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DESIGN OF PRODUCT DEVELOPMENT PROCESS: A MULTIPLE CASE STUDY OF MEDIUM-SIZED ENTERPRISES

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1. Introduction

In the 1980s, innovation was considered to be a success factor for firms [Silber 1981]. Nowadays on saturated markets it became "a condition of survival" [Benghozi 2000]. On one hand, firms need to develop new high technological products at a fast pace. On the other hand, they need to improve the success rate of their new product launches. A key in such improvements is to work on their Product Development Processes (PDPs) [Anthony and McKay 1992].
In 1982 a study revealed that firms working with a formal PDP performed better than the other firms [Booz et al. 1982]. At the same time, the slowness and rigidity of the traditional Phased Project Planning were pointed out [Takeuchi and Nonaka 1986], calling for a new organization of product developments. During the following decades, many authors proposed development rules such as eliminating the delays associated with synchronization and queuing [Smith and Reinersten 1992], structuring documentation in a way that make it useful for its authors [Parnas and Clements 1986] and structuring development processes. Many development processes can be found in the literature nowadays, for example Spiral software development [Boehm 1988], Stage-gate product development [Cooper 1990], or Engineering design systematic approach [Pahl et al. 2007]. Since formalized PDP had flourished, Unger and Eppinger analyzed the diversity of existing PDPs [Unger and Eppinger 2009]. The authors categorize PDPs according to the number and flexibility of iterations (i.e. loops in the process) and reviews (i.e. control and decision points). Unger and Eppinger then proposed to analyze project risks and to design the PDP accordingly [Unger and Eppinger 2011].
When implementing a development process stemmed from the literature, a company should adapt it to fit its own organization [Högman and Johannesson 2013]. However existing studies seldom address small and medium-sized enterprises (SMEs) [McAdam et al. 2004], [Šenk et al. 2010] despite the fact they represent unique organizational constraints (limited financial and human resources [Bruce et al. 1999], lack of managing skills [Roy and Potter 1990], low formalization and intensive decisional centralization [Nicolescu 2009]). The aim of this paper is to analyze how the product development process and its formalized representation stemmed from the literature are appropriate for medium-sized firms. Before attempting to improve existing PDPs, the difficulties met by these enterprises in PDP management and the factors which shaped their process over the years should be identified. This paper does not provide a new product development process but contributes to improve the implementation of such process in SMEs.
This article starts with a review of the product development process literature. Then, it describes the qualitative research method adopted based on cross-case analysis. Next, the PDPs of three cases are explored according to the Stage-Gate process proposed by Cooper [1990, 2008]. For each case, we have analyzed (1) the differences between the recommendations stemmed from literature and the formalized process implemented in the company studied and (2) the difficulties met by the firm to

respect its process. The results are susceptible to be generalized and could contribute to the improvement the PDPs of other firms in regards of their specific needs and constraints.

2. Theoretical background

Among enterprises, PDPs vary greatly but they are all composed of the same elements: stages (where the work is done) and formal reviews (where the work is controlled and collegial decisions are made). The variables are the number of reviews in the development process and the number of times the process iterate (over one or several stages). Unger and Eppinger categorized PDPs by measuring on one hand the frequency, breadth and degree of planning of iterations, and on the other hand the frequency and flexibility of reviews [Unger and Eppinger 2009]. They identified four categories of PDPs: staged processes (also called waterfall processes), spiral processes and two kinds of hybrid processes [Unger and Eppinger 2011]. The relationship between the metrics and the categories is represented on Figure 1.

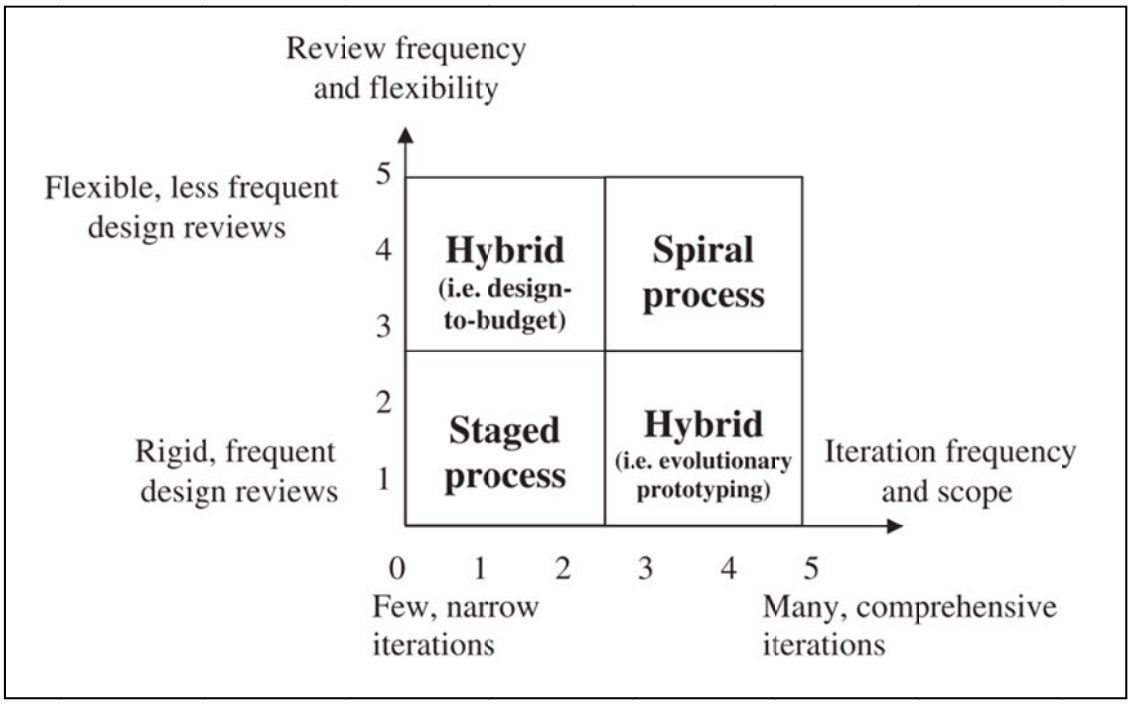

Figure 1. PDP categories based on review and iteration characteristics [Unger and Eppinger 2011]

2.1 Staged processes

One of the main staged processes is the *Stage-Gate Idea-to-Launch* process [Cooper 1990].
In Stage-Gate, every stage ends with a review called a gate. The gates are rigid: the deliverables to produce for a gate and the decisions one can take at a gate are defined in the process description. Also, gates cannot be skipped. They are meant to ease critical project management decision: they make consolidated data available and are opportunities to involve external referents and experts.
At each gate the development can either continue, stop, go back to the beginning of the stage (narrow iteration) or go back to a previous stage (comprehensive iteration). Cooper explained that Stage-Gate is not linear and that iterations are part of the process [Cooper 2008], but Stage-Gate do not plan iterations: it only allows them. Moreover, gates ease narrow iterations because the consolidated data can be used as a basis for a new start, but the drawback is that going back to a previous phase means destroying this basis. Comprehensive iterations are usually perceived as increases in the project cost and as challenging the competence of the managers and experts who had validated the previous gates.

A weakness of staged processes is that they do not encourage integrating information from the later phases and feedback from the customers. Thus despite being introduced as a tool to manage marketing risk [Cooper 1990], Stage-Gate is better suited to managing technical risk [Unger and Eppinger 2009]. Another weakness is the batch & queue logic of the gates, the slowest task ends constraining the length of the stage [Smith and Reinersten 1992].

2.2 Spiral processes

Spiral processes are built upon the principle that large iterations can reduce the project length and cost by integrating data from all the stages. Several large-scale iterations are planned from the start: the development goes through several stages, is followed by tests (if possible with the user), then iterates [Boehm 1988], [Schwaber 1997]. These processes also follow Gilb and Finzi's "learn-before-your-budget-is-used-up" principle [Gilb and Finzi 1988] by moving through the different stages faster with the full expectation to return to them later [Unger and Eppinger 2009].
After each loop, there is a gate where the risks are evaluated and the objectives of the next loop are defined. Spiral processes are similar to agile methods but produce more documentation, and each loop does not necessarily produce functional parts [Qumer and Henderson-Sellers 2008]. However the ability to prototype and test products is a prerequisite for implementing a spiral process [Unger and Eppinger 2009].
Thanks to the strong emphasis they put marketing risks, spiral PDPs showed good results on complex projects with unclear or changing specifications [Unger and Eppinger 2011]. Moreover, unlike staged processes, they allow effective parallel work.
Unger and Eppinger pointed out two weaknesses of the spiral processes: first, the intense and quick iterations are heavy to manage; second, working with flexible specification can lengthen the development of complex subsystems [Unger and Eppinger 2009].

2.3 Hybrid processes

In their PDP categorization, Unger and Eppinger distinguish two kinds of hybrid processes and give an example for each one. Design-to-budget processes begin like staged processes but iterate over the detailed design and testing stages until a budget limit is reached. The iterations are narrow, and the gate between detailed design and testing is loosened. These processes aim to balance between the project cost and the product cost.
Evolutionary prototyping processes focuses on using early prototypes to refine the initial specifications. A large iteration is planned, but once the specifications are clear evolutionary prototyping is similar to a staged process.

3. Methodology

The main question of this paper is "How the process and representation stemmed from the literature are appropriate for medium-sized firms" A case study approach has therefore been chosen as it is the most appropriate method of investigating a how question [Yin 2009].
The case studies were conducted in three SMEs, with the help of three interns (one per enterprise) during 5 months. The process of each firm was described by its R&D manager. This description was then confronted to the documentation available in each firm. The interns completed the process description by using direct observation of the development processes. The three final descriptions and the cross-analysis were validated during a workshop with the three interns, the three R&D managers and the researchers. The diversity of sources to collect data enables the triangulation approach advocated suggested by Yin [2009] in qualitative research.

3.1 Case description

The three studied firms are considered as medium-sized – employing between 250 and 1 000 people. Their R&D departments are composed of 25 to 100 members. A common factor is the fact that they cannot afford to separate Research and Development in two distinct departments. Thus the same people are maintaining the existing products and developing the new ones.

Projects are assigned to project leaders. The number of project to be managed at the same time by a single project leader varies from 5 to 36 projects according to the firms and the scope of the projects. Projects leaders drive project teams, usually composed of 2 to 6 members.
Firm-A designs, produces and installs manufacturing equipment (B-to-B). There is a single development and production site. The production consists essentially in assembling supplied components.
There is a department responsible for the configuration and installation of the equipment. This department is a prescriber for the R&D department. The number of external clients is limited, with 4 customers representing 80% of the sales.
The products are sold with a life span of ten years. Firm-A is still maintaining products that are 30 years old. For this reason the update and maintenance of existing products represent about half of the hours spent in R&D. The other half of R&D time is equally divided between development pulled by the marketing department and development pushed by the R&D department.
Firm-B designs, manufactures and installs large transportation systems (B-to-B). All the components are supplied, most of them to subsidiary enterprises. Firm-B possesses a production site for pre-assembling modules and reducing the assembly time on the system's construction site.
As in Firm-A, a dedicated department configures and installs the systems: this department is a prescriber for the R&D department. A difference with Firm-A is that the customers of Firm-B are not end-users but service providers.
The systems are sold to work ten years, but this duration can be extended and the average age of existing systems is twenty years. Firm-B offers a support to customers through maintenance kits and expertise. This expertise service represents fifteen percent of the R&D department workload. Recently Firm-B created a dedicated cell to tame the disruptive aspect of this service (direct contact with customer being always of high priority). Most of the developments follow a design-to-order logic because the systems are sold with a high degree of customization. Firm-B does not have a marketing department: innovative developments can be pulled by the management (i.e. strategic projects), pulled by a customer or pushed by the R&D department. Project pulled by the management are usually large-scope project and can last a few years due to their complexity. Projects pulled by customers are always technically feasible and last one or two years, with strong deadlines. Projects pushed by the R&D department progress slowly, up to five years, and give uncertain results.
Firm-C designs and manufactures sport equipment (B-to-C). The firm possesses a single R&D center and several production sites.
The R&D department is split in technical units (metallic, textile, mechatronic, etc.), plus a packaging unit. Development project usually belong to a single technical unit. The marketing department is stronger than in the two other firms: first, most developments are pulled by the marketing (some product updates concern aesthetics only); second, the marketing department have strong decisional power and can terminate development pushed by the R&D department.
Firm C can also respond to specific orders, in a design-to-order logic, through a dedicated cell but this kind of project is anecdotic. All the others development projects are time-driven by exhibitions: two per year (for the summer and winter seasons).

3.2 Data analysis

The theoretical processes collected in the three firms were all depicted as linear processes with little explicit iterations. But the level of the detail changed from a firm to another, according more or less flexibility. The PDPs were categorized, according to Unger and Eppinger's metrics, in Figure 2.
Firm-A's process is based on an extensive list of the deliverables a project team may have to produce. In this list, the documents are grouped by stages. Project leaders use this list as a guideline, and define what the documents to produce for each gate are: some are mandatory, many are optional. It is a formal process that allows skipping documents and reviews accordingly to the needs of the project. Also the firm can "take its time" and is not afraid of iterations because its developments are not time driven by exhibitions or contracts: new product developments on affair are uncommon. This process belongs to the staged processes category.

Firm-B's process was poorly described in the firm's documentation. Structuring documentation exists, like in Firm-A, but is lighter. Moreover some gates can be skipped or postponed according to the technical risk. For example simulation controls are often conduced after the production of the final product because the technical risk is low. Most development being constrained by contractual deadlines, the number of iterations in the process is low. A consequence is that customized components are usually oversized to reduce the technical risk further. Thus, this process is close to the limit between staged processes and design-to-budget processes.
Firm-C's process is the more formalized and rigid of the three case studies. Short interval management is used: there is at least one non-optional review per week. The use of prototypes is encouraged even for complex mechatronics products. In this respect, prototyping facilities have been installed in the R&D building. Since the projects are time-driven by exhibitions, and since one to three weeks are necessary to obtain a prototype, the number of iterations is limited. This process is close to the limit between staged processes and evolutionary prototyping.

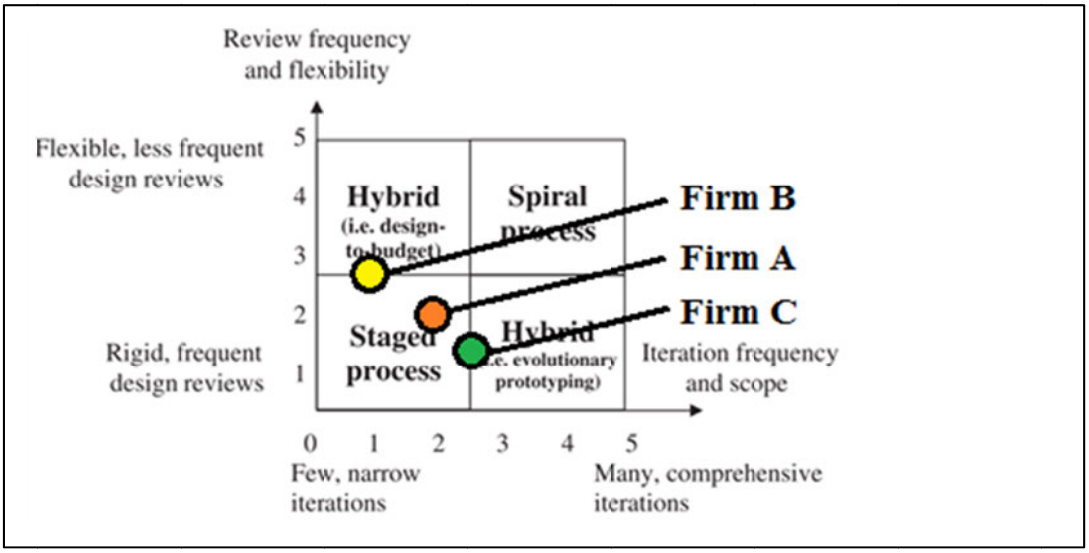

Figure 2. Categorization of the studied PDPs

Since the three PDPs belong or are close to the staged-process category, we used the Stage-Gate process as a comparison basis. Stage-Gate is composed of 5 stages and 5 gates. Through the successive stages, ideas are brought to maturity, enabling more precise evaluations at each gate. The classical representation of this process (Figure 3 [Cooper 1990]), does not make iterations visible but theoretically each gate can lead to any of the previous stages – its author explained that it might have been unfortunate for the good comprehension of the process [Cooper 2008].

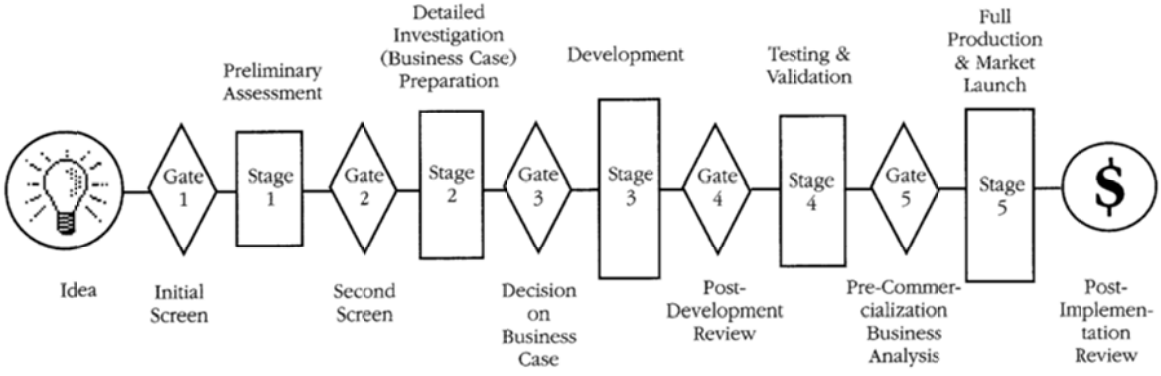

Figure 3. Overview of the (full) Stage-Gate process [Cooper 1990, 2008]

4. Results

The processes of the three firms are composed of the same stages than Stage-Gate so they could easily be represented on the same diagram (Figure 4). The rectangles on Figure 4 represent the decisional milestones.

Firm-A's new product development projects have a horizon of two or three years.

Projects pulled by the marketing department starts with the conjoint validation of the expression of the need by the firm's director, the marketing department and the R&D department. During this validation, a budget is allocated to the preliminary assessment stage of the project. Technic push projects do not go through this validation: they are directly financed by the R&D department. But since these projects are usually technological development, and not product development, we will not explore their specificities in further detail.

The objective of the preliminary assessment stage is to produce detailed functional specification that will satisfy the need expressed by the marketing, to identify necessary investments, to estimate the cost of the development project, the target cost of the product and the expected margin. These elements compose the project monitoring document. The project then follows the Stage-Gate process, the project monitoring document is revalidated at each gate.

Soon after the development stage, a first functional prototype is produced because simulations tools are not enough to validate the complex behavior of Firm-A's products. This pre-commercialization analysis gate is fuzzy, and most of the time if the prototype is validated then the product can be commercialized. This is because the prototype is not only fully functional, but was also produced through the same process than the future series (manufacturing prototype).

The pre-series validation is done in a real industrial environment: the production site of a customer.

The post-launch review is a very light review where the budget and the remaining work are assessed, but there is no lessons-learned insight.

Firm-B's new product development can span from two to five years.

Every new project is defined by a simple design brief and a project budget. The validation of the brief and the budget (initial screening) is done by the firm's directory board. Most of the information exchanged during the board is not transmitted to the development actors.

Projects are first entitled to a project leader who must convert the design brief into a project charter. A project charter is a document stating the project objectives, the project budget, the project scope (impact on existing products), the deliverables and their respective deadlines, and the people that will constitute the project team (namely, or by function). This project charter is validated by the R&D director with the advice of the R&D planning manager.

There is no clear distinction made between detailed investigation and product development (it varies from a project leader to the other: the specifications can be validated when most of the components geometries have already been drawn if the R&D director does not impose a design review).

The validation of the components is not exhaustive because manufacturing prototypes are too expensive: usually a first version of the product is sold, but still requires an optimization and tweaking phase. The R&D department tries to limit the number of such sales – as they know free of charges upgrades are obligatory – but the commercial department is powerful, and sometimes "too enthusiastic". An early commercialization decision can unexpectedly shorten the development schedule. Eventually, the R&D department will not have enough time to optimize the product before its complete commercialization.

Firm-C's new product developments take place in two years cycles. If a project is late and miss the deadline for an exhibition it can be extended for a third year.

The projects arrive to R&D from the marketing department as functional analyzes. Most projects (60%) are well defined as they are renewal of existing products. When a project begins, the project leader must propose technical requirements that will comply with the marketing's analyze. If the marketing department accepts these technical requirements, a project contract defining the cost, quality and delivery time is signed by both parties. The project leader is then entitled to a development team.

Some project can be pushed by the R&D department. All the members of R&D are allowed to use 10% of their time on innovation, and some of them develop their own concept products. They then have to convince the marketing department to add these new products to the strategic plan of the firm.
The following process resembles Stage-Gate, with two more gates. The "pricing green light" is used to allow the presentation of a product at the exhibition. It must be validated one month before the exhibition. The "delivery green light" is the commercialization authorization, delivered if the ramp-up is going well.
As in Firm-A, the project closure is a very light review.

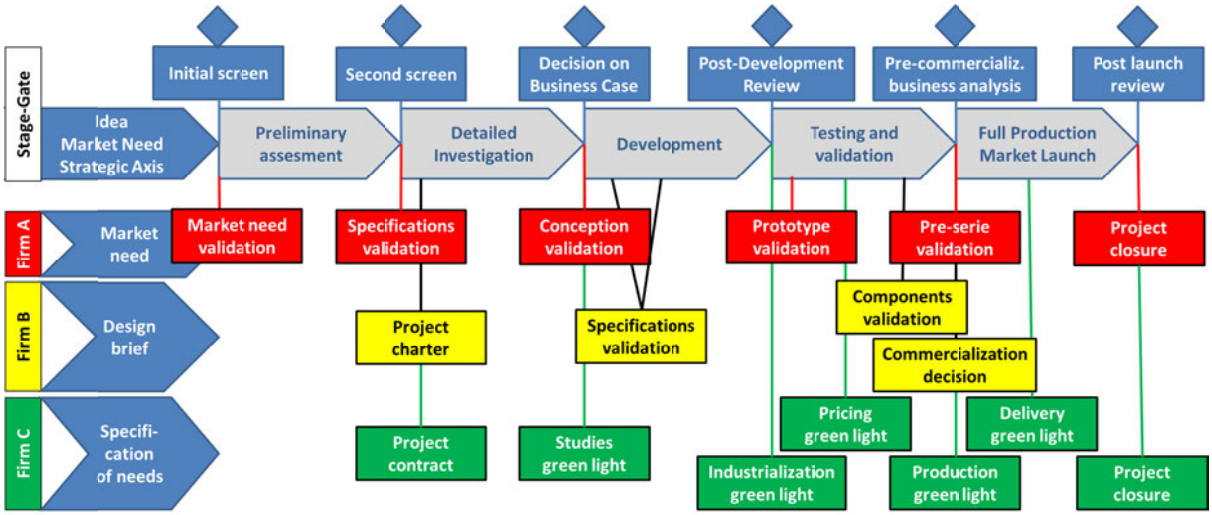

Figure 4. Cross-analysis of the three PDPs with Stage-Gate as reference

In Firm-B and Firm-C, the initial screen is assimilated to the budget allocation at the beginning of the fiscal year. This was not represented on the diagram because, for the firms, it does not belong to the project but to an annual routine. In these two firms, the Preliminary Assessment is not identified clearly as a stage: it is assimilated to the beginning of the Detailed Investigation. In Firm-B, there are usually two months between the design brief and the project charter, but only a few days of effective work. In Firm-C, the project contract is often late: it is signed when the development is already in progress.
Unger and Eppinger observed that PDPs were not the result of a rational process but were rather influenced by organizational shifts, leading individuals trying to address specific problems, and consultants providing "by the book" processes [Unger and Eppinger 2009]. It was indeed the case for Firm-A and Firm-B, but the PDP of Firm-C is the result of a standardization effort.

5. Discussion

When we try to interptrete our results in the light of exisiting literature, three different recommendations catch our attention:

- Adopt a high level process and allow flexibility [Tatikonda and Rosenthal 2000].
  Firm-B works with such a high level process, but the enterprise is facing several inconveniences: projects are unnecessarily long due to poor coordination between the different actors. Firm-B handles many design-to-order projects, thus the reduction of the lead time is at the center of the firm's strategy and the PDP will have to evolve to ease effective parallel work and stage overlapping.
- Adapt your PDP to fit the organization and risk profile of your enterprise [Högman and Johannesson 2013], [Unger and Eppinger 2011].
  This is the logic Firm-C followed when it developed its standard process. Firm-C's PDP gives satisfying results on projects pulled by the marketing – i.e. the majority of the project in Firm-C's case. But when new functionalities are required or when the project is pushed by the R&D

department, the process becomes heavy, bureaucratic and uneasy to follow: it is hindering the development of breakthrough innovations.

- Adopt a project-specific approach to project management [Shenhar 2001].
  Firm-A tries to adapt its process to each project but the structure of the process is always the same: a staged process with a strong emphasis on project cost and product cost. Firm A has formalized deliverables for each project but they are not enough to allow an efficient scheduling. The variability from a project to another hinders the project portfolio management.

Our case studies suggest that enterprises should be able to deploy different PDPs accordingly to the specificities of their projects. They suggest also that adapting a process to a project is a difficult task, requiring a certain process expertise and strong managing skills. Designing the PDP at the beginning of each project sounds like an unrealistic option: the amount of work would be considerable, each project would be delayed, and the variability from a process to another may cause collateral difficulties as witnessed in Firm-A. Shenhar suggested to work with a project typology, and proposed to categorize projects according to their technological uncertainty and product complexity [Shenhar 2001].

6. Conclusion and future research

The development process stemmed from the literature is appropriate for the studied SMEs, but its formalized representation is not fostering flexibility and can hinder the development of breakthrough innovations.

The exploratory nature of the research opens up several avenues for future research.

First, we suggest developing three-dimensional models to categorize projects and processes according to marketing risk, technical risk and product complexity.

Secondly, working with a project typology on one hand, and a process typology on the other, sounds like an interesting option. But then, whose role is it to analyze a project and to select the corresponding process? This new process-choosing task could be assumed by project leaders, but in Firm-A and Firm-B project leaders are essentially technical experts and lack managing skills. We suggest investigating the cost and benefits of a employing a process expert in charge of analyzing new projects, selecting adapted PDP, and refining the process typology in light of past projects. The centralization on a single person could be an opportunity for SMEs because they usually have a single R&D center, and because the number of projects they handle could be compatible with the amount of work necessary to adapt processes to projects.

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