Managing the fuzzy front-end: insights from process firms

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Abstract

Purpose – The aim of this paper is to inform researchers and practitioners about the fuzzy front-end (FFE) of the innovation process in process firms.

Design/methodology/approach – A multiple case study of four process firms was conducted, with a total of 64 semi-structured interviews.

Findings – The paper gives new insights into the FFE in non-assembled product and process development in process firms. The FFE of non-assembled product and process development is first conceptualized and key activities are identified. Further, how the strong relationship between product and process development can be managed in the FFE is discussed.

Research limitations/implications – All four firms are from the mineral and metals industry, prompting caution when generalizing the results to other contexts. This research offers insights about the FFE in process firms. Theoretical implications are added to the existing literature on the FFE and general process development literature, and the paper increases our understanding of innovation management in general.

Practical implications – From a practical point of view, the paper gives advice on how managers in process firms can increase speed and clarity in the FFE. The conceptualizations and the identified front-end key activities are suggested as checklists for improving the FFE stage.

Originality/value – This study compares how the FFE within two different types of innovations is conceptualized and managed. Thus, the FFE in non-assembled product and process development is explored. The FFE of process development is an unexplored context.

Keywords Product development, Innovation, Fuzzy control, Materials management

Paper type Case study

1. Introduction

The importance of innovation is clear – either firms take advantage of new opportunities or they are replaced by other firms that do (Cooper and Kleinschmidt, 1987; Utterback, 1994) – but the critical challenge is how to achieve innovation. In the past decade, the fuzzy front-end (FFE) of innovation has been given increased attention (Björk and Magnusson, 2009; Chang *et al.*, 2007; Seidel, 2007), because the foundation of successful innovation is found in the FFE stage (Cooper and Kleinschmidt, 1987; Koen *et al.*, 2001). The FFE starts when a firm has a new idea that is shared in a social structure, as opposed to residing within the head of an individual (Khurana and Rosenthal, 1998), and ends when the firm makes a decision to either launch a formal development project or, alternatively, decides not to do so (Kim and Wilemon, 2002).

The FFE is recognized as the most difficult stage to manage in the innovation process (Kim and Wilemon, 2002), as it involves a significant degree of uncertainty and equivocality (Chang *et al.*, 2007). In addition, the FFE is often characterized by *ad hoc* decision making and conflicting organizational pressures (Khurana and Rosenthal, 1998; Montoya-Weiss and O'Driscoll, 2000). For example, the FFE is difficult to plan

and conduct as there are several sources of uncertainty and many ideas arise outside the formal systems (Griffith-Hemans and Grover, 2006). The potential market and the underlying technology are the two main sources of uncertainty in the FFE (Montoya-Weiss and O'Driscoll, 2000; Verworn, 2006).

The FFE of product development has been conceptualized several times in the literature (Cooper, 2008; Griffith-Hemans and Grover, 2006; Koen *et al.*, 2001) and key activities have been identified therein as well (Khurana and Rosenthal, 1998; Kim and Wilemon, 2002). Some studies focus on one specific activity in the FFE, e.g. ideation (Björk and Magnusson, 2009; Griffith-Hemans and Grover, 2006), screening of ideas (Khurana and Rosenthal, 1998), and the creation of a product concept (Seidel, 2007), while others take a broader perspective and explore the whole FFE and identify general success factors at the front-end (Koen *et al.*, 2002; Kim and Wilemon, 2002). However, the FFE literature is criticized for presenting one generic front-end for various kinds of innovation types, in whatever industry (Nobelius and Trygg, 2002). Since many of the early research endeavours do not take into account factors such as innovation type, degree of newness and industry, it is difficult for firms to actually apply this research to their specific innovation process.

Most of the existing research on the FFE of the innovation process has focused on assembled product development (Khurana and Rosenthal, 1998; Seidel, 2007; Verganti, 1997). Assembled products are put together by several different components, which constitute the end product (Utterback, 1994). Non-assembled products, on the other hand, are composed by only one or a few materials and they are typically used as input in somebody else's production (Barnett and Clark, 1996). Textiles, chemicals, minerals, metals and food are examples of non-assembled products. Firms producing non-assembled products are commonly referred to as process firms.

Process firms are suppliers of input materials to a variety of different manufacturing industries, for example, the automotive industry, the construction industry, the consumer food industry, etc. Steel, for example, is an important metal, which has become a cornerstone in every home, household and in the entire society (SGU, 2008). Process firms have historically been important in building up the prosperity and civilization of today's society. Still, process firms have received modest attention in the innovation management literature compared to other manufacturing industries (Barnett and Clark, 1996; Lager, 2002; Lager *et al.*, 2010; Pisano, 1997). It is of great importance for the prosperity and civilization in the whole society to increase the knowledge of how process firms can improve their innovation processes.

In process firms and several of the traditional manufacturing firms, process development is the key innovation type, rather than product development (Utterback and Arbernathy, 1975; Hucheson *et al.*, 1995). Compared to product development, process development has received limited attention in the innovation management literature (Reichstein and Salter, 2006). However, process development is important for building long-term competitive advantages in manufacturing firms (Pisano, 1997).

This paper explores the FFE in non-assembled product and process development. It is motivated by the narrow focus on product development in the FFE literature, which fails to account for the intricacies of the innovation process as it applies to other innovation types (e.g. processes, non-assembled products and services), and by the difficulty that firms have in applying the existing research to their specific innovation process. Limited attention has been paid to the FFE of non-assembled products

(Bröring *et al.*, 2006; Elmquist and Segrestin, 2007) and more research is needed to understand the FFE in this context. No studies have addressed the FFE of process development, but a few studies have found that the FFE of process development is important for the overall success of the innovation project (Lim *et al.*, 2006; Pisano, 1997). The aim of this paper is to inform researchers and practitioners about the FFE of the innovation process in process firms. Specifically, the research questions are the following:

- RQ1.* How is the FFE of the innovation process conceptualized in process firms?
- RQ2.* What are the differences and similarities in terms of key activities in the FFE of product and process development?
- RQ3.* How is the relationship between product and process development managed in the FFE of the innovation process?

The rest of the paper is organized as follows. Since the FFE in process development has hardly been studied in the extant literature, the theoretical background in Section 2 is based on the literature about the FFE of the innovation process (mostly referring to assembled products) and general literature on process development (primarily conducted within process firms). In Section 3, the method is presented. The empirical findings based on the multiple case studies are presented in Section 4 of the paper, and finally, a discussion of theoretical and managerial implications is given as well as suggestions for future research.

2. Theoretical background

Technical innovations can basically be divided into product development (products can be either physical or in the form of services) and process development (Utterback, 1994; Reichstein and Salter, 2006). These two innovation types have different focuses and objectives, and they work according to different logics. For example, while product development is driven by the desire to create a new product, process development relates primarily to internal production objectives, such as cost reductions, enhancement of production volumes or sustaining more environment-friendly production (Lager, 2002; Pisano, 1997). Thus, the market for process development is internal to the firm, whereas the market for product development is external to the firm.

The stage-gate model is by far one of the most applied models for managing the innovation process (Cooper, 2008). Cooper's model consists of a series of stages including a number of activities ranging from idea to launch, which are complemented by gates where go/kill decisions are made on whether the firm should invest further in the project or not. The model describes the product development process, beginning with an ideation stage called discovery and ending with product launch (Figure 1). The front-end in product development involves all the activities, which preceded subsequent formal development efforts, and thus the stages of idea screening, scoping and building a business case. This is a common way to conceptualize the FFE in product development, although several different conceptualizations of the FFE exist in the literature (Griffith-Hemans and Grover, 2006; Khurana and Rosenthal, 1998; Koen *et al.*, 2001).

Several scholars picture the FFE in product development as a sequential process, consisting of several sub-phases with iterations among and within them (Cooper, 2008; Griffith-Hemans and Grover, 2006; Khurana and Rosenthal, 1998). For example, if an

Figure 1.
A typical stage-gate
process

Source: Cooper (2008)

idea is rejected at the first gate, it can be refined and given a second chance. Khurana and Rosenthal (1998) have divided the FFE into three sub-phases: pre-phase zero, phase zero and phase one in their model. In a similar vein, Griffith-Hemans and Grover (2006) divide the FFE into idea creation, idea concretization and idea commitment. Their conceptualization is done on the individual level and highlights informal activities. In the idea creation phase, an employee comes up with a product idea. Facets of the potential new product are specified in the following phase, idea concretization, for the purpose of convincing the stakeholders. Then in the idea commitment phase, resources are committed to the concretized product idea and the organization formally accepts it.

Koen *et al.* (2001) describe the FFE as a five-part circle, instead of a sequential process. The elements are opportunity identification, opportunity analysis, idea genesis, idea selection and concept and technology development. Ideas are expected to flow and iterate among the five elements in the model. All these previous conceptualizations are based on assembled products, however, which raises the question whether they are applicable to the FFE of non-assembled products as well.

Compared to the product development literature, few attempts have been made in the process development literature to conceptualize the FFE. In this literature, the FFE is pointed out as one of the most critical stages for achieving successful process development (Lim *et al.*, 2006; Pisano, 1997). The FFE in process development can be defined as the activities conducted before a new process concept is implemented into the production process (Lager, 2002; Pisano, 1997). It seems logical to assume that the FFE is conceptualized differently, since the objectives and activities differ in product and process development. However, as no conceptualizations of the FFE in process development have been made in the existing literature, the *RQ1* addresses this knowledge gap.

2.1 Key activities in the front-end of the innovation process

One of the first activities generally undertaken in the FFE is preliminary opportunity identification (Khurana and Rosenthal, 1998; Kim and Wilemon, 2002). For example, one individual identifies flaws or gaps in the current state of thinking. The sources of

new innovative products or processes can be either inside or outside the boundaries of the firm. Idea generation is not always done explicitly, but when the idea is shared in a social structure (Khurana and Rosenthal, 1998) it becomes explicit. The next step is typically to refine the idea (Griffith-Hemans and Grover, 2006); the idea is further considered, specified and screened. Screening typically takes place in two dimensions: business analysis and feasibility analysis (Khurana and Rosenthal, 1998). First, an idea is evaluated in terms of its viability as a business proposition. Then, the feasibility of the product idea is determined. Product ideas can be screened and evaluated accordingly, if the firm has the required technological and knowledge resources.

Preliminary market and technology analysis constitute another set of key activities in the FFE (Khurana and Rosenthal, 1998). Information is gathered about the feasibility of the idea in terms of market and technology assessment. Customer needs, target market and definition of market requirements are examples of information collected (Cooper and Kleinschmidt, 1987; Montoya-Weiss and O'Driscoll, 2000). Other information includes identifying the technical solution required to develop the product, as well as an estimation of related costs (Cooper and Kleinschmidt, 1987; Verworn, 2006). Moreover, the proposed product requires evaluation against the existing business plans and products within the firm's product and portfolio strategy (Khurana and Rosenthal, 1998). The idea should further be evaluated against the competitive situation, with competitors' prospective and current product offerings, and environmental scanning and analysis should be conducted.

The next step is typically to create a product definition. This includes a product concept, information about target markets, customer needs, product specifications and product positioning and requirements (Cooper and Kleinschmidt, 1987). The product concept is a representation of the development goals of the project (Montoya-Weiss and O'Driscoll, 2000; Seidel, 2007), and is one of the most essential parts of the product definition. A well-defined product definition, created early on, will facilitate the important go/kill decision that determines whether the product idea will enter formal development or not (Cooper, 2008).

Finally, project priorities among scope (product functionality), scheduling (time) and resources (costs) are required. Previous research has shown that unclear priorities are a major cause of delays (Murphy and Kumar, 1997). Thus, product definitions are often evaluated by a cross-functional executive committee (Khurana and Rosenthal, 1998).

Owing to the limited amount of previous research on the FFE in process development, most of the key activities in this section are derived from (assembled) product development. Nevertheless, some of these activities are usually also critical when developing new processes and non-assembled products (e.g. preliminary opportunity identification, idea refinement and preliminary technology assessment). It seems reasonable to assume that idea generation and refinement are conducted similarly, regardless of whether products or processes are being developed. Preliminary technology assessment is another key activity that is important to consider in the FFE of process development, i.e. when new technology is introduced into the production process.

In the general process development literature, early key activities include: managing and converting raw materials, identifying internal production needs, pre-testing and transferring development results to full-scale production (Reichstein and Salter, 2006). The importance of FFE activities (e.g. identifying internal production needs and performing pre-testing) has been noted (Lager, 2002; Lim *et al.*, 2006; Pisano, 1997), yet

research on the FFE in process development has not been conducted to the best of our knowledge. The fact that product and process development have different objectives suggests that some key activities in the FFE are product-specific whereas others are process-specific. The *RQ2* addresses the differences and similarities in key activities in the FFE of product and process development.

2.2 The relationship between product and process development in process firms

As stated in the beginning, there is a strong relationship between product and process development in process firms. New products often require new or modified processes, whereas new processes sometime allow concepts that were previously impossible to develop (Barnett and Clark, 1996; Lim *et al.*, 2006). Linton and Walsh (2008) show that for non-assembled products, any change of the manufacturing process results in significant changes of the end product. This makes it important to consider both product and process development simultaneously.

In the process industry, product and process development are often required within the same innovation project. Thus, an activity can span both product and process domains at the same time. The purpose of an activity often determines whether it is classified as a product- or a process-development project (Lager, 2002; Lim *et al.*, 2006). For example, product development in the process industry often entails changes in chemistry and adjustments in process parameters, which together result in a modified or new product (Barnett and Clark, 1996). Hence, it is difficult to separate product development from process development since many projects entail a little of both.

However, it is also a challenge to integrate them, as product and process development have different objectives (i.e. efficiency and effectiveness), key activities and customers (production versus external customers). The *RQ3* explores how the relationship between product and process development is managed in the FFE of the innovation process.

3. Method

A case study approach was selected for several reasons. The iterative and complex nature of the FFE favoured the case study methodology (Chang *et al.*, 2007; Montoya-Weiss and O'Driscoll, 2000; Murphy and Kumar, 1997). Another motive was to ensure methodological fit among the research questions, data collection, data analysis and the status of the current theory (Edmondson and McManus, 2007; Eisenhardt and Graebner, 2007).

A multiple-case study approach is more likely to yield accurate, generalizable theory than a single-case study (Eisenhardt and Graebner, 2007). The cases in the study were selected according to the literature. The cases were expected to replicate each other and extend the emerging theory of the FFE of the innovation process. Each case was treated as an independent analytical unit (Eisenhardt and Graebner, 2007; Yin, 1994).

Four process firms from the mineral and metals industry were selected. Since process development is the primary innovation type in process firms, the process industry was considered an ideal setting for this study (Barnett and Clark, 1996). Although the firms produced different (non-assembled) products, it was assumed that the FFE of the innovation process most likely was managed and organized in a similar way. The four case study firms all had great experience of conducting both product and process development, and good access was given to all firms. See Table I for a summary of the research sites.

Table I.
Research sites

Case study firms	Alpha	Beta	Gamma	Delta
Main business	Metal producer	Supplier of metal powder	International high-tech minerals group	Global producer of several different high-strength steel products
Main application areas/products	The main metals are copper and zinc, but lead, gold and silver are other important metals	A variety of application areas, including sintered components, soft magnetic composites, hot polymer filtration, and surface coating	Produces upgraded iron ore for the steel industry and industrial minerals products for other industries	Application areas are primarily bridges, buildings, ships, various forms of vehicles and lifting devices
Product development	Does not develop products in a traditional way, as the smelters extract and produce predetermined basic metals out of ore. The challenge is to produce a product of consistent quality even though the quality of the input materials varies	Techniques to produce differentiated products include adding coating to the metal powder or mixing the metal powder with different alloys. Thus, product development typically includes small-scale tests, where the aim is to find a metal powder with the optimal properties for the customers' production processes	The product development includes both improving existing products and developing new products with different properties. One typical product development project is to change the properties of the iron ore, thereby customizing the product	Product development includes development of totally new products as well as improvements of existing products. A large part of all product development is customer-driven
Process development	The focus of process development is on continuous improvements of the production process within each plant	The process development is divided into local and global development; incremental process development is conducted locally at the production plants, and process development with higher degree of newness (e.g. decisions on reducing the number of steps in the production plan or to invest in new process equipment) is centralized	The process development primarily focuses on improving the existing process technology, not on implementing radically new process technology into the production process	The process development is mainly conducted at the blast furnaces where the steel slabs are produced. The steel slabs are transported to the production plants to be processed in the rolling mills. Some process development is performed in the production plant as well. Process development includes a range of activities from continuous improvements to investment in more modern process equipment
Approximate number of employees	4,400 employees	1,440 employees	3,700 employees	9,000 employees
Number of interviews	About 14 interviews totally, all focused on process development	About 17 interviews totally, where five focused on process development and 12 on product development	About 17 interviews totally, where eight focused on process development and nine on product development	About 16 interviews totally, where five focused on process development and 12 on product development

3.1 Data collection

Interviews were the primary data collection method, and this is generally the most efficient approach to collect rich empirical data (Eisenhardt and Graebner, 2007). A total of 64 interviews were conducted. A first round of interviews (with one informant for each case) aimed to achieve an overall understanding of general information on innovative activities and identify suitable informants for the subsequent investigation. In the later interviews, more specific questions were asked to address the research purpose explicitly. A total of 32 interviews were conducted with employees primarily developing new products, while 28 interviews were conducted with employees mainly working with process development (See Table I for more information).

The informants were selected from different hierarchical levels to get diverse perspectives of the management of the FFE of the innovation process, and it also mitigated respondent bias (Eisenhardt and Graebner, 2007). Moreover, we selected highly knowledgeable informants who had diverse perspectives concerning the FFE in both product and process development in order to limit bias. A “snowball/chain sampling” approach was used to select the informants, and this approach allowed us to identify the key persons working with product and process development (Miles and Huberman, 1994).

Two semi-structured interview guides were designed. One focused on the FFE in product development while the other concerned the FFE in process development. The interview guides were based on prior research of the FFE, and general literature on product and process development. The interview guides included four sections. Section 1 provided background information of the informant. The Section 2 covered general questions about the firm’s product and process development practices and organization of the development work. The following section focused explicitly on front-end practices, i.e. key activities, roles, responsibilities, problems and opportunities present in the FFE. The final set of questions included the informants’ view of what factors and activities in the FFE were most critical to successful outcomes. A clear research framework was designed and discussed among the research team prior to the data collection process, which strengthened internal validity (Yin, 1994).

To create overlap between data collection and data analysis, frequent discussions and preliminary analysis of emergent findings were shared among the research team. To further increase reliability (transparency and future replication), a case study protocol was constructed containing case study notes, documents, and the narratives collected during the study, all with the aim of facilitating retrieval for future studies (Yin, 1994). The interviews ranged from 30 minutes to 3.5 hours and were conducted over the course of approximately two years, ranging from August 2008 to October 2009. The interviews were tape recorded and transcribed. Informal discussions, observations and group meetings and seminars with R&D managers and engineers were used to complement the interviews. Moreover, secondary data were collected on documented procedures, annual reports and other company information. This permitted empirical triangulation of each firm’s product and process development practices.

3.2 Data analysis

The analysis of the empirical data started with a separate analysis for each case of the FFE in product and process development. A total of seven case study histories were created, based on interviews, field notes, observations, informal discussions and

secondary data. As alpha does not develop products in the traditional way, only its process development was analysed. Several shorter telephone interviews were conducted at this stage to retrieve missing information. The main unit of analysis is the FFE stage in product and process development, whereas the relationship between product and process development, at the firm level, constitutes an embedded unit of analysis. This affected how the empirical data have been structured in the paper. Since the main unit of analysis is the FFE and not the firm level, the empirical findings are displayed according to the research questions which do not take into account differences on the firm level.

All interviews were transferred into a spreadsheet for further analysis. Relevant questions were conceptually clustered together according to one of three general themes, which facilitated the analysis (Miles and Huberman, 1994). The first theme included questions related to the conceptualization of the FFE, the second theme focused on activities done in the FFE and the third theme brought together questions related to the relationship between product and process development in the FFE. This was an effort to establish a clear chain of evidence which would allow the readers to see how the research questions matched with key conclusions (Yin, 1994).

The next step was to compare and contrast the findings for product and process development across the cases studied (Yin, 1994) within each theme. Several times, the empirical findings were evaluated against the theoretical framework. This was important, as the empirical data were collected from another context and the theoretical framework was largely based on assembled product development and to some extent on general process development literature. The analyses thus required repeated reading of the interview files, notes, secondary data and the theoretical framework.

4. Empirical findings and analysis

The empirical findings are displayed according to the research questions. Subsequently, the FFE of the innovation process is conceptualized in Section 4.1. Thereafter front-end key activities are analysed, and in Section 4.3, the relationship between product and process development is explored.

4.1 Conceptualizing the FFE of the innovation process in process firms

All firms had two different sequential project models – one for the overall product development process, and the other for the process development process. The FFE was present in both models, although the models were not applied in each and every case. The case study firms organized the early stages slightly differently, depending on whether a new product or process was being developed (Figures 2 and 3). The figures are based mostly on the informants’ descriptions of what they did in the FFE of product and process development, and the formal project models for the overall processes were used as well.

Figure 2.
The FFE in product
development

The FFE in non-assembled product development was divided into three sub-phases: informal start-up, formal idea-study and formal pre-development study. The typical starting point for the FFE in product development was an idea, which typically came from the customers, or from internal development personnel. In the last sub-phase, a product concept was created and a decision to proceed to formal development or not was made, which marked the end of the FFE. The stage after the FFE was typically formal development, where more tests were done to further develop the product concept and to validate it at larger scale.

The FFE of process development included four sub-phases: informal start-up, formal idea-study, formal pre-study and formal pre-project. Thus, one extra sub-phase constituted the FFE in process development. Similar to the FFE in product development, the starting point was an idea for an improvement in the production process. The ideas typically came from inside the firm and most ideas came from the production department or from other departments nearby, such as the R&D department, product development or the central process development department. Process development mainly has an internal focus; accordingly the ideas typically involved cost reductions and quality problems with existing products. The end of the FFE was called a pre-project. In this final sub-phase, the process concept was specified, and the decision was made on whether the new idea should be implemented or not in the production process. After the FFE in process development, no more tests were done; instead the process concept was implemented.

Several of the informants described the FFE as a trial-and-error process with a number of iterations among the different sub-phases, regardless of whether products or processes were developed. The formal description of the two FFE stages were described as linear processes, but it is important to stress that in some cases, the sub-phases may overlap, run in parallel or be repeated, which is represented by the dotted arrows in both figures. Figures 2 and 3 represent ideal types of the FFE in product and process development. Thus, these figures capture most ideas and events in the FFE in process firms, but not necessarily all of them.

A development engineer at Delta expressed the iterations like this: "It is an iterative process; sometimes you must go back and fix a number of parameters, so all phases are connected, and it is not a linear process". This quotation is not peculiar to Delta; iterations were common in all cases and they were carried out in all sub-phases, especially when preliminary tests were done.

The FFE differed depending on whether products or processes were developed. For example, the nature of the development project typically influenced how the FFE was organized. Because process development is systemic in nature, it affects other sub-processes throughout the firm, not just the intended change in the production process.

Figure 3.
The FFE in process
development

This, combined with the large range of process development projects (process development ranges from incremental adjustments in existing operations to creating or buying totally new process equipment), clearly made it difficult to conduct all process development within the formal project model. Hence, it was difficult to have a generic work process for process development. One of the plant managers at Beta described this:

One deficiency is that we don't have a work process when performing process development projects and we move forward too fast. We are in fact at the prototype stage but it is already implemented in the production process.

Several interviewees from all cases described process development as complex and unsystematic, primarily because of the systemic nature and the diversity in different types of process improvements. When developing new products, the complexity was instead related to technological and market uncertainty.

The degree of newness also affected how the FFE was organized and conducted. For larger improvements in the production process, there was a high degree of formalization in the FFE, due to high capital costs and risks. When conducting large improvements, it was very important to consider every possible aspect in the FFE, so that failures could be avoided early and not when the process change was implemented in the production process. Ideas with a lower degree of newness (incremental process development projects) were accordingly often conducted informally, outside the formal project model. The same pattern was found in the FFE of product development as well.

4.2 Front-end key activities in the FFE of the innovation process

The front-end key activities were divided into general activities (i.e. conducted in both of the FFE stages) and specific activities, which were carried out when either products or processes were developed. Table II gives an overview of the different key activities in the FFE of the innovation process.

Idea generation was a general key activity. In product development, customers were the most important source for new product ideas, and other sources were the R&D or marketing departments. Ideas for process changes came from a variety of internal sources. Ideas were mostly informally created. Although formal systems existed to capture ideas from employees, they were seldom used.

Once an idea was generated, it was typically explored further by one person or a small team. The idea was first discussed with colleagues, and then senior researchers

Table II.
Key activities in the FFE
of the innovation process
within process firms

General key activities in the FFE of the innovation process	Specific key activities in the FFE of the innovation process
Idea generation	Primary product specific key activities
Idea refinement	<i>Anticipation of customers' process requirements</i>
Literature review	Identification of a process window
Analysis of input materials	Customer involvement
Preliminary test at small scale (bench scale, laboratory test, etc.)	Primary process specific key activities
Pilot plan tests	<i>Anticipation of end-product changes</i>
Full-scale tests	Risk analysis
Creation of a product/process concept	Construction/modification of process equipment
Creating a project plan and a budget	

helped to refine the idea. These activities normally took place outside the formal project model. Informal discussions were important in order to further refine the ideas throughout the whole FFE. As ideas often were fuzzy, unclear and containing multiple loose ends, idea refinement at the beginning of the FFE was an important key activity for developing both new products and processes.

The next general key activity was to conduct a literature review. The aim was to map the existing knowledge of that particular area and to reduce uncertainty. The literature review usually kicked off the next sub-phase, the formal idea-study. The results of the literature review were discussed with colleagues and senior researchers, and the results were evaluated once again before conducting empirical tests. This sub-phase is more theoretical than empirical, as most of the knowledge was acquired by exploring existing theoretical knowledge in the literature.

The literature review was typically followed by more empirically grounded work, such as analysis of input materials and preliminary tests. This was especially critical if new materials were suggested in product development. Raw materials were used in the case study firms, and these often vary in quality and have unique chemical properties, which made analysis of input materials essential. At this stage, the product or process engineers typically conducted several different empirical tests (e.g. laboratory tests and tests at bench scale) to get a feel for the problem and the optimal solution. When feasible, preliminary tests at bench scale and laboratory tests were done when developing both products and processes. More fine-grained tests, larger-scale tests such as pilot plant tests and ultimately full-scale tests were also performed. The next sub-phase generally began once these tests achieved more accuracy.

The final output of the FFE is a product or process concept where several different objectives are summarized. The creation of a product or process concept was a general key activity in the FFE for all case study firms. Creating a project plan and a budget were also important, in which costs, resources and timeframes were estimated. Together, these formed the basis for deciding whether the project idea should be developed further or terminated.

Besides, the general key activities, a number of specific key activities were also found. Key activities specific for product development in the FFE were anticipation of customers' process requirements, identification of a process window and customer involvement.

Anticipation of customers' process requirements was crucial for achieving the best performance, since the performance level of the final product was largely determined by how the customers used it in their production. Identification of a process window was a metaphor used by several informants to describe the opportunities and constraints of the production process when developing new products. This is further elaborated upon in Section 4.3 where the relationship between product and process development is described. Finally, customer involvement in the FFE was described as a key activity, as some of the best product concepts often were developed in close collaboration with customers. Two of the three key-specific activities focused on achieving satisfied customers, which corresponds to the general objective of product development – to produce products that provide benefits for the firm's customers. As customers were the most important source of new product ideas, a large part of the product development at the case study firms was customer-driven. The third specific key activity, identifying a process window, shows that the interdependence between product and process

development was strong already in the FFE of product development. This will be discussed in Section 4.3.

In the FFE of process development, specific key activities were anticipation of end-product changes, risk analyses and construction/modification of process equipment. Changes in the production process were often done to decrease the production cost or to increase quality in the existing products. However, due to the close relationship between product and process development, these changes could occasionally lead to deteriorations in the end-product, which made anticipation of end-product changes a key activity in the FFE. The systemic nature of process development could lead to unexpected changes in other processes close by. Depending on the proposed idea, the process concept sometimes included construction/modification of process equipment. When conducting larger changes in the production process, construction/modification of process equipment was often an essential activity. The final specific activity in the FFE of process development was risk analysis. Since most process changes involve changes in routines and work methods, risk analysis was central in the FFE. A number of different risk analyses were conducted to verify that the intended change had no negative effects, on either the internal or the external environment. For example, work environment and safety issues were typically analysed before deciding whether a process change could be implemented or not. Risk analysis is important when developing new products as well, although it was not a key activity in the FFE of product development. In product development, risk analyses are usually done in the formal development stage after the FFE. Finally, since process development efforts range from minor changes in work methods to significant investments in new process technology, the key activities varied according to the type of project.

To summarize, many of the general key activities presented in Table I are also conducted in assembled product development, such as idea generation, refinement and creation of a product concept (Khurana and Rosenthal, 1998; Reid and de Brentani, 2004). Whereas analysis of input materials, tests at smaller scales, and pilot plant test are specific for process firms producing non-assembled products. A number of specific key activities were identified, whether the goal of the innovation project was to produce a new product or to improve the production process. Thus, the FFE of the innovation process involves different activities depending on the type of innovation that is developed.

4.3 The relationship between product and process development in the front end

There is generally a high degree of interdependence between product and process development in process firms. For example, changes in the production process often change the properties of the final product. Therefore, process engineers must anticipate, as early as possible, how the final product is affected when a process development project is planned. From the perspective of the product engineers, the production process holds opportunities and constraints for what products can be developed. An efficient production process can speed up the firm's ability to develop new products. Constraints need to be considered as well, so that product concepts that are impossible to produce in the existing production process are terminated early on.

A product idea can be either outside or inside the process window. Being inside the process window means that the process technology is known and the product idea is possible to develop without new production equipment. Whereas being outside the

process window represents radically new product ideas that require investments in new equipment, and the process technology is unknown. Integration is more important when the product idea is outside the process window. Thus, identifying the process window in the FFE is essential for process firms.

For all case study firms, several product and process engineers and senior researchers confirmed that the interdependence between product and process development was strong. For example, process development projects could sometimes be initiated by the development of a new product. As one of Beta's interviewees said: "I got a feeling that almost all changes in the production process are derived from new products and not from the process itself".

Many development projects entailed both product and process development, and there were no clear borders between them. The process development manager at Delta stated:

It is a problem when you think that you can isolate one part from the other. Unfortunately, it happens all the time. An example is when changes in the production process are made, which they don't think are significant, but which considerably affect the end product.

However, integrating product and process development was often difficult. Product and process development were divided into different departments in all case study firms, and they were often located at different places. In the FFE, before any formal project was created, personal relationships were critical in order to manage the strong relationship between product and process development.

5. Discussion

The FFE is identified as the weakest stage in the whole innovation process, but the decisions made in the beginning largely determine the outcomes of the innovation process (Koen *et al.*, 2001). Existing research on the FFE has focused on assembled product development, while research on other innovation types is still limited. Specific characteristics of process firms make it difficult to apply previous knowledge on the FFE. An absence of studies on the FFE in process development further entitles the focus on process firms. Therefore, the aim of this paper was to inform both researchers and practitioners about the FFE of the innovation process by exploring non-assembled product and process development within process firms. Three research questions were created: How is the FFE of the innovation process conceptualized in process firms? What are the differences and similarities in terms of key activities in the FFE of product and process development? And how is the relationship between product and process development managed in the FFE of the innovation process?

The first research question explores how the FFE is conceptualized in non-assembled product development and process development, respectively. Figures 2 and 3 show the FFE in product and process development in process firms. The conceptualizations showed that the FFE starts similarly in both cases. Typically, a new idea was generated which originated either outside the firm or within the firm. Perhaps, the most central difference was the following stage in the innovation process. When products were developed, the next stage was typically formal development, which included more tests and validations of the product concept (Cooper, 2008), while implementation in the production line was the stage after the FFE in process development (Lager *et al.*, 2010). The process concept was instead implemented in the

production process. This explains to some extent why the FFE in process development includes one extra sub-phase, compared to the FFE in product development.

By conceptualizing the FFE in process firms, it can be concluded that the FFE is contingent on whether new products or processes are being developed. Previous research has addressed the deficiencies of early stages in the process development process (Pisano, 1997) as well as the lack of contingency factors when studying the FFE (Bröring *et al.*, 2006; Nobelius and Trygg, 2002). This paper adds new insights into what constitutes the FFE in process development and non-assembled product development.

The second research question compares key activities in the FFE of product and process development. Table II shows that some general key activities are conducted in the FFE of both product and process development, despite contradictory objectives. Idea generation, screening and the creation of a product or process concept (Khurana and Rosenthal, 1998; Kim and Wilemon, 2002) are examples of fundamental activities in the FFE regardless of innovation type or context. The specific key activities for each innovation type suggest that extant knowledge of the FFE in product development cannot be directly transferred to process development, as they work according to two different logics (product development is mainly effectiveness driven and process development is mainly efficiency driven) and with different objectives.

Moreover, it was found that both informal and formal activities were performed in the FFE regardless of the innovation type. Informal and unstructured activities were described as very important in the literature for generating new ideas in the context of discontinuous product development (Reid and de Brentani, 2004). This study shows that this was the case even in more incremental product and process development.

Regarding the final research question, how the relationship between product and process development is managed in the FFE of the innovation process, the relationship was described as strong in all case study firms. In the literature, the relationship has been explored on the firm level and the industry level (Lim *et al.*, 2006; Linton and Walsh, 2008; Utterback and Arbernathy, 1975). However, there have been few empirical examples of how the relationship looks and how it can be managed. This paper shows that the relationship needs to be considered as early as in the FFE of the innovation process. This has not been reported previously, either in the FFE literature or in the literature on process-based innovations.

From a practical point of view, these findings can increase the speed and conduct of the FFE. The conceptualizations of the FFE are a first attempt to clarify and structure what is done in the FFE of non-assembled product development and process development, and what needs to be done. The conceptualizations and the identified front-end key activities can be used as checklists, and they are a first step toward making the FFE less fuzzy. This is an initial and important measure for improving the overall innovation process.

The FFE in process development was described as complex and unsystematic in all case study firms, and most of them lacked a formal process development work process. Thus, the FFE of process development would benefit from increased formalization. A formalized work process in the FFE should guide the employees so that they know what is expected of them and the decision-making responsibilities are clear (Khurana and Rosenthal, 1998). However, formalization has a back side as it can cause rigidity, and it is important to find the appropriate level and not impose too much formalization.

To manage the relationship between product and process development, managers are advised to encourage informal activities and strengthen interpersonal relationships between product and process engineers. Then problems and mistakes can be addressed early on in the innovation process.

6. Limitations and suggestions for future research

As with any research, there are limitations associated with this study. The empirical data are collected within one specific industry (i.e. the mineral and metals industry) and therefore care should be taken when generalizing the findings to other contexts. The findings should be considered in their contextual setting, but some implications may be extended to other manufacturing firms. Analysis of the empirical data is more valid for process firms due to the sampling strategy; however, it limits theoretical generalization to other contexts (Eisenhardt and Graebner, 2007). Retrospective sense making must be considered, as well as keeping in mind that interviews are the primary data source, since informants can forget or misinterpret important facts (Eisenhardt and Graebner, 2007).

The FFE of product development differs in many respects from process development, and therefore only parts of existing research can be used to understand the FFE in process development. This suggests that the FFE in process development warrants its own realm of study. More research is suggested to better understand the specific conditions of organizing and managing the FFE of innovation. The product- and process-specific key activities found in this exploratory study need to be validated further. Finally, to increase the understanding of the FFE, more research is needed on innovations other than assembled product development, as the existing knowledge is still limited.

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Further reading

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