simplifying assumptions are justified, the two following combinations are the sufficient conditions in order to observe High Knowledge Transfer in NPD projects:

- High use of Coding & Storage AND High use of Global Product Visualization OR
- High use of Coding & Storage & High participation of boundary spanner.

4.2   QCA results for Knowledge Translation

Necessary conditions
The analysis conducted in Tosmana shows that high participation of Boundary Spanner to the project is the only necessary condition to observe a high knowledge translation on projects.
Sufficient conditions
The two following combinations are the sufficient conditions in order to observe High Knowledge Translation in NPD projects:
- High participation of Boundary Spanner and High use of Global Product Visualization
- High participation of Boundary Spanner and High use of Real Time Collaboration

Regarding these two peripheral conditions (Fiss, 2010) in the above projects, the 3D CAD 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 on which negotiations and decisions can then center.

4.3   QCA results for Knowledge Transformation

Necessary conditions
The analysis conducted in Tosmana shows that the high supplier integration is the only necessary condition to observe a good level of knowledge transformation on projects. This result seems normal and quite basic because with sub-contracting or white box configurations, the novelty is limited. In black box configuration, it is necessary to clearly define the product specifications because the supplier manages the technical knowledge, whereas the client has limited technical knowledge. In gray box configuration, it is really a co-design situation that is relatively complex to manage.
Sufficient conditions
The two following combinations are the sufficient conditions in order to observe High Knowledge Transformation in NPD projects:
- High supplier integration and High participation of Boundary Spanner
- High supplier integration and High use of Real Time Collaboration

5   Discussion and conclusion

5.1   Key IT leveraging capabilities to ensure knowledge integration for IONPD

With respect to our research question, we have identified configurations that explain knowledge integration. Depending on the knowledge integration situation (Knowledge Transfer, Translation or Transformation), the impact of PLM sub-systems leveraging capabilities will differ. While OMS, PRMS and CWS all have an effect on dynamic capabilities (Pavlou, El Sawy, 2010), we would expect that they all reinforce learning and thus knowledge integration. Our results clearly show that they do albeit on different facets of knowledge integration. Indeed, four PLM sub-systems have specific effects. The effect on knowledge transfer is mostly dependent on OMS and on two conditions which both emphasize a more global view of the product and project. This result may be dependent on the cross-cultural differences empirically investigated in the case. Results also show that the level of supplier relationships conditions is important to ensure knowledge translation and transformation. The effect on knowledge translation depends mainly on the boundary spanner. The effect on knowledge transformation is especially interesting, as it depends on the nature of supplier integration and thus on the respective actor's role in requirements definition, a problem also well known in IS projects. Knowledge transformation is the only dimension of knowledge integration that may not depend on a PLM sub system when both levels of relationship conditions are met.

5.2 Added value and limitations of QCA methodology

This paper also explicates one of the first applications of QCA, with its simplest version, the dichotomous approach of the crisps sets. With Boolean algebra, this method brings rigor to the explanatory case study, especially when the cases become too numerous, even to the point that it is impossible to control the influence of each potential causal mechanism on each observed configuration. This is all the more important, as the case study method is one of the most frequently used approaches in IS. However, we also had difficulties in implementing the method, because even if we put aside the philosophical problem of sufficient conditions, which is very important, the justification of the « unobserved » configurations requires extensive complementary search, or rests on theoretical justification. In the latter case, this means that the empirical evidence cannot be complete.

Beyond the issue of the unobservables, the identification of the causal mechanisms is a problem in itself. The method is an analysis tool, but it does not infer the mechanism itself. Once this is done by the researcher, the modeling of the causal mechanism is very different if we choose, as we did here, a dichotomous approach with attributes present or absent, or whether we consider its core or peripheral character (Fiss, 2010 ; El Sawy et al., 2010). In particular, it might be interesting to apply it due to the definition of the « storage and coding » variable, first operationalized by a percentage before coding. Even if the current separability of our sample is good when using the dichotomous approach (Fichman, 2004) – i.e., none of the 42 projects is close to 90 % of key projects deliverables stored which is the crossover point chosen – it would be more accurate to use this measure if we were weighing core and peripheral attributes rather than using crisp sets. Thus, there may be some sensitivity to the coding, which is dependent on the type of condition that is considered in the modeling. In this sense, the application of the method reinforces the dialog between theoretical ideas and facts (Ragin, 1994). Despite these limitations, by focusing on exceptions and outliers, in a systematic way, QCA is a very important and promising tool for all those who want to engage in explanatory case studies.

However, Fichman (2004, p.324) explains that "the method works best when the entire universe of cases can be identified." Thus, he recommends focusing "on largest scale phenomenon that are well publicized and have a smaller universe instances." While projects using PLM in international inter-organizational NPD can be numerous, they are easily accessible. Sampling only 42 projects and later finding those that match the simplifying assumptions would have been a nearly impossible task for someone who only knew the phenomenon from the outside, for instance, through interviews. QCA is a method that requires very good empirical knowledge of the phenomenon. While it may not be the preferred research method for young PhD students, it is very appropriate for professionally qualified doctoral students (Klein and Rowe, 2008) or those who can work in an organization while doing their PhD.

QCA is not a magic bullet. The justification we have to perform, due to limited diversity, soon becomes intractable with too numerous conditions and/or cases. It would have been interesting in our study to include other conditions. We have somehow reduced the problem in choosing to study a particular context of NPD: that of international and inter-organizational NPD in a moderately turbulent environment. To make it interesting, we were lucky to have access to enough quality observations (182) in that still under-explored context. To refine the analysis, we would have liked to include other conditions which are more well-known and may play a role in the phenomenon. Despite this main limitation of the approach, we obtained very interesting results. When one wants to take into account many conditions, the statistical approach is the only recourse, but the price is to give up the holistic idea of configurations.

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Appendix 1. Data coding matrix

Concept	Variable	Measure	Dichotomous measure	QCA crisp value
PLM sub systems	Organizational Memory Systems use 1: Coding & Storage	For the minimal 40 BOs, there is a specific place in the project structure which is predefined with a standardized BO content associated for some key BOs. Based on the 42 projects, an average of 90% of BOs respect the common storage rules and BO content on the project.	Limited use of PLM coding and storage: ≤ 85% of BOs are stored in PLM project structure and respect the predefined standard codification	0
			Important use of PLM coding and storage: ≥ 95% of BOs are stored in PLM project structure and respect the predefined standards codification	1
	Organizational Memory Systems use 2: Global Product Visualization	3D CAD viewer is particularly used during the 4 first stages: scoping, build business case, development and testing and validation. During those stages, 3D CAD viewer should be used 2 times a month at a minimum. An average stage is 2 months so 16 times for those 4 stages. The CAD viewer is exceptionally used for the launch phase. PLM 3D CAD viewer should be used 16 times as a minimum during the	* Limited use of 3D CAD viewer: ≤ 15 times during the project and * limited use of visual representation BOs	0
			* Important use of 3D CAD viewer: ≥ 17 times during the project and * important use of visual representation Bos	1
	Project & Resource Management Systems use: Scheduling & Monitoring	The global project dashboard is launched for each stage gate (5 times for global project dashboard). There is an intermediary project meeting called product committee which is organized every month. For this intermediary project meeting, one marketing and product dashboard and one technical dashboard should be generated (10 times for each during the project) A minimum of 25 launches of PLM dashboards should be generated during the project.	* Limited use of project monitoring: ≤ 23 dashboards launches during the project and * limited use of detailed planning functionalities	0
			* Important use of project monitoring: ≥ 27 dashboards launches during the project and * Important use of detailed planning functionalities	1
	Cooperative Work Systems use: Real Time Collaboration	Web conferences should be used every month at a minimum on the four first stage gates: scoping, build business case, development and testing and validation (8 times) and then exceptionally on the last launch phase.	Limited use of PLM web conferencing solution: < 8 times during the project (average of 1 time a month during the 4 first stage gates) Limited use of 3D viewer with the web conferencing solution	0
			Important use of PLM web conferencing solution: > 8 times during the project Important use of 3D viewer with the web conferencing solution	1
Type of relationships in inter organizational NPD project	Level of supplier integration	Important prescriptions from client for the new product design: * Make to print configuration: huge design prescriptions from client * White box configuration : important design prescriptions from client	Limited supplier integration: Make to print configuration and White box configuration	0
			Important supplier integration: Black box configuration and Gray box configuration	1
	Level of Boundary Spanners participation	The Chinese outsourcing engineer has an average of 5 projects to manage in the same time so he spends an average of 20% of its workload on one project. The real time spent on each project is declared every month by the outsourcing engineer.	Limited participation of Boundary Spanners: ≤ 19% of its workload of Chinese outsourcing engineer time dedicated on the project	0
			Important participation of Boundary Spanners: ≥ 21% of its workload of Chinese outsourcing engineer time dedicated on the project	1
Knowledge Transfer	Boundary Objects exchanged between client and supplier	The average number of BOs on a project is 60 which correspond to the 40 minimal required BOs and an average of 20 other BOs which are exchanged in order to precise or validate a specific need or an ask for complementary information.	* Limited knowledge transfer: ≤ 57 exchanged BOs and * limited iterations on mediating BOs	0
			* Important knowledge transfer: ≥ 63 exchanged BOs and * numerous iterations on mediating BOs	1
Knowledge Translation	Misunderstandings between customer and supplier	The average number of glitches during the project is 10.	Limited knowledge translation: ≥ 11 situations of glitches	0
			Important knowledge translation: ≤ 9 situations of glitches	1
Knowledge Transformation	Situations resulting in construction of new product solution	The average number of complex problem solving situations on projects is 3.	Limited knowledge transformation: ≤ 2 complex problem solving situations during the project	0
			Important knowledge transformation: ≥ 4 complex problem solving situations during the project	1