Managing Open Innovation in Process Industries

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To my family and friends.
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David Rönnberg Sjödin
Abstract

The concept of open innovation has received increased attention among practitioners as well as in academia in recent years. It provides a conceptual platform for understanding how external sources of knowledge drive internal growth in industrial firms. In addition, it addresses the internal configurations needed for managing a more externally oriented innovation process. However, many firms still experience major managerial challenges in trying to adopt the principles of open innovation. The perhaps most important challenge in realizing the potential benefits of open innovation lies in modifying existing innovation activities and processes to incorporate the principles of open innovation, rather than creating something completely new. Therefore, the overall purpose of this thesis is to study the problems and opportunities arising when firms attempt to integrate and manage open innovation activities within their development processes.

Empirically, the results are based on three exploratory case studies within the process industries. In total, this thesis is based on 73 interviews from two process firms and nine equipment suppliers to the process industries. Data were gathered in several countries, and collectively these firms represent perspectives from Sweden, Norway, Finland, Switzerland, Germany, the Netherlands and the United Kingdom.

Three papers are appended with the thesis. Paper I studies the overall challenges of integrating open innovation activities within an existing product development process. The key contribution is the enactment of a practitioner-oriented work model, named the open Stage-Gate model, which exploits the advantages of “openness” while simultaneously capturing the benefits deriving from the systematic and structured approach implied by the Stage-Gate process. Paper II studies a concrete application of open innovation by focusing on the development and installation of new or upgraded process equipment in process plants, where collaborative efforts by a process firm and various suppliers of process equipment often are required. The analysis focuses on problems and opportunities in different stages of the equipment’s lifecycle, and finds that the content and the intensity of the collaboration should be tailored to the different stages of the equipment’s lifecycle. As such, the conclusions highlight the fact that being totally open in development activities is not always the most suitable option. Instead, different degrees of “openness” may be suitable at different stages. Similarly, Paper III studies collaboration during design and implementation of customized process equipment, from an equipment supplier perspective. In particular, collaboration is essential for transferring knowledge about the equipment from the equipment supplier to the process firm in the start-up stage, where intimate educational activities are typically required. However, these projects are often very complex to manage, as interdependences among a number of actors and activities create problems for both buyer and supplier. Collectively, Papers II and III contribute to increased knowledge of the management of collaborative development activities within the process industries.
Keywords: Open Innovation, Collaborative Development, Process Industries, Buyer-Supplier Relationships, Process Equipment, Stage-Gate, Lifecycle Stages.
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Appended Papers


In addition to the appended papers, the following publications have been accomplished during the research work.


Part I
Introduction

This chapter provides a background on the process industries and proceeds to describe the research problem more thoroughly. The chapter is concluded with the research purpose and a brief overview of the thesis' structure.

1.1 Background

The process industries are of critical importance in the world today because they provide the building blocks for many products that sustain the development of human societies. By using large amounts of heat and energy to physically or chemically transform materials, these industries help meet the world's most fundamental needs for food, shelter and health, as well as products that are vital to such advanced technologies as computers, telecommunications and biotechnology. Worldwide, it has been estimated that process industries, which include the metals and minerals, pulp and paper, chemical and food industries, among others, constitute nearly one third of all manufacturing industries in terms of revenues and R&D expenses (Lager, 2011). Despite their significant financial contribution to national economies, and their numerical strength as a group, the process industries have largely been ignored by innovation management researchers (Barnett and Clark, 1996; Lager et al., 2010; Pisano, 1997; Hutcheson et al., 1995). Even so, innovation in terms of both products and processes is of critical importance to firms in these industries because of increased price competition and product commoditization.

Moreover, a number of contextual characteristics make these firms especially interesting and challenging to study, and distinguish them from other manufacturing industries. Inputs to the production process are often raw materials rather than components from suppliers, the production plants are typically very large and strongly integrated on one site, and the production process is often continuous with on-line control in real time (Lager, 2011). Moreover, products developed and produced are non-assembled, and typically used in somebody else's subsequent production. In addition, product lifecycles are often very long, while the production process is inert and inflexible, and therefore difficult to change, and also very capital-intensive (Hutcheson et al., 1995; Lager, 2002). Furthermore, process firms are characterized by high degrees of interdependence between product development...
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and process development (Linton and Walsh, 2008). That is, changes to the production process frequently result in changes to the end product, such as when process parameters are altered. Conversely, new product concepts often require significant changes to the production process.

In addition, process firms are typically active in mature industries, with tight cost control and an emphasis on process innovation (Hutcheson et al., 1995; Utterback and Abernathy, 1975). However, many process firms strive to move up the value-chain, deliberately trying to offer more customized and tailor-made products (Lager and Blanco, 2010). Such efforts often presuppose development of new and improved process technology to enable both product innovation 1 and process innovation 2, an issue addressed in detail in this thesis.

1.2 Research problem

In the process industries, process innovations in terms of new process equipment usually originate from equipment suppliers (Hutcheson et al., 1995). Therefore, collaborative relationships with equipment suppliers have an increasingly important effect on competitiveness in terms of both products and processes for firms in these industries (Lager, 2011). Similarly, equipment suppliers are also strongly reliant on collaborating with process firms and other external actors to enhance their innovative activities. This trend goes along with the current open innovation movement and is also apparent in many other industrial settings (Chesbrough, 2003a; Lichtenthaler, 2008). Therefore it has been ascertained that a new era within innovation management is emerging: the era of open innovation (Chesbrough, 2003b). Henry Chesbrough, who coined the term, defines open innovation as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively” (Chesbrough et al., 2006, p. 1). The inherent logic of this definition is simply that firms can and should use external as well as internal knowledge and ideas, and both internal and external paths to market, when they seek to maximize returns from development activities.

The logic of open innovation is underscored in process firms. Although in-house development and installation of new process equipment do occur, such activities frequently necessitate collaboration with various suppliers of process equipment (Hutcheson et al., 1995). Nevertheless, the required equipment may not be readily available in the equipment supplier’s product portfolios. Consequently, a process firm may have to devote significant resources to design and develop competitive production solutions in collaboration with equipment suppliers. The main reason for

1 Product innovation is defined as: new outputs introduced into a market ‘external’ to the firm, with the purpose of providing benefits to external customers (Gopalakrishnan and Damanpour, 1997). In this thesis the terms product innovation and product development are used as synonyms.

2 Process innovation is defined as: The implementation of new or significantly improved production or delivery methods. This includes significant changes in techniques, equipment and/or software (OECD, 2005). In this thesis the terms process innovation and process development are used as synonyms.
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this is the often idiosyncratic nature of process equipment needed by process firms (Lager and Frishammar, 2010). Hence, it is not only advisable but of the utmost importance to have good contacts and strong collaboration with various equipment suppliers in order to explore new development opportunities (Lager & Hörte, 2005).

Moreover, collaborative development of process equipment may be referred to as either product development or process development depending on the viewpoints of the parties concerned (Hutcheson et al., 1995). From the equipment supplier’s perspective, this kind of development is seen as product development, whereas from the process firm’s perspective it is typically discussed in terms of process development. Therefore, a critical aspect in getting the collaboration to work is to develop a mutual understanding about the equipment and its application in the market (Emden et al., 2006).

Nevertheless, it is important to adopt an unbiased perspective when exploring whether and when to enter into open and collaborative innovation activities (Chesbrough & Schwartz, 2007; Knudsen & Mortensen, 2011) – especially because the motives and driving forces for getting involved in these activities often differ among the collaborating firms. Furthermore, potential opportunities and problems arising from open innovation activities may vary among different stages of the development process (Enkel et al., 2009).

Opportunities include getting access to novel ideas, finding new partners, an ability to leverage development on someone else’s budget, speeding up development, and saving costs (Chesbrough, 2003a). For example, an equipment supplier may obtain and refine new ideas for product concepts by collaborating with a qualified key customer (i.e. lead user) within the process industries (e.g. von Hippel 1986). In addition, collaborating with research institutes or universities can facilitate access to advanced technological knowledge with the potential of creating radical developments for both process firms and equipment suppliers (Enkel et al., 2009). Moreover, engaging in open innovation can create a greater sense of urgency for internal groups to act on ideas and technology and, over time, an opportunity to create a more innovative culture from the “outside in” through continued exposure and relationships with external innovators (Herzog & Leker, 2010).

However, there are also a number of potential problems. A firm can lose control over its own technology as it leaks out to partners, and complexity increases as more partners are involved in development (Enkel et al., 2009). For example, through deep collaboration, a process firm runs the risk of having its core knowledge related to the production process spread to competitors via suppliers of process equipment active on a global market (Lager, 2011). On the other hand, a supplier of process equipment may be reluctant even to enter a joint collaborative project without the option to further diffuse technology and knowledge created in that project. Additionally, in larger projects a process firm typically collaborates with a network of equipment suppliers and other actors (Hutcheson et al., 1995), which often leads
to problems in coordinating a large number of diverse activities (Lager & Frishammar, 2010). For these reasons, collaboration can be anything but efficient, resulting in high coordination and transaction costs, often as a result of contractual negotiations, which may arise from involving external parties in the innovation process (Van de Vrande et al., 2006; Christensen et al., 2005). In particular, a lack of facilitating routines and processes for open innovation is a serious impediment for the implementation of open innovation activities in many firms (Chesbrough & Crowther, 2006). Accordingly, there is a need for further research on processes and practices for open innovation in the process industries.

1.3 Research purpose

Prior research into open innovation has mostly focused on new product development in high-tech industries (e.g. Chesbrough, 2003a; Christensen et al., 2005). Although some recent studies have established that open innovation practices are apparent also in more mature industrial settings like the process industries (Spithoven et al., 2011; Lichtenthaler, 2008), such studies are few. Consequently, there is a need for further studies within these industries to determine the potential of open innovation in a dominant sector of the global economy.

Moreover, while open and collaborative innovation in general has been studied extensively in recent years there are still many issues in need of research (Chesbrough et al., 2006). In particular, the need for combining open innovation with earlier theoretical work has been highlighted (Elmqvist et al., 2009). One theoretical area that seems promising for investigating along with open innovation is product development processes (i.e. stage-gate processes), where hitherto research has been limited (Cooper, 2008). Specifically, research on the integration of open innovation and Stage-Gate processes is important (Cooper, 2010; Lichtenthaler, 2011) as more than 60% of industrial firms employ some kind of Stage-Gate process (Griffin, 1997).

Another promising area for research is the implication of open innovation for process development (Chesbrough et al., 2006). This is an important observation as prior literature in general has made a substantial contribution to understanding product development (e.g. see Brown and Eisenhardt, 1995; Cooper, 2008) while much less attention has been devoted to process development (Pisano, 1997; Reichstein and Salter, 2006). In addition, problems and opportunities of managing open innovation in dyads have been highlighted as an issue in need of further study (Chesbrough et al., 2006). In particular, the opportunity to capture the perspectives of both sides of a dyad has been underlined as a promising avenue for further research (Chesbrough et al., 2006).

Therefore, the overall purpose of this thesis is designed to address these gaps while explicitly focusing on development activities within the process industries. In accordance with the discussion above, the overall purpose of this thesis is to study the
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problems and opportunities arising when firms attempt to integrate and manage open innovation activities within their development processes.

1.4 Structure of the thesis

This thesis consists of two main parts. The first part is an introductory text to the second part where three appended papers are presented, each with a specific research purpose. In the following section a literature overview of open innovation, product development processes and buyer-supplier relationships within process industries is conducted while the purpose of each of the three papers is outlined. The next section describes the methods used in the thesis. The fourth section summarizes the papers appended in Part II. Finally, a short discussion of the findings is made and theoretical and managerial implications are provided as well as conclusions and limitations of the study.
This thesis draws on research mainly from the field of open and collaborative innovation. This chapter starts by introducing the concept of open innovation, followed by a brief description of the literature about product development processes (i.e. stage-gate processes) and a presentation of a lifecycle model for collaborative development in buyer-supplier relationships.

2.1 Introduction to open innovation

The concept of open innovation has gained widespread acceptance in different lines of research, and it has had a major impact on both research and practice since its coining in 2003 (Chesbrough, 2003a; Lichtenthaler, 2011). The concept of open innovation is, however, more than just a new term. “Open innovation is both a set of practices for profiting from innovation, and also a cognitive model for creating, interpreting and researching those practices” (Chesbrough et al., 2006, p. 286).

In essence, firms can pursue open innovation in two different directions. First, firms can engage in inbound open innovation activities: enriching the company’s own knowledge base by integrating suppliers, customers, or other actors, such as innovation intermediates, into the internal innovation process (Enkel et al., 2009). Second, firms can also pursue outbound open innovation activities, such as technology licensing, thus earning profits by bringing ideas, patents, and other forms of intellectual property rights to market (Lichtenthaler, 2008). In addition, firms can combine these two logics into a “coupled process” of both inbound and outbound innovation, through co-creation with complementary partners (Enkel et al., 2009).

With this background, the concept of open innovation has made a substantial contribution to theory and practice. In comparison with the older literature, it provides not only a more detailed but also a more holistic perspective on external collaboration and commercialization. Lichtenthaler (2011) identified a couple of characteristics of the open innovation framework, which distinguish it from earlier approaches to collaborative innovation. In particular, the open innovation framework integrates inward and outward knowledge transfer, while most prior work addressed only one direction of opening up the innovation process. In addition, the open innovation literature emphasizes the complementary character of
internal and external innovation-related activities in many firms (Enkel et al., 2009). Perhaps open innovation is best described by its main principles (Chesbrough, 2003a). A comparison of the principles of closed and open innovation is displayed in Table 1.

Table 1. Comparing the principles of closed and open innovation (Chesbrough, 2003a).

<table>
<thead>
<tr>
<th>Closed Innovation Principles</th>
<th>Open Innovation Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>The smart people in the field</td>
<td>Not all the smart people</td>
</tr>
<tr>
<td>work for us.</td>
<td>in the field work for us.</td>
</tr>
<tr>
<td>To profit from R&amp;D, we must</td>
<td>External R&amp;D can create</td>
</tr>
<tr>
<td>discover it, develop it, and</td>
<td>significant value:</td>
</tr>
<tr>
<td>ship it ourselves.</td>
<td>internal R&amp;D is needed to</td>
</tr>
<tr>
<td>If we discover it ourselves,</td>
<td>claim some portion of</td>
</tr>
<tr>
<td>we will get it to the market</td>
<td>that value.</td>
</tr>
<tr>
<td>The company that gets an</td>
<td>Building a better business</td>
</tr>
<tr>
<td>innovation to the market first</td>
<td>model is better than</td>
</tr>
<tr>
<td>If we create the most and the</td>
<td>getting to the market first.</td>
</tr>
<tr>
<td>best ideas in the industry, we</td>
<td>If we make the best use of</td>
</tr>
<tr>
<td>will win.</td>
<td>internal and external ideas, we will win.</td>
</tr>
<tr>
<td>We should control our IP, so</td>
<td>We should profit from</td>
</tr>
<tr>
<td>that our competitors don't</td>
<td>others' use of our IP,</td>
</tr>
<tr>
<td>profit from our ideas.</td>
<td>and we should buy others'</td>
</tr>
<tr>
<td></td>
<td>IP whenever it advances</td>
</tr>
<tr>
<td></td>
<td>our business model.</td>
</tr>
</tbody>
</table>

2.2. Development processes for managing open innovation

Development processes and other organizational routines are important to organize and manage development work (Brown and Eisenhardt, 1995; Cooper, 2008). Therefore, a specific problem in the implementation of open innovation activities is that existing development processes and systems are typically internally focused or inclined to conventional ways of working (Witzeman et al., 2006). A challenge in realizing the potential benefits of open innovation thus lies in modifying existing development processes, to fit with open innovation principles, rather than creating something completely new (Chesbrough & Crowther, 2006; Witzeman et al., 2006).

Given this background it seems fruitful to devote attention to adapting the most widely embraced new product development (NPD) process in the world, the Stage-Gate process (Griffin, 1997). A Stage-Gate process brings structure and order to the sometimes chaotic process of product development, and has been described as both a conceptual and an operational model for moving a new product from idea to launch. To this end, the purpose of the Stage-Gate process is to manage the NPD process to improve effectiveness and efficiency by integrating discipline into a process described as ad-hoc and seriously deficient in many firms (Cooper, 1990).
In essence, the Stage-Gate process consists of a series of stages where essential activities are carried out, and gates where interim achievements are evaluated. Over the course of a NPD project, both activities and evaluation criteria vary, because the process struggles with different technical, managerial and organizational issues throughout. Traditionally, stage-gate processes have been internally rather than externally orientated, thus focusing on achieving efficiency and effectiveness mainly by utilizing a firm’s internal development resources (Cooper, 1994). However, recent proceedings in the Stage-Gate literature underscore the importance of open innovation activities, and some best-practice firms have already begun to open up their NPD process (Cooper, 2008; Cooper, 2009; Cooper 2010). However, the existing literature falls short on describing how these companies have adapted their internal work models and processes to facilitate open innovation (Cooper, 2008; Cooper, 2009). Nevertheless, going from ad-hoc processes to clearly defined open innovation processes with clear roles and responsibilities is critical in order to ensure successful adoption of open innovation in industrial firms (Chesbrough & Crowther, 2006).

Consequently, there is a need for a new and revised Stage-Gate model which helps practitioners adapt their current NPD process to incorporate the principles of open innovation. Therefore, the purpose of Paper I is to explore how firms can benefit from opening up the NPD process by integrating the principles of open innovation with the well-known and widespread Stage-Gate process.

2.3. Buyer-supplier collaboration within the process industries

A specific focus in this thesis is the collaborative activities of process firms and equipment suppliers when developing and installing new process equipment. In essence, these kinds of collaborative relationships relate to the coupled process of open innovation, which implies co-creation with complementary partners during which give and take are crucial for success (Enkel et al., 2009). For example, a process firm may share and jointly develop ideas for new process equipment in collaboration with the equipment supplier while additionally providing the possibility of testing the equipment in production plants (Lager & Frishammar, 2009). Moreover, the equipment supplier may devote significant resources to educational activities with end users at the process firm to enhance the operational performance of the equipment (Athaide & Klink, 2009). Accordingly, it is important to find a partner with the appropriate technical knowledge and capabilities, strategic intent and long-term collaborative orientation (Emden et al., 2006).

Lager and Frishammar (2010) presented a lifecycle model addressing the development of process equipment in the metals and minerals industry. Drawing on their work, the lifecycle model applied in this thesis has been divided into five stages: pre-study, purchasing and development, assembly and installation, start-up,
Collaborative activities in these stages include; careful joint selection and design/development of proper process equipment for the process firm’s specific production applications, mobilisation of joint resources for a smooth installation and start-up, and subsequent efficient operation utilising the combined expertise of both parties. Although the stages are presented as sequential, activities performed during the lifecycle are frequently overlapping and heavily interconnected.

Throughout the lifecycle, equipment suppliers may seek active involvement from potential customers, ranging from co-designing of products to seeking feedback on product-related problems or desired modifications (Athaide et al., 1996). Nevertheless, customer integration imposes risks such as the potential loss of know-how, being overly dependent on customers’ views, and being limited to incremental innovation (Enkel et al., 2005). To diminish these risks, collaborative tools may be used to enhance the development of trust and commitment among the partners (Eriksson, 2008). Examples include: joint objectives, joint office building, teambuilding activities, partnering facilitators, joint IT-tools, and joint risk management (Olsen et al., 2005; Eriksson, 2008).

The driving forces behind collaboration between process firms and equipment suppliers differ, as problems and opportunities in the collaboration vary over the lifecycle of the equipment. The importance of understanding drivers for buyer-supplier relationships is pointed out by Rahman et al. (2009). Nevertheless, previous research has mainly studied the early stages of the lifecycle (Schiele, 2010; Ro et al., 2008). It may, however, be advantageous to collaborate not only in the early design stages but also throughout all of the stages of the lifecycle (Athaide & Klink, 2009). For that reason, investigating collaborative development over the full lifecycle of process equipment appears necessary in order to increase the detailed understanding of these projects (Langner & Seidel, 2009). Thus, all lifecycle stages of the equipment should be investigated in order to explore the opportunities and problems arising from open and collaborative innovation practices. Therefore the purpose of Paper II is to explore the problems and opportunities faced by process firms and their equipment suppliers throughout the lifecycle stages of collaborative development projects.

3 The names of the stages in the lifecycle in Paper II are slightly different.
4 Paper II studies these projects from the perspective of the process firms.
However, a majority of the collaborative development projects between process firms and equipment suppliers can be regarded as operational projects (Lager, 2011). An operational project is a project with the purpose of designing and implementing customized process equipment. These projects focus on the purchasing, installation and post-installation stages of already developed equipment, as the activities performed in these stages have a strong impact on the operational performance of the equipment (Athaide & Klink, 2009). While collaboration during product development projects could be regarded as open innovation (Chesbrough, 2003), it is also possible refer to collaboration in operational projects as “open operation”, conceptualising a more open approach towards external actors in these projects (Lager, 2011).

Indeed, collaboration in operational projects in process industries is of critical importance (Lager, 2005; Lee et al., 2010) because the high complexity and customization of the equipment for each process plant can create significant challenges for buyer and supplier (Stump et al., 2002). For example, poorly articulated needs and specifications from the process firm can lead to miscalculations in the design of the equipment (Cooper, 1988), and deficient start-up activities may lead to problems and high costs for both parties (Agarwal et al., 1984). As a result, these projects often have prolonged start-up periods before the equipment is working as expected (Lager, 2011). To handle these problems, collaborative relationships between equipment suppliers and process firms are often essential over the course of the project. However, research on collaboration in operational projects is limited, and more knowledge is necessary to facilitate improved methods and work-practices for collaborative efforts between process firms and equipment suppliers (Lager & Frishammar, 2010). Therefore, the purpose of Paper III is to explore the problems and opportunities faced by equipment suppliers in collaboration with process firms throughout the different stages of operational projects.

As such, Paper III studies the collaborative activities from the supplier’s perspective, which is important because previous research has often studied collaboration from the buyer’s perspective. In order to capture a complete picture, however, one should also address the supplier’s perspective to get the perspective from both sides of the dyad (Chesbrough et al., 2006). This is especially important since buyer and supplier often may regard these projects as process and product development respectively (Hutcheson et al., 1995).

2.4. Summarizing the theoretical perspectives

The processes of industrial innovation are being innovated (Rothwell, 1994, Mowery, 2009). The locus of innovation is changing, from largely being limited to operation within the four walls of the firm, to a more distributed, open model of innovation (Chesbrough, 2003a). In this more open approach, useful knowledge

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5 This fact is indeed highlighted by Lager (2011), but this was also a main finding from Study III which subsequently inspired the purpose of Paper III.
can be found from a wealth of possible sources. Firms need to adapt their management processes to make greater use of external knowledge in their own innovation systems. In turn, firms would do well to let their own unused ideas flow to other businesses for them to use (Lichtenthaler, 2008). Against this background, it is important to recognize the opportunity of engaging with customers, suppliers and other actors in more collaborative processes of innovation. Along this line of reasoning, buyer-supplier relationships have long been regarded as a way of increasing the innovative output of NPD for both buyer and supplier (Athaide & Klink, 2009). As such, open innovation and buyer-supplier collaboration may in some cases be two sides of the same coin. Even so, open innovation is a broader concept of leveraging diverse external sources of know-how and technology to drive internal growth, and has generated substantial attention in academia as well as in practice. On the other hand, engaging in external collaboration confronts important problems and opportunities that need to be understood and managed. To this end, this thesis contributes to our increased knowledge by studying the problems and opportunities arising when firms attempt to integrate and manage open innovation activities within their development processes.
In this chapter the methods used in the present research are presented and discussed. This includes sections on the choice of research strategy, literature search, data collection, data analysis, and finally a discussion of the quality of the chosen research approach.

3 Research Method

3.1 Research strategy

“People who write about methodology often forget that it is a matter of strategy, not of morals. There are neither good nor bad methods but only methods that are more or less effective under particular circumstances” (Homans, 1949, p. 330)

Given the previously outlined purpose, exploratory case studies were employed as a research strategy. This is justified because case-study research is recommended when the knowledge in a research area is limited (Edmondson & McManus, 2007). In such a research setting, gathering rich information from cases is expected to help identify new aspects and phenomena (Eisenhardt, 1989; Yin, 2008).

Moreover, the overall purpose of this thesis is to study the problems and opportunities arising when firms attempt to integrate and manage open innovation activities within their development processes. Given that detailed illustrations are required in order both to address these issues and to outline more particular challenges and managerial implications, a qualitative method would enable the kind of descriptions that are needed, as it enables “richness and holism, with strong potential for revealing complexity” (Miles and Huberman, 1994, p. 10). Furthermore, case studies allow the researcher to investigate social phenomena in real-life contexts (Miles and Huberman, 1994; Yin, 2008) – thus enabling the investigation of formal as well as informal activities within collaborative development projects. Therefore case studies are appropriate for examining and articulating processes (Edmondson & McManus, 2007; Pratt, 2009), such as the activities at different stages of a development project. For this reason, qualitative data often provide a good understanding of the dynamics underlying uncovered relationships within empirical data (Eisenhardt, 1989).
Describing the approach as deductive or inductive in a setting like this can be tricky, as the process when performing case studies is to a great extent iterative (Eisenhardt 1989; Yin 2008) – starting from theory, the general (deduction), moving on to the individual case, and back, building new theories (induction). A combination of these approaches is often made, i.e., abduction (Alvesson and Sköldberg 2009). However, the general description of this project would be an inductive one, as the centre of gravity of the discussion is more on the inductive side.

3.2 Literature review

The literature review was not carried out at one particular time during the work on the thesis, but can best be described as a continuous process. This has to do with the way that the thesis work was planned. Being a collection of research papers, each specific study and subsequent paper required additional readings and adjustments to the theoretical framework and the literature base. Moreover, accessing the literature is never a sequential process. Rather, it is an ongoing iterative process whereby new literature is continuously accessed and analyzed (Croom, 2008). As such, the literature review underlying this thesis was conducted continuously through a wide variety of sources. Examples include: keyword searches in leading academic databases (e.g. EBSCO, Science Direct), bibliometric analyses of most cited works in Scopus, and searching through reference lists of seminal articles and books. Moreover, to gain an understanding of where the research agenda is progressing, I subscribed to table-of-contents alerts from the latest issues of the leading journals within technology and innovation management, as well as highly ranked journals within general management and marketing which provided a number of recent references for the thesis. In addition, the literature review was very much affected by other people. Supervisors, reviewers and colleagues have given input on specific areas. PhD courses completed in parallel with the research project also influenced the development of my theoretical framework. In sum, the purpose of the literature review was to continuously increase my understanding of the main theories within innovation management and how they have been applied and developed, as well as the main criticisms that have been made of work on the topic. As such, the review forms the basis of the understanding of the topic and the frame of reference, but the emerging frame of reference also forms the basis of further reading (Hart, 1998).

3.3 Case studies

Three different case studies within the process industries form the basis of this research. The first one was conducted as a single case study at Vetco Gray, an equipment supplier to the oil industry located in Oslo, Norway. The second study

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Examples of keywords include: Open innovation, collaborative development, new product development, stage-gate, dynamic capabilities, core capabilities, process equipment, equipment suppliers, process innovation, business models, innovation management etc.
was conducted at two process firms in the metals and minerals industry in Sweden\(^7\). The third study was conducted at eight equipment suppliers to the metals and minerals industry, with data from several different countries. In the next section the reasons for selecting these cases are provided along with some information about the setting of each case.

### 3.3.1 Case selection

#### Study I
This study was a single case study, set in the upstream oil and gas industry, investigating the potential of integrating the principles of open innovation with the stage-gate process. Single case studies are particularly powerful in exploring a phenomenon in its context while retaining the richness of the studied incident and its context (Eisenhardt and Graebner, 2007).

The specific firm studied was Vetco Gray, hereafter referred to as VG, which is a part of General Electric’s Oil & Gas business. VG is specialized in upstream drilling and process technology for the subsea oil and gas industry. With 5,000+ employees located in over 75 countries, the firm is a major global equipment supplier to some of the world’s largest oil companies such as ExxonMobil, BP and Chevron. For both theoretical and pragmatic reasons, VG constitutes an ideal case in light of the research purpose (see Paper I). Finally, deep personal contacts at this firm facilitated the access to and retrieval of rich data.

#### Study II
To investigate collaborative practices within the process industries, two process firms in the metals and minerals industry were selected by means of judgement sampling (Denzin & Lincoln, 1994), henceforth referred to as Alphacorp and Betacorp. This was motivated as the setting of these firms is particularly interesting, since development of process equipment for the metals and minerals industry provides several challenges. The operations include heavy materials that wear and tear the equipment, idiosyncratic process needs, and a critical need for reliable equipment. Hence, collaboration is often a necessity as the equipment must be customized to the idiosyncratic needs of each firm.

Both firms have their main R&D departments and their centre of gravity of operations in Sweden, but sell their products on a global market. Alphacorp develops and produces upgraded iron ore and industrial mineral products for the steel and other industry sectors. Betacorp develops and manufactures metal powders for the global market. Metal powder technology is used in a variety of application areas, including sintered components, soft magnetic composites, hot polymer filtration, and surface coating. Table 2 provides some further information about Alphacorp and Betacorp.

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\(^7\) In order to keep the firms anonymous the names of these firms are not disclosed. In paper II these firms are referred to as Alphacorp and Betacorp.
Table 2: Information about the case firms in study II

<table>
<thead>
<tr>
<th>Firm Pseudonym</th>
<th>Main products</th>
<th>Number of employees</th>
<th>Annual turnover</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alphacorp</td>
<td>Iron ore and iron pellets</td>
<td>4 100</td>
<td>2 325 M€</td>
<td>Sweden</td>
</tr>
<tr>
<td>Betacorp</td>
<td>Metal powders</td>
<td>1 600</td>
<td>614 M€</td>
<td>Sweden</td>
</tr>
</tbody>
</table>

Study III
To investigate collaborative practices within the process industries, eight equipment suppliers operating in the metals and minerals industry were selected. These firms are located in Sweden, Finland, Switzerland, Germany, the Netherlands and the United Kingdom. The selection was done in collaboration with industry professionals in leading roles at Alphacorp and Betacorp by means of judgement sampling (Denzin and Lincoln, 1994) based on the equipment suppliers’ involvement in collaborative projects with their customers. Table 3 provides some additional information about the selected firms.

Table 3. Information about the case firms in study III

<table>
<thead>
<tr>
<th>Firm Pseudonym</th>
<th>Main Products</th>
<th>Number of employees</th>
<th>Annual turnover</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Griffin</td>
<td>Sieves</td>
<td>200</td>
<td>21 M€</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Nippon</td>
<td>Blenders</td>
<td>170</td>
<td>25 M€</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Tiger</td>
<td>Automated lifting cranes</td>
<td>8</td>
<td>6 M€</td>
<td>Sweden</td>
</tr>
<tr>
<td>Alpine</td>
<td>Press tools</td>
<td>50</td>
<td>6 M€</td>
<td>Switzerland</td>
</tr>
<tr>
<td>Delphi</td>
<td>Presses</td>
<td>450</td>
<td>60 M€</td>
<td>Germany</td>
</tr>
<tr>
<td>Gold</td>
<td>Mill linings</td>
<td>200</td>
<td>112 M€</td>
<td>Sweden</td>
</tr>
<tr>
<td>Silver</td>
<td>Separation equipment and slurry pumps</td>
<td>240</td>
<td>100 M€</td>
<td>Sweden</td>
</tr>
<tr>
<td>Lakeland</td>
<td>Mineral processing equipment</td>
<td>3200</td>
<td>878 M€</td>
<td>Finland</td>
</tr>
</tbody>
</table>
3.4 Data collection

Data for this thesis were gathered primarily through individual, in-depth interviews at the case firms. The choice of interviews as the primary source for gathering information was motivated by the fact that they can provide insightful information and can be focused directly on research topics (Yin, 2008). Moreover, my focus on understanding problems and opportunities with implementing open innovation practices in different stages of development underscores the importance of being able to discuss back and forth with the respondents and being able to ask follow-up questions. Some specific information about the three studies in this thesis is provided in Table 4.

In Study I the focus was on understanding the NPD process and how it can be modified to facilitate open innovation (see appendix I). However, development in the process industries is usually conducted in project-based relationships. Hence, the main unit of analysis for Studies II and III was the collaborative relationships among equipment suppliers and process firms during different lifecycle stages of collaborative development projects. Given my exploratory focus, the interviews focused on general tendencies and patterns of collaborative relationships in the process firms’ portfolios of development projects (see appendix II & III). However, in all of the studies, relevant and interesting examples from specific projects were explored in detail in order to explicitly illustrate key problems and opportunities.

In total, 73 interviews form the basis of this thesis (see Table 4). To mitigate bias in the data collection, knowledgeable respondents were selected from different hierarchical levels who viewed the collaborative relationships from diverse perspectives (Eisenhardt & Graebner, 2007). As such, the respondents were selected carefully in dialogue with key informants at the participating firms, based on their involvement in and knowledge of the development process with regard to open and collaborative innovation. Deliberate effort was thus spent on including respondents from both the strategic and operational levels in the case firms. The respondents varied in age, years of employment, academic training and position, and were therefore able to contribute with diversity in perspectives. The different positions of the respondents included vice presidents, various department managers (e.g. Technical Support, R&D, and Facilities), project managers, production managers, marketing managers, engineers, and technical specialists.

The interviews were semi-structured and guided by a list of questions designed on the basis of the literature review (see appendices I, II and III) in order to capture a clear view of the observed phenomena. During the interviews, discussions outside the content of the interview guide were permitted and often encouraged in the

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8 Six of the interviews in study III were conducted over the phone
9 For a more detailed description of the different respondents, see the method chapter in the appended papers I, II and III.
interest of exploring new and potentially fruitful points. The format of the interviews was accordingly adapted and changed slightly from one interview to the next to pursue interesting and particularly relevant new facets of the case study as they emerged (Eisenhardt, 1989). Moreover, the interviews in Study I were conducted by two interviewers in order to obtain investigator triangulation (Denzin, 1994). All interviews were recorded and subsequently transcribed. Additionally, document studies were performed in each study – regarding company reports, descriptions of the formal development process and documents from specific projects, thus allowing for empirical triangulation of the firm’s NPD practices.

Table 4. Specific information about the three studies in this thesis.

<table>
<thead>
<tr>
<th>Study</th>
<th>Main Questions</th>
<th>Unit of analysis</th>
<th>Paper</th>
<th>Data Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study I</td>
<td>How is the NPD process structured? Why, when and how are inbound and outbound open innovation practices used? How are core capabilities and business models leveraged and developed in NPD? (See appendix I)</td>
<td>The NPD process.</td>
<td>I - Open Innovation and the Stage-Gate Process: A Revised Model for New Product Development</td>
<td>Semi-structured interviews, internal and external documents. Average interview time 1 hour.</td>
</tr>
<tr>
<td>GE Oil &amp; Gas</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>(34 interviews)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study II</td>
<td>Why engage in collaborative development projects? During which stages of development is collaboration most intense, and why? How are collaborative development projects organized and managed? (See appendix II)</td>
<td>Collaborative development process of the process firms.</td>
<td>II - Open Innovation in the Process Industries: A Life-cycle Perspective on the Development of New Process Equipment</td>
<td>Semi-structured interviews, internal and external documents. Average interview time 1.5 hours.</td>
</tr>
<tr>
<td>Alphacorp &amp; Betacorp</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(17 interviews)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study III</td>
<td>Why engage in collaborative development projects? During which stages of development is collaboration most intense, and why? How are collaborative development projects organized and managed? (See appendix III)</td>
<td>Collaborative development process of the equipment suppliers.</td>
<td>III - Open Operation: Buyer-Supplier Collaboration in Operational Projects</td>
<td>Semi-structured interviews, internal and external documents. Average interview time 1 hour.</td>
</tr>
<tr>
<td>Eight equipment suppliers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(22 interviews)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10 The interviews in Study I were conducted together with Johan Grönlund.

11 In paper II the interview data from study II were complemented by additional data from 10 interviews on the topic of the paper conducted by Per Erik Eriksson.

12 In study III six of the interviews were conducted by telephone.
3.5 Data analysis

The data analysis for each of the studies was conducted in a similar way. Each interview was summarized and transferred to a spreadsheet for further analysis. The spreadsheet was structured as a conceptually ordered display (Miles & Huberman, 1994). As such, the analysis was conducted by addressing the individual interview questions and subsequently identifying the evidence that addresses each question (Yin, 2008) and drawing a tentative conclusion. Moreover, several interview questions were conceptually clustered together in rows according to the general topic that they were exploring, to facilitate further analysis among questions concerning specific themes (Edmondson & McManus, 2007; Miles & Huberman, 1994). Each theme was explored and summarized and later discussed among the researchers to arrive at a common result. Moreover, iterations between results, theory, and empirical data were performed to enact emergent conclusions (Eisenhardt, 1989; Yin, 2008). This procedure was thereafter repeated for all questions in an iterative manner to reach a final conclusion. Frequent discussions between me and my co-authors were held to create overlap between data collection and data analysis, besides the continuous taking of field notes.

3.6 Research quality

To enhance reliability, that is, transparency and future replication, a case study data base was constructed for each of the studies. Each data base contained case study notes, documents and reports collected from the firms, and the records and transcripts of the interviews collected during the study. Accordingly, the case study data base facilitates retrieval for future studies (Yin, 2008). Moreover, highly knowledgeable informants were selected, all with different roles and perspectives (e.g. project engineers, project managers, and department managers), to mitigate potential biases in the data collection process. In addition, during the writing of the two co-authored papers (Papers I and II), discussions among the authors were continuously held to create overlap between data collection and data analysis.

Since the studies in this thesis could be categorized as exploratory, pattern matching (a comparison between observed patterns and those established in previous studies) was not performed. On the contrary, patterns needed to be explored rather than confirmed (Eisenhardt and Graebner, 2007). Construct validity was addressed mainly by trying to establish a clear chain of evidence to allow readers to see how the purpose of each study matched with key conclusions (Yin, 2008). Moreover, as described above, triangulation among different data sources was conducted to increase the validity (Yin, 2008). In addition, the use of multiple case studies strengthens the external validity, as this approach is suitable when the aim is to build new theory (Eisenhardt and Graebner, 2007). Finally, the fact that all cases in this thesis were selected within the process industries with similarities in their contextual characteristics is beneficial because it is easier to see clear patterns and draw valid conclusions. Nevertheless, this also implies some limitations, as external validity
(generalizability) is problematic with a research design like the one in this thesis. However, the main objective is to employ analytical generalization – from empirical observation to theory – rather than extension to a population. Hence, no attempt is made to generalize the findings beyond the sample investigated. Still, this project is focused on contributing to our knowledge about open and collaborative innovation rather than strictly following methodological postulates. In his seminal article “Theory Construction as Disciplined Imagination” (Weick, 1989), Weick highlights this issue:

“Therists often write trivial theories because their process of theory construction is hemmed in by methodological strictures that favour validation rather than usefulness (Lindblom, 1987). These structures weaken theorising because they de-emphasise the contribution that imagination, representation and selection make to the process, and they diminish the importance of alternative theorising activities such as mapping, conceptual development, and speculative thought. Theory cannot be improved until we improve the theorising process, and we cannot improve the theorising process until we describe it more self-consciously, and decouple it from validation more deliberately.”
Summary of the results in the appended papers

This chapter presents the main results of the appended papers based on the empirical analysis. These three appended papers collectively contribute to fulfill the purpose of this study. In this chapter, a brief introduction to the purpose of the appended papers and, finally, the results of each paper are presented. The next chapter will provide a discussion of these results in relation to the theory and practice.

4.1 Paper I


Summary

The purpose of this article is to explore how firms can benefit from opening up the NPD process by integrating the principles of open innovation with the well-known and widespread Stage-Gate process. By means of a case study, we probe the existing occurrences and potential opportunities of employing the principles of both inbound and outbound open innovation within new product development at Vetco Gray (VG), a firm in the upstream oil & gas industry.

Based on the case study data, we argue that there are great virtues in systematizing the currently opportunistic occasions of open innovation practices within VG’s NPD process. The interviews and observations indicate positive attitudes towards current open innovation practices, but highlight in addition the need for increased systematization of those practices. The empirical evidence further indicated limitations in the current business model and core capabilities, thus underscoring the need to continuously reexamine and, if applicable, initiate a process to rethink these.

By combining information and experiences from the firm studied with relevant theory, the paper outlines a potential new and revised model for NPD. The key contribution is the enactment of a practitioner-oriented work model, named the open Stage-Gate model, which exploits the advantages of “openness” while simultaneously capturing the benefits deriving from the systematic and structured
approach implied by the Stage-Gate process. While the open Stage-Gate model allows explicit consideration of import and export of know-how and technology through gate evaluations, it also allows firms to continuously assess their core capabilities and business model. The model has major implications for how to capture value from both internal and external technology exploitation in increasingly open innovation processes.

4.2 Paper II


Summary

The purpose of this article is to explore the problems and opportunities faced by process firms and their equipment suppliers throughout the lifecycle stages of collaborative development projects. By means of a case study in two process firms and by combining literature on open innovation, collaborative development and buyer-supplier relationships, this paper sheds light on the problems and opportunities arising in different lifecycle stages when new process equipment is developed with multiple partners involved.

The empirical findings identified several potential opportunities and risks in collaboration, for both the process firm and the equipment supplier, during the different stages of the equipment lifecycle. Consequently, the collaboration intensity also differs according to stage. Moreover, the findings underscore the importance of a lifecycle perspective since the collaboration intensity is interconnected across different stages. Deficient collaboration in early stages can be difficult to improve significantly in later stages. Moreover, collaboration in the FFE, start-up, and operation stages is primarily of a dyadic nature – whereas the development and assembly stages involve collaboration in a network of suppliers, especially when concurrent engineering is adopted. These differences bring about a need for process firms to tailor their collaborative practices and mechanisms to changing contingences in different stages.

This paper highlights the fact that strong collaboration is neither positive nor negative in general. Rather, opportunities, problems, and collaboration intensity are strongly contingent on the specific stage in the lifecycle of process equipment. The main implication of this paper is therefore the adoption of a lifecycle perspective on the development of process equipment, making it possible to assess all development stages in terms of idiosyncrasies and interconnections.
4.3 Paper III


Summary

The purpose of this article is to explore the problems and opportunities faced by equipment suppliers in collaboration with process firms throughout the different stages of operational projects. Empirically, results are obtained from 22 interviews in a multiple case study of seven equipment suppliers to the process industries.

The results show that strong collaboration is often required in operational projects to facilitate technology transfer and better operational performance. In particular, collaboration is essential to transfer knowledge about the equipment from the equipment supplier to the process firm in the start-up stage, where intimate educational activities are typically required. In addition, collaborative activities during production are increasing as the equipment suppliers expand their business models to be service providers.

By focusing on the collaborations between process firms and equipment suppliers in the operational stages, this study has shown how open innovation can facilitate not only product innovation but also process innovation, by means of collaborative selection and installation of new process equipment – i.e. “open operation”. As such, this study complements earlier research on open innovation that has mainly focused on collaboration during the development stages. The conclusion is that opportunities and problems are strongly contingent on the specific stage in the operational project. The findings of this paper can be used to remind managers in equipment suppliers of the problems and opportunities that arise during the different stages of operational projects. In particular, it is important to recognize that failure to address problems in early stages will often compound and create bigger problems at later stages.
Summary of the results in the appended papers
5

Discussion

In this chapter an overall discussion of the results is first put forward as a backdrop for in-depth discussions of the most prominent theoretical implications of the study. Then, managerial implications are provided. The final sections present limitations, suggestions for future studies, and conclusions.

5.1 Discussion

By examining the problems and opportunities arising when firms attempt to integrate open innovation activities within their development processes, the studies in this thesis have shown that while considerable value can be generated by opening up the development process, the adoption of open innovation practices is not without challenges.

Study I highlighted some of the struggles that many firms are likely to face when attempting to integrate open innovation principles with conventional Stage-Gate methodologies for NPD. In Study I, the respondents highlighted the lack of structures and systematized processes for open innovation as a major impediment in their open innovation attempts. Consequently, the open Stage-Gate model was developed in Paper I, as a first step to overcome these limitations and deficiencies. The model underscores the need for increased systematization in the process of importing and exporting know-how and technology to leverage the opportunities presented by open innovation.

Studies II and III focus on a more concrete application of open innovation by examining collaborative development and installation of process equipment among process industry firms and their equipment suppliers. The analysis highlighted a number of problems and opportunities in the different lifecycle stages. Furthermore, as studies II and III represent the perspectives of process firms and equipment suppliers respectively, this allows the possibility of comparing the perspectives from the two sides. As could be expected, there were a lot of similarities in the opinions from the two sides.

The early pre-study stage of collaboration was recognized as critical by both parties, but still there were problems at this stage. The main challenge at this stage was
posed to the process firms in establishing clear and explicit goals and objectives for the project in order to communicate these effectively to their collaborating partners, thus highlighting a critical issue for firms engaging in inbound open innovation activities (Slowinski et al., 2009; Witzeman et al., 2006).

In addition, the start-up stage was regarded as difficult and critical by both parties. A project manager at Lakeland even described this stage as “characterized by chaos”. However, despite the parties’ explicit awareness of the problems at this stage they still struggled with finding appropriate ways of countering these problems. Nevertheless, some practices seemed to be helpful in achieving a proficient start-up. Among these was early planning and organization of start-up activities and many respondents highlighted the appointment of a start-up manager at an early stage as best practice. In addition, this stage was considered critical for efficient transfer of the equipment to the end user. This issue was particularly underlined by the equipment suppliers.

In the operation stage the respondents from the process firms described a fear of letting the equipment suppliers learn too much about the way they run their processes. On the other hand, for the equipment suppliers getting more knowledge and being more involved in the production stages was a strategic objective. Therefore, the issue of collaboration during production should be of prime concern for both process firms and equipment suppliers to consider in the future. In particular, study III showed that the equipment suppliers were generally trying to increase their lifecycle commitments by complementing their product offerings with service innovations (i.e. service, maintenance and optimization). Nevertheless, the process firms in study II did not seem particularly interested in these services as they wanted to keep such competences in-house. However, new entrants within the process industries that have not yet established competences in these areas were underlined as potential customers to these service innovations.

5.2 Theoretical implications

The studies in this thesis complement earlier open innovation research, by studying the open innovation concept within the process industries.

Paper I makes several contributions to the technology and innovation management literature. First, the paper provides a theoretical starting point for integrating the principles of open innovation with mainstream models for NPD (Lichtenthaler, 2011). As such, it addresses previously noted deficiencies in the open innovation literature (Lichtenthaler & Lichtenthaler, 2009, Elmqvist et al., 2009). This is important as theoretical development is made by building on earlier conceptual and theoretical insights. While the open innovation concept is not a new theory, it may benefit from combining it with earlier work to arrive at a sound theoretical foundation of open innovation research (Lichtenthaler, 2011). Moreover, Paper I fill a gap in the Stage-Gate literature by outlining an open Stage-Gate model, an area
Discussion and Conclusion

where the existing literature lacks sufficient details (Cooper, 2009; Cooper, 2008). In particular, it provides a starting point towards further studies of open stage-gate processes and how they should be designed. Overall, the paper contributes to advancing the somewhat abstract theory of open innovation to a more concrete and useful level.

The main theoretical contribution of Papers II and III is the adoption of a lifecycle perspective on the development of process equipment, making it possible to assess all development stages in terms of idiosyncrasies and interconnections. The empirical findings underscore the importance of a lifecycle perspective since the collaboration intensity is interconnected across different stages. Deficient collaboration at early stages can be difficult to improve significantly at later stages. However, risks of losing core knowledge may be higher in specific stages for the collaborating partners. As such, the respondents mainly highlighted the risks in the development stage for suppliers and in production for process firms. Therefore, these studies highlight the fact that being totally open in development activities is not always the most suitable option (Enkel et al., 2009; Lazzarotti & Manzini, 2009). Instead, different degrees of “openness” may be suitable at different stages.

In addition, Papers II and III extend the research on open innovation by focusing not only on product development but also on process development, by means of development and installation of new process equipment. This is an important contribution as prior research on open innovation has neglected this issue (Chesbrough et al., 2006). More importantly, process development is of critical importance for firms in mature industries (Utterback & Abernathy, 1975). Despite this fact, prior research on process development is scarce (Pisano, 1997; Reichstein and Salter, 2006). In particular, Paper III shows how collaboration between equipment suppliers and process firms facilitates process development through activities such as joint selection and design/development of proper process equipment for the process firms’ specific production applications, mobilisation of joint resources for a smooth installation and start-up, and subsequent efficient operation utilising the combined expertise of both parties. With this background, the term “open operation” is used to conceptualize these activities.

Moreover, Studies II and III address the dyadic relations between process firms and equipment suppliers, as well as the inter-organizational networks constructed from these dyads – an issue considered important in open innovation research, as most previous research has emphasized the activities of the single firm (Chesbrough et al., 2006). As such, the analysis of these studies facilitates better understanding of the different activities over the lifecycle by simultaneously capturing the perspective of both the process firms and the equipment suppliers. Further, by comparing the different perspectives a clearer interpretation of the critical challenges in these collaborations is possible.
In addition, Papers II and III have highlighted the importance of the start-up stage, which has been neglected in prior research.

A final note is that Paper III underlined the importance of service innovations for equipment suppliers as a way of increasing their lifecycle commitments. This corresponds with reports from previous literature (Hicks and McGovern, 2009; Ivory and Alderman, 2009, Shelton, 2009). Moreover, these developments are in line with the ideas of open services innovation (Chesbrough, 2011) where business models are expanded as firms find new revenue streams in a services-based economy.

5.3 Managerial implications

For firms attempting to manage open innovation within the process industries, several recommendations can be made based on the results of this thesis.

First and foremost, managers are encouraged to look into the principles of the open Stage-Gate process, developed in Paper I, because it represents a more open and dynamic perspective on the NPD process. The model systematizes import and export of know-how and technology, and reminds the NPD team as well as gate-keeping managers to pay attention to the opportunities that may arise from opening up the NPD process. In particular, the open Stage-Gate model devotes significant attention to the opportunities of exporting internally generated knowledge to increase the profits from internal NPD. It also systematically allows managers to evaluate whether import of know-how and technology can add value to the firm’s own development activities. Furthermore, by systematically assessing the firm’s core capabilities and business model, a first step is taken towards creating a dynamic and adaptable NPD process that sustains long-term competitive advantage and allows the firm to fully realize the benefits of open innovation. In addition, the open Stage-Gate model reminds managers that the NPD process is an organizational vehicle for uncovering core rigidities and for the exploration of potentially new capabilities and business models. Consequently, the open Stage-Gate model represents a new, more externally aware and dynamic way of viewing the NPD process, and provides a basis for firms seeking to apply the principles of open innovation within their NPD process.

Secondly, on a general level both Papers II and III highlight the importance of adopting a lifecycle perspective on collaborative development projects. The findings of these papers underline the fact that the need for collaboration at each stage is different because the collaborating firms struggle with different technical, organizational, and managerial activities at each stage. Therefore, managers from both sides should tailor the content and the intensity of the collaboration to manage problems and opportunities in the different stages of the equipment’s lifecycle. Moreover, there are considerable overlaps and interconnections among different stages, in terms of activities performed and resources required. As such, it is important to underscore that collaboration intensity is interconnected across stages.
Discussion and Conclusion

That is, deficient collaboration at an early stage may lead to significant problems later on during the project. To this end, process firms and equipment suppliers should at an early stage during purchasing discussions be aware of and jointly discuss potential problems and opportunities in future stages during the lifecycle.

Third, the start-up stage was underlined as a crucial stage for collaboration by both process firms and equipment suppliers, since it is particularly difficult and of strategic importance in process firms. Therefore, managers in process firms and equipment suppliers should devote significant attention to the management of this stage. Primarily, the respondents agreed that the start-up stage should be planned in detail and organized purposefully from the outset of the project. Furthermore, many respondents highlighted the appointment of a start-up manager at an early stage as best practice. In addition, collaboration during the start-up stage is critical in order to fully transfer the process equipment to end users (Hausman and Stock, 2003). This issue was particularly underlined in Paper III. The respondents agreed that while formal mechanisms are appropriate for capturing and transferring explicit parts of technology, other approaches are necessary for sharing the tacit component, which is non-codifiable in nature (Lynskey, 1999). As indicated by the respondents, this is particularly true for the operation of complex process equipment. In particular, it was noted that operators at the process firm cannot learn all of the capabilities of the equipment by merely studying written documentation about the equipment. Rather, the tacit knowledge often has to be transferred through hands-on education, such as direct, first-hand observation and operation in collaboration with knowledgeable personnel from the equipment suppliers. As such, this study further highlights the need for collaboration and knowledge management during the start-up stage as essential for the technology transfer of process equipment (Lager, 2011).

Another recommendation is to involve end users (i.e. operators, maintenance personnel) at an early stage, to obtain their input to the design work. If end users' input to design is acquired early, the design can be “frozen” early in order to avoid late changes. Previous research has found that late client-initiated design changes are a common cause of both time and cost overruns (Assaf & Al-Hejji, 2006; Oladapo, 2007), which underscores the importance of early end user involvement. Moreover, Study III highlighted the fact that early involvement of end users had a positive effect on their commitment and willingness to take part in the start-up stage.

Moreover, risks of losing core knowledge may be particularly high in specific stages for the collaborating partners (e.g. in the development stage for suppliers and in operations for process firms). Consequently, managers from both sides must carefully think through why, when, and to what extent collaboration is needed, and make sure that the advantages outweigh the disadvantages.
5.4 Conclusions, limitations and outlook

Managers and researchers alike will benefit from the findings in this thesis as they attempt to find appropriate ways of managing open innovation. A couple of general conclusions can be made based on the key findings from the appended papers. The first one is that as firms attempt to implement open innovation practices, increased systemization is needed to coordinate the activities. The second conclusion is that as activities vary over the different stages of a development project, different management approaches and different degrees of openness are typically required.

Nevertheless, a couple of important limitations of this thesis are worth mentioning. Although a large number of interviews constitutes the empirical basis of the thesis, case study data still delimit generalizability. In particular, all empirical data are collected from the process industries and therefore caution should be taken in generalizing the findings to other contexts. As such, the findings in general should be considered in their contextual setting, but some implications may very well be extended to comparable manufacturing firms. As a result, the selection of firms from one industry makes the analysis of the empirical data more applicable for process firms, but it limits theoretical generalization to other contexts (Eisenhardt and Graebner, 2007). For example, the start-up stage which is a key concern in process industries may be critical in other manufacturing industries as well. However, managers in these manufacturing firms must interpret the findings in this thesis and relate them to their specific context.

To further increase our understanding of open innovation in the process industries, research on the project level would add to our detailed understanding of how different project characteristics affect collaboration. Moreover, larger operational projects are, according to the empirical data, especially complex to manage, and could thus be an interesting avenue for further research. In addition, it would be fruitful to investigate more innovative development projects in the context of the process industries. Another relevant approach would be to quantitatively investigate these different types of collaborative development projects in order to make more general conclusions possible and to compare different types of process industries (e.g. pulp/paper, food, and metals/minerals). In addition, more research on firms that have implemented open Stage-Gate models should provide further empirical bases, and practical advice, for what is partly a conceptual construction.


References


Part II
Appendix I: Interview guide for Study I

A) General questions

1. What is your formal position?
2. What are your work duties?
3. How much of your work time is dedicated to product development?
4. What is your background and education and how long have you been working for Vetco Gray?

B) Questions regarding the product development process (Tollgate)

1. We are familiar with the Tollgate process currently in use. Are there any differences between the "conceptual process" put on paper and the one used in reality? If so, where in the process do these differences exist?
2. On which criteria are projects evaluated, and who participates in the evaluation process?
3. What are the main reasons as to why projects are stopped?
4. What happens to projects that have been stopped? Is there a formal and documented mechanism for handling stopped projects or is it done on an ad-hoc basis?
5. In general, when projects are stopped, do you believe that they possibly are stopped too early or too late? Please explain and elaborate.
6. If you were to change the product development process, what changes would you suggest? Is there room for improvement in the process? If so, where?

C) Questions regarding the use of external know-how & technology and external paths to market

1. Does Vetco Gray make a practice of bringing in external know-how and/or technology?
   If yes:
   a. What kind of know-how and technology?
   b. Where do this know-how and technology come from? (E.g. universities, start-ups, industry groups, parent company, other business units?)
   c. When in the process are external know-how and/or technology most commonly used? (Refer to the Tollgate process.)
   d. How are know-how and technology accessed? (Joint ventures, acquired, licensed etc.)
   e. Are external know-how and technology used on a systematic basis or ad-hoc (opportunistically)?
   f. How has bringing in external know-how and technology helped Vetco Gray?
g. How important are external know-how and technology in the NPD process?

2 To what extent are the Global Research Centers (GRC) and other GE businesses used in order to find applicable know-how and technology?

3 Does Vetco Gray practice external paths to market for know-how and/or technology that, for various reasons, have been chosen not to be used internally? (E.g. patents, components, new technologies, blueprints.)

If yes:
a. What kind of know-how and technology?

b. Who buys/licenses this know-how and technology? (Industry groups, public-private cooperation, patent brokers.)

c. When in the process is this most common? (Refer to the Tollgate process.)

d. Which modes are most common when know-how and technology are exported? (Joint ventures, sold, licensed out etc.)

e. Is this done on a systematic basis or ad-hoc (opportunistically)?

f. What impact has exporting know-how and technologies had on Vetco Gray?

D) Core capability and business model considerations

1 How would you define Vetco Gray’s core capabilities?

   a. Have the current core capabilities always been core capabilities? Elaborate.

2 How much of your working time is spent on core activities?

3 To what extent are the non-core activities (necessary to complete the offering) sourced from outside the ATO organization? I.e. conducted by someone external to Vetco Gray?

4 Do you believe that non-core activities which are conducted in-house today could be performed by external partners to a greater extent than what is currently the case?

5 How would you characterize Vetco Gray’s business model?

6 What strengths and weaknesses do you see with the current business model? Elaborate.
Appendix II: Interview guide for Study II

A) Background information

1. What is your formal position?
2. What is included in your work tasks?
3. What are your background and education, and how long have you worked for your present employer?
4. What experience do you have of collaborative projects with equipment suppliers? (Explain briefly.)

B) Driving forces for collaboration

1. Is collaborative development with equipment suppliers a part of your company’s strategy? If yes, in what way? Elaborate and explain!
2. What are the main goals/driving forces for collaborative development from your company’s perspective?
   a. Which of these goals/driving forces is most important for your company?
   b. How is this goal related to the goals and needs that your company’s customers have?
3. What are the main goals/driving forces for collaborative development from the equipment supplier’s perspective?
   a. How do you work in order to comply with these goals/driving forces?
4. Goals and driving forces are not always the same for process companies and equipment suppliers. When differences arise, how do you work in order to align your goals/driving forces with those of the equipment suppliers?
   a. Are the goals/driving forces for collaboration discussed between the companies?
   b. How would you characterize the differences between process companies and equipment suppliers regarding goals/driving forces?
5. How do you think the equipment supplier looks upon developing equipment that is specifically developed to meet your company’s needs and therefore cannot be sold further to other customers? Problems/opportunities?
6. Which type of knowledge and technology is your company mainly interested in obtaining from your equipment suppliers?
7. Which type of knowledge and technology are your equipment suppliers mainly interested in obtaining from your company?
8. When collaboration is initiated, is this driven by the process company or the equipment supplier?
C) Problems and opportunities in different phases in the lifecycle of process equipment

Respondents were shown the Lager and Frishammar (2010) model of the different stages in the life cycle of process equipment.

9. How is work performed during the different stages in the lifecycle of process equipment? (Respondents were asked to elaborate on each stage)

10. How would you describe the intensiveness of the collaboration in each stage of the life cycle of process equipment? (Respondents were asked to elaborate on each stage)

11. In which phase is it most important to collaborate? Why?

12. Which are the most frequent problems/risks in collaborative projects for development of process technology?
   a. In which stages of the process equipment’s life cycle are these problems/risks greatest?
   b. What do you consider to be the causes of these problems/risks?
   c. How do you deal with these problems/risks?

13. Which are the central advantages/profits of collaboration between process companies and equipment suppliers?
   a. In which stages of the process equipment’s life cycle are these benefits/opportunities greatest?
   b. How do you work to profit from these benefits/opportunities?

D) Management and organization of collaboration

14. How are collaborative projects organized?
   a. Which departments and persons are involved?
   b. Who is responsible for what in the project during different stages?

15. How do you choose suppliers for collaborative projects?
   a. When are these typically engaged?

16. Which forms of contract and compensation are used in the joint collaborative projects?

17. Does your company influence the equipment supplier’s choice of subcontractors?
   a. Is there any difference between purchasing of “installation” and “components”?

18. Are agreements written in regard to secrecy in projects so as to prevent the spread of knowledge and technology to competitors and/or other actors? (e.g. non disclosure agreements)
   a. How are these agreements designed?

19. How are rights in regard to intellectual capital handled for joint development?

20. To how high a degree do collaborative projects with equipment suppliers fulfil the given goals?
Appendix III: Interview guide for Study III

A) Background information:

1. What is your formal position?
2. What are your primary working tasks?
3. What are your background and education, and how long have you worked for your present employer?
4. What experience do you have of collaboration projects with your customers? (Explain briefly.)

B) Describe a collaboration project:

To focus the discussion the respondent is asked to think of an important collaboration project with a customer and to reflect on this by answering a number of questions that discusses the collaboration through the project’s life cycle. (Do not think only of successful projects; failures and why they happened are also interesting.) The answers on the project level is compared with the equipments suppliers overall portfolio of collaboration projects with customers throughout.

5. What was the purpose of the project?
   a. Which product was developed?
   b. How large was the project in terms of time and money?
6. Who initiated the collaboration – you or the customer?
7. To what degree did you discuss and take account of the respective parties’ aims and motives for the project?
8. What were the main aims/motives for development collaboration from your company’s perspective?
   c. Was the possibility discussed of creating equipment that can also be sold to your other customers, and the problems/opportunities with such an arrangement?
9. What were the main aims/motives for collaboration from your customer’s perspective?
10. What were the biggest differences in aims/motives between process company and equipment suppliers?
11. What were you most interested in getting from the customer in the project? (knowledge/technology)
12. What was the customer most interested in getting from you in the project? (knowledge/technology)
13. How high was the degree of newness of the equipment that was developed in the collaboration project? (Low, medium, high?)

Degree of newness is defined as how new and untested the technology is within the process industry.
   d. How did the degree of newness influence the collaboration project’s conduct?
14. How high was the customer adaptation of the equipment that was developed in the collaboration project? (Low, medium, high?) Customer adaptation is defined as the degree to which the equipment is adapted (tailor-made) to the customer’s specific needs.
   e. How did the degree of customer adaptation influence the collaboration project’s conduct?
15. How high was the complexity of the equipment that was developed in the collaboration project?
   Complexity is defined as the degree to which the equipment and the development collaboration consisted of several integrated and mutually dependent components, activities and actors.
   f. How did the degree of complexity influence the collaboration project’s conduct?
16. Which forms of contract and compensation were used in the collaboration project?
17. Was an agreement signed about secrecy in the project to prevent spreading of knowledge and technology to competitors and/or other actors?
   g. How was this agreement designed?
18. How were questions handled regarding patents, drawings, and intellectual capital?
19. Did you have an interest in making a larger life-cycle commitment for the process equipment that was developed? (Such as remaining the owner of the equipment and being responsible for the operations.)
   h. What were your motives for this?
   i. Is this something your customers were interested in?

C) Collaboration during different phases of the life cycle:

![Flowchart of life cycle phases](image)

*The respondent is asked to answer the following questions for each of the stages in the life cycle (pre-study, purchasing and development, assembly and installation, start-up and production):*

20. What did the collaborative activities where conducted during this phase? (Who did what? When?)
21. Who was most committed during this phase – you as equipment supplier, or your customer?
22. Were any competing suppliers involved in this phase, and what were the effects?
23. Did you also collaborate with other complementary suppliers (customers?) during this phase?
24. Which of your departments and persons were involved, and how did they collaborate?
25. Which of the customer’s departments and persons were involved, and how did they collaborate?
26. How did the internal collaboration work in the respective company?
27. How high was the intensity of the collaboration during this phase, and what were the reasons?

D) Summarizing reflections:

28. In which phase was it most important to collaborate? Why?
29. What was the outcome of the project?
   a. Did the project fulfill your and the customer’s aims?
   b. Were both parties satisfied?
   c. How well did the project agree with the budgeted/estimated time and cost? How are the deviations explained, if any?
   d. Did you achieve the expected profits from sales of the equipment?
   e. What were the biggest advantages that you achieved by collaborating?
   f. What were the most important reasons why the collaboration worked well?
30. What were the greatest problems with collaboration during the project?
   g. What were the reasons for these?
   h. How did you handle these problems?
   i. Could you have done anything differently?
   j. What are the most important changes that you can think of making in order to achieve even better collaboration in the future?
Open Innovation and the Stage-Gate Process: A Revised Model for New Product Development
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Open Innovation and the Stage-Gate Process: A Revised Model for New Product Development

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“...innovators win” is the common message in much of today’s business literature. The question is no longer why to innovate, but how to innovate. However, all innovative activities need not be performed by a local firm. A recent trend in the evolution of innovation theory recognizes that not all good ideas come from inside the firm; neither need all good ideas emerging within the particular firm be commercialized by that same firm. Henry Chesbrough coined the term “open innovation” to describe this trend, and it has been ascertained that a new era with innovation management is emerging: the era of open innovation. Chesbrough defines open innovation as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively.” The inherent logic of this definition is simply that firms can and should use external as well as internal ideas, and both internal and external paths to market, when they seek to maximize returns from new product development (NPD).

Indeed, some firms have come to realize that in today’s global competition, it is not enough to use innovative ideas generated internally. Procter & Gamble, for example, went from “Research & Develop” to a revised development strategy called “Connect & Develop” aimed at profiting from the use of ideas from millions of external inventors worldwide. This allowed the company to increase R&D productivity by about 60%, while simultaneously approaching the goal of finding half of its innovations outside the company. Similarly, Air Products uses its “identify and accelerate” strategy to accelerate the innovation process.

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process. This strategy includes deliberate external partnering strategies, global R&D in-sourcing, Internet-based knowledge providers, and formal mechanisms to evaluate external ideas. This strategy has enabled Air Products to innovate faster, better, and at lower cost. Although somewhat anecdotal, these two examples illustrate some of the benefits resulting from a more open approach to innovative activities.

Given the success of some pioneering firms, it seems justified to ask why the majority of companies do not adopt a more open approach to innovation. One reason is that many firms struggle with the challenge of sustaining internal commitment over a sufficient period of time to realize the benefits of open innovation. Moving from a set of ad-hoc processes to clearly defined open innovation practices, systems, roles, and responsibilities is critical in order to ensure successful adoption of open innovation across the organization. A challenge in realizing the potential benefits of open innovation thus lies in modifying existing innovation activities and processes to fit with open innovation principles, rather than creating something completely new.

The purpose of this article is to explore how firms can benefit from opening up the NPD process by integrating the principles of open innovation with the well-known and widespread Stage-Gate process for organizing NPD. This article presents a dynamic and practitioner-oriented work model that leverages the benefits of open innovation, minimizes the associated risks, and allows systematic evaluation and reconfiguration of the way value is created and captured through NPD. Some best-practice firms have already begun to open up their NPD process. However, the existing literature falls short on describing how these companies have adapted their internal work models and processes to facilitate open innovation. There is a need for a new and revised model that helps practitioners adapt their current NPD process to incorporate the principles of open innovation. Accordingly, such a model provides a point of departure in the transformation process toward a more “open,” yet systematic, approach of conducting NPD.

Theoretical Framework

Open Innovation

To understand the principles of open innovation, it is important first to know the fundamentals of “closed innovation.” In a closed innovation model, the development as well as marketing of new products takes place within the boundaries of the firm. Resources are fed into a development funnel for inventions to appear in the end. This approach to managing innovation was dominant
during the late 20th century. However, as a result of environmental changes, companies began to look for new ways of managing the innovation process, resulting in what Chesbrough refers to as the open innovation model.\textsuperscript{10} The fundamental difference between the closed and the open innovation models is that, in the open model, know-how and technology can pass out of, as well as into, the NPD funnel side over time. While a cancelled NPD project is put on the shelf in the closed innovation funnel, the open innovation funnel allows know-how and technology generated from the project to exit and find external paths to market. For firms to prosper in the era of openness, they need to realize that they do not employ all the smart people, they do not have to originate research in order to profit from it, and that it is imperative to make the best use of internal as well as external ideas.\textsuperscript{11}

Although the term “open innovation” is new, the fundamental ideas are not altogether new.\textsuperscript{12} External collaboration is as old as the first invention.\textsuperscript{13} The concept of open innovation is, however, more than just a new term. It is a broader concept of leveraging external sources of knowledge to drive internal growth. It also explicitly addresses the internal configurations needed for managing a more externally oriented innovation process. In comparison with the older literature, it provides not only a more detailed, but also a more holistic perspective on external collaboration and commercialization. The main benefits of open innovation are the ability to leverage NPD on someone else’s budget, a greater sense of urgency for internal groups to act on ideas and technology and, over time, an opportunity to create a more innovative culture from the “outside in” through continued exposure and relationships with external innovators.\textsuperscript{14}

Adapting open innovation principles requires proficiency in several different activities. Such activities include: seeking opportunities, evaluating each opportunity, recruiting potential partners, value-capturing through commercialization, and extending the innovation offering.\textsuperscript{15} Hence, more than technological systems need to change in order to benefit fully from external opportunities, especially since companies often train their employees to think “internally” by introducing introspective concepts such as core competences, Stage-Gate, and Six Sigma.\textsuperscript{16} A fundamental change is required to increase external thinking, and management plays an important role in the transition.

Nevertheless, previous research has also identified possible downsides of open innovation. Christensen and colleagues mention the coordination costs, mainly as a result of contractual negotiations, that may arise from involving external parties in the innovation process.\textsuperscript{17} Furthermore, customer integration imposes risks when practicing open innovation such as the potential loss of know-how, being overly dependent on customers’ views, and being limited to incremental innovation. Still, not integrating customers at all might expose firms to even greater risks.\textsuperscript{18}

The concept of open innovation provides an important foundation for our research by highlighting the opportunities associated with utilizing external know-how and technology, as well as the benefits arising from external paths to market.
The Stage-Gate Process

Stage-Gate methodologies are recognized and widely embraced in companies all over the world as a method of bringing order to the sometimes chaotic process of product innovation. After surveying NPD best practices, Griffin noted that 60% of responding NPD functions were using some form of Stage-Gate methodology.\textsuperscript{19} Robert Cooper, who coined the concept, describes it as both a conceptual and an operational model for moving a new product from idea to launch. The focus lies on managing the NPD process to improve effectiveness and efficiency by integrating discipline into a process described as ad-hoc and seriously deficient in many firms.\textsuperscript{20} The original Stage-Gate process was the result of extensive research on how successful companies were structuring their NPD processes.\textsuperscript{21}

The Stage-Gate process consists of a series of stages where essential activities are carried out. The stages are complemented by gates where interim achievements are evaluated. The stages comprise the actual development work. The specific activities performed depend on which stage the project is in. In the early stages, activities generally focus on discovering opportunities and generating ideas, while the later stages focus on concept development, testing, and commercialization. Stages are typically cross-functional and each activity is undertaken in parallel with others so as to enhance speed to market. Each stage typically costs more than the preceding one, resulting in increased commitments but also in a reduced number of unknowns and uncertainties so that risk is effectively managed.\textsuperscript{22}

The gates function as stop/go and prioritization points where decisions for the future of the project are made. The gates are typically manned by a cross-functional group of senior managers, called gatekeepers, who evaluate projects on the basis of quality of execution, business rationale, and the quality of the action plan. The gates serve the important function of canceling or redefining projects that fail to meet objectives. The gates contain three significant elements: deliverables, criteria, and outputs. The deliverables are inputs to the gate review, i.e., the project manager's and team members' contributions. These should be defined in advance and are the results of the activities executed in the preceding stage. Usually, a standard menu of deliverables is specified for each gate. The projects are then evaluated by a set of criteria. The decision criteria are often divided into must-meet criteria (focusing on weeding out misfit projects quickly) and should-meet criteria used to prioritize the remaining projects. These criteria are usually organized into a scorecard and include both quantitative and qualitative criteria. Examples of criteria include strategic fit, expected financial returns, and whether the project leverages the company's core competences.\textsuperscript{23} The last element, output, represents the actual results of the gate review. Output from the gate review includes a stop/go decision and an execution plan, including date and deliverables for the next gate review.\textsuperscript{24}

Research shows that the Stage-Gate process has been highly appreciated.\textsuperscript{25} If well implemented, the Stage-Gate process can energize and speed up a firm's NPD efforts.\textsuperscript{26} However, the Stage-Gate process has not been received
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without criticism. It has been said to be time-consuming, resulting in time-wasting activities. Other downsides include bureaucratic procedures, no provision for focus,27 and restriction of learning opportunities.28 As a response to the criticism, the next-generation Stage-Gate process was developed, which focused on speeding up and improving the efficiency of the process by incorporating a series of overlapping, fluid stages with fuzzy or conditional-go decisions.29 Recently, further developments of the Stage-Gate process have been reported,30 primarily focusing on making the NPD process both faster and more effective as well as increasing flexibility and adaptability.31 Moreover, some firms have adapted their Stage-Gate processes to accommodate open innovation activities. However, while recent advances in the Stage-Gate literature do underscore the importance of open innovation activities, it fails to provide guidelines for how to actually incorporate such activities.32

The Stage-Gate process provides another important foundation for our research. First, it provides structure and is currently applied by a majority of firms conducting industrial NPD. Second, some of its inherent limitations can be overcome by incorporating the principles of open innovation. Finally, gate evaluations provide an arena for managers assessing and rethinking core capabilities and business models.

The Role of Core Capabilities and Business Models in NPD

During the 1990s, Prahalad and Hamel, among others, brought attention to the concept of core capabilities.33 In order to compete successfully in the long term, they argue, firms should focus on developing a limited set of distinctive core capabilities that would allow specialization and synergistic economies, through which firms would be able to deliver an ongoing flow of innovations to multiple markets. Essentially, core capabilities refer to a firm’s expertise or skills in key areas that directly yield superior performance.34 The inward-looking view of core capabilities is rooted in the resource-based view.35

Today, in light of an increasingly dynamic and open industrial landscape, focusing on appropriating value from unique capabilities has become a mandate for sustained firm prosperity.36 Specifically, the fact that firm’s often collaborate in value networks (including a variety of different partners) highlights the need for individual firms to focus on core capabilities to add value.37 A distinctive set of core capabilities also underpins a firm’s business model.38 In particular, the relationship between core capabilities and business models has been underscored in recent years with the shift towards more open innovation processes.39 In essence, a business model is based around two key parts: creating value, and capturing a portion of that value.40 As such, a business model provides a focusing device that mediates between development efforts and value creation,41 and that underscores the way the firm generates profits.42

However, neither core capabilities nor business models should be regarded as static entities. Leonard-Barton noted that core capabilities could both enable and inhibit innovation.43 Core capabilities can turn into core rigidities that inhibit a firm’s evolution if managers are unwilling or unable to adjust these
to changing conditions. Thus, core capabilities present a paradox: they simultaneously enhance and inhibit development. At any given point in a firm’s history, core capabilities should be evolving, and corporate survival depends on successfully managing that evolution. Similarly, business models must not be viewed as static entities. Companies should continuously test and evaluate their existing as well as potential business models, since the probability of long-term success increases with the rigor and formality with which an organization tests its strategic options. Consequently, firms have to enact and, if necessary, adjust or replace current business models. That is, they need to engage in the exploration of new ways of value creation and capturing, i.e., business model innovation.

According to prior literature, NPD serve as an organizational vehicle for adjustment of both core capabilities and business models. The need to continuously adapt and adjust capabilities in light of environmental changes is widely supported in the dynamic capabilities literature. Moreover, the dynamic capabilities literature portrays NPD as the key example of what constitutes a dynamic capability. As such, NPD projects pave the way for organizational change by highlighting possible core rigidities and the need to reconsider one’s core capabilities. Capabilities are, however, inert to change and are established in path-dependent learning cycles. Moreover, the accumulation of capabilities is driven by complementary assets and industry opportunities. Therefore, capabilities are not dramatically altered by a single project, but NPD projects nevertheless provide the opportunity to challenge current practices and to model alternative capabilities. Similarly, NPD can be a source of business model innovation because not all NPD projects fit with the established business model. Consequently, business model experiments need to be a fundamental part of managing the NPD process.

The idea of viewing the business model and core capabilities as dynamic entities, which need to evolve along with changing demands, adds an important aspect to our research as these concepts are paramount to understand how value is created and captured within a firm. Moreover, viewing NPD as a dynamic capability explicitly allows configuration of core capabilities and business models.

**Method and Research Approach**

A case study was employed as a research strategy in order to capture a more complete, holistic, and contextual assessment of the complex and iterative activities that constitute NPD. The choice of a case study is further justified given the aim of theorizing and improving existing theory. Despite the inherent limitations of single-case studies, such as the inability to perform cross-case analysis, the ability to focus time and effort solely on one case creates the possibility of acquiring a rich understanding, thus allowing greater depth and clarity.

The case firm studied is set in the upstream oil and gas industry. Due to the constantly increasing demand for energy, oil and gas are today being exploited in places that until recently have not been either economically
profitable or technologically possible. From being limited to onshore exploration, the oil and gas industry has moved offshore and to increasingly deeper waters and more remote sites. Until the late 1980s, subsea oil and gas exploitation was limited to a maximum depth of 250-300 meters, where the subsea equipment was manually installed by divers. Today, modern technology allows subsea systems to be installed at a depth of more than 2,500 meters by remotely operated vehicles facilitating the installation process. Under these extreme conditions, the process equipment is expected to last up to 50 years, which implies great technological challenges. Some of the larger subsea oil and gas fields can cover up to 100 wells and come at a total cost of $1.5-2 billion. As a result, the cost of failure is very high and the industry is conservative regarding new technologies.

The specific firm studied was Vetco Gray, hereafter referred to as VG, which is a part of General Electric’s Oil & Gas business. VG is specialized in upstream drilling and process technology for the subsea oil and gas industry. With 5,000+ employees located in over 75 countries, the firm is a major global supplier to some of the world's largest oil companies such as ExxonMobil, BP, and Chevron.

For both theoretical and pragmatic reasons, VG constitutes an ideal case in light of the research purpose. First, VG resembles the situation of many other industrial firms trying to adopt open innovation. That is, while understanding conceptually the possible advantages of open innovation principles, they struggle with implementation issues. Consequently, the case provided first-hand knowledge on interim struggles and key problem areas in need of future improvement. Second, choosing an “average” rather than “best-practice” firm diminishes problems with halo effects, i.e., a cognitive bias whereby the perception of one specific trait is influenced by the perceptions of former traits in a sequence of interpretations. That is, selecting a firm skillful at integrating open innovation and Stage-Gate processes may have clouded the factors that make such integration possible. Thus, much can be learned by studying not only firms that tried and succeeded, but also the interim struggles of other firms. Finally, deep personal contacts at this firm facilitated the access to and retrieval of high-quality data.

Data for the study were gathered primarily through individual, in-depth interviews at the Advanced Technology Organization in Norway, which is the organizational unit responsible for NPD at VG. The interviews were complemented with observations made through informal conversations with employees, participation in meetings, and other firm activities during a 3-month site visit. In total, 33 formal interviews were conducted. For additional information on the sample, see Table 1.

The interviews ranged from 30 minutes up to two hours, with an average of about one hour. These were augmented by secondary data such as documented procedures and company brochures, allowing empirical triangulation of the firm’s NPD practice. The respondents varied in age, years of employment, academic training, and position and were therefore able to contribute with diversity in perspectives.
Open Innovation and the Stage-Gate Process: A Revised Model for New Product Development

TABLE 1. Sample Information

<table>
<thead>
<tr>
<th>Position</th>
<th>Years of Employment</th>
<th>Academic Training</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 1: Unstructured Interviews</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Department Manager</td>
<td>9</td>
<td>MSc</td>
</tr>
<tr>
<td>Project Specialist</td>
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</tr>
<tr>
<td>Department Manager</td>
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<td>None</td>
</tr>
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<td>Department Manager</td>
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</tr>
<tr>
<td>Global Account Director</td>
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<tr>
<td><strong>Phase 2: Semi-Structured Interviews</strong></td>
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<td></td>
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<tr>
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<td>10</td>
<td>MSc</td>
</tr>
<tr>
<td>Senior Process Engineer</td>
<td>1,5</td>
<td>MSc</td>
</tr>
<tr>
<td>Senior Researcher</td>
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<td>PhD</td>
</tr>
<tr>
<td>Project Manager</td>
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<td>PhD</td>
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<tr>
<td>Marketing Manager</td>
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<td>MSc</td>
</tr>
<tr>
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<td>MSc</td>
</tr>
<tr>
<td>Project Manager</td>
<td>26</td>
<td>MSc</td>
</tr>
<tr>
<td>Project Manager</td>
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<td>MSc</td>
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<td>MSc</td>
</tr>
<tr>
<td>Project Manager</td>
<td>2</td>
<td>MSc</td>
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<tr>
<td>Senior Engineer</td>
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<td>MSc</td>
</tr>
<tr>
<td>Junior Researcher</td>
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<td>MSc</td>
</tr>
<tr>
<td>Junior Engineer</td>
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<td>MSc</td>
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<td>PhD</td>
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<tr>
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<td>MSc</td>
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<tr>
<td>Program Manager</td>
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<td>Senior Engineer</td>
<td>2,5</td>
<td>MSc</td>
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<tr>
<td><strong>Phase 3: Focused Interviews</strong></td>
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<td></td>
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<tr>
<td>Principal Engineer</td>
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<tr>
<td>Lead Engineer</td>
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<tr>
<td>Financial Analyst</td>
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<td>BSc</td>
</tr>
<tr>
<td>Sourcing Specialist</td>
<td>&lt;1</td>
<td>BSc</td>
</tr>
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</table>
The data collection was divided into three different phases. First, five exploratory and unstructured interviews were conducted, with the aim of providing general information regarding NPD as well as identifying further qualified respondents. In the second phase, 24 semi-structured interviews were conducted, which addressed the research purpose explicitly. These interviews were guided by an interview guide corresponding to the theoretical framework (see the Appendix for the interview questions). Departures from the specific questions were permitted; the format of the interviews was accordingly adapted and changed slightly to pursue interesting and particularly relevant new facets as they emerged. During the third phase, four focused interviews were conducted with the aim of gathering information on a couple of illustrative NPD projects at VG.

To increase reliability, most interviews were conducted by multiple investigators, which enhanced confidence in conclusions and increased the likelihood of surprising findings. To create overlap between data collection and data analysis, frequent discussions between the interviewers were held in addition to the continuous taking of field notes. Each interview was recorded, transcribed and transferred into a spreadsheet for further analysis. The spreadsheet was structured as a conceptually ordered display. To facilitate the analysis, several interview questions were conceptually clustered together in rows according to the general theme that they were exploring. Each theme was explored and summarized by the researchers individually and later discussed among the researchers to arrive at a common understanding. To further increase reliability (transparency and future replication), a case study protocol was constructed together with a case study data base, containing case study notes, documents, and the narratives collected during the study, all with the aim of facilitating retrieval for future studies.

To strengthen internal validity, a clear research framework was designed and extensively discussed within the research team prior to data collection. As the current study is of new rather than of replicated nature, pattern matching (a comparison between observed patterns and those established in previous studies) proved impossible, which might have influenced internal validity negatively. Construct validity was addressed mainly by the establishment of a clear chain of evidence to allow readers to see how initial research questions match with key conclusions. Although case studies are not devoid of generalizations, external validity (generalizability) is problematic with a research design such as the current one. Nevertheless, the main objective is to employ analytical generalization—from empirical observation to theory building. Hence, no claim is made to generalize the findings beyond the sample investigated.

Empirical Findings

The position of VG in the subsea oil and gas industry is sustained by the firm’s business model, whose purpose is to offer (through a single interface) customized or standardized subsea solutions to meet the needs of any drilling
and production project from concept to full production. VG’s specialization in upstream drilling and process technology is further reinforced by core capabilities related to engineering know-how and the ability to provide complete and reliable subsea solutions.

NPD projects at VG are managed by applying the GE Tollgate process. The Tollgate process is structured and comprehensive, and it follows the same basic logic as the conventional Stage-Gate process. As such, it covers all stages of the NPD process, from idea generation to product launch. The evaluation process taking place in the gates is well described in terms of roles, responsibilities, and methodology. The review process is carried out by three teams: the business leadership team, the program execution team, and the review team. The business leadership team is the unit responsible for the evaluation process. It ensures that all applicable deliverables are completed by the members of the execution team—a cross-functional team responsible for development and documentation as well as for providing feedback to the project manager. The final decision to approve or fail at a Tollgate is made by the review team. The composition of the different teams may vary with the type of NPD project pursued. However, all Tollgate reviews within VG are overseen by a corporate-level GE gate-director.

The Tollgate process consists of 8 gates and, consequently, 8 stages starting with the identification of a business opportunity and ending with the introduction of the new product followed by measurement and feedback. Formal reviews with the representatives from the departments concerned are held prior to each gate. The work executed in the stages is guided by pre-defined questions that constitute the foundation of the gate reviews. The answers to the critical questions are what constitute the deliverables to each gate.

Overall, the respondents pictured the current NPD process as explicit and unambiguous, although some deficiencies were identified as well, such as difficulties in prioritizing among both new ideas and current projects. The Tollgate process does not explicitly consider the import of external know-how and technology from outside GE. However, it deliberately addresses the possibility of finding relevant know-how and technology within the GE organization that could add value to the NPD project being reviewed. Export options for internally developed know-how and technology are not addressed in the Tollgate reviews—neither to other GE businesses, nor to external actors outside GE.

A general attitude among the majority of the respondents was that VG cannot, and should not, conduct all development activities internally, but has to rely on external technology providers while taking the role of a system provider. “The goldsmith does not mine the gold himself,” as one of the respondents put it. A major part of VG’s NPD is to suit and reengineer existing land-based technologies to a subsea environment. However, the assessment and importing of external know-how and technology were described as ad-hoc with no underlying formal methodology. Moreover, respondents generally had a hard time specifying when importing options were considered during the NPD process, although most answers centered on the early stages.
On the occasions when know-how and technology was imported to support continued in-house development, the results were described as satisfying overall, although some problems had been experienced as well. Given the generally positive experiences from previous import situations, some respondents felt that scanning for importing opportunities could be done more frequently and rigorously, highlighting the need for “external thinking.” Some respondents described situations when the lack of external knowledge resulted in the organization “reinventing the wheel.” In particular, many respondents had the opinion that a lot could be gained from extending the search for know-how and technology outside the oil and gas business. However, procedures for doing this systematically were not currently in place.

Few of the respondents had considered the possibility of exporting know-how and technology to firms outside GE, although the idea was positively welcomed. Some exporting issues that were raised were the potentially high transaction costs associated with exporting activities, the potential loss of IP, contractual complications, the lack of underlying facilitating routines, and a poor awareness of export of know-how and technology as an option. The lack of facilitating routines was apparent as most respondents were unsure of in which situations, and during what stages of the NPD process, export options should be considered.

Nevertheless, there were cases when VG exported technology through the GE system, and many respondents considered the exporting possibilities to have great potential. In contrast, one of the respondents mentioned that one of VG’s competitors had established a stand-alone venture capitalist business that captured ideas from within the parent company that were outside the current business model. It was suggested that this might be a good idea for VG as well, given the firm’s position as a provider of integrated solutions and a generator of many ideas that lie outside the firm’s current business model. Frequently, limitations with the current business model stopped many NPD projects of high potential future value. Several senior managers also mentioned that VG needed to find new ways to create value for its customers as proactive measures for future growth. As for the future of VG’s NPD, a desire to broaden the core capabilities to encompass all parts of the subsea field was identified among the respondents.

In sum, the empirical data showed that import of know-how and technology was done primarily on an opportunistically ad-hoc basis. Moreover, import activities focused mainly on know-how and technology existing within GE, and not on the opportunities that the world outside GE presented. There were occasions of export of know-how and technology as well, although infrequently and without underlying supporting routines. However, the experience from the import and export of know-how and technology among the employees was generally positive. In addition, limitations with the current business model and core capabilities were spotted among the respondents.
Towards a Revised Model for New Product Development

Based on the case study data, we argue that there are great virtues in systematizing the currently opportunistic occasions of open innovation practices within VG’s NPD process. The interviews and observations indicate positive attitudes towards current open innovation practices, but also highlight the need for increased systematization of those practices. The empirical evidence further indicated limitations in the current business model and core capabilities, thus underscoring the need to continuously reexamine and, if applicable, initiate a process to rethink these. By combining information and experiences from the firm studied with relevant theory, we outline a new and revised model for NPD, referred to as the open Stage-Gate model.

The main idea of the open Stage-Gate model is illustrated in Figure 1, taking the Tollgate process of VG as the point of departure. With its inherently systematic and structured approach, this traditional Stage-Gate model constitutes the foundation of the open Stage-Gate model. The arrows indicate the permeable boundaries of the process that allow external and internal know-how and technology to enter or exit the process at any given point, not only as ideas entering the funnel at its beginning or as new products coming out the other end.

To create and sustain an open Stage Gate process, a number of additional activities need to be considered at different stages of the process. The open innovation potential at each stage is different because the NPD process struggles with different technical, organizational, and managerial activities at each stage. In addition, partner selection for inbound and outbound activities also seems partly stage-contingent. Table 2 provides a description of VG’s NPD activities as defined by the Tollgate process, complemented by the key inbound and outbound open innovation activities suggested by the open Stage-Gate model.
Inbound open innovation is fundamentally about make-or-buy decisions, and typically occurs in the early stages of the process.\textsuperscript{68} Outbound open innovation (e.g., technology licensing) is typically conducted in the later stages, when the NPD project has generated substantial know-how and technology that can be commercialized externally.\textsuperscript{69} That is, inbound and outbound activities have a clear center of gravity. However, it is important that managers continuously and throughout all process stages evaluate the potential for inbound and outbound open innovation activities.

For a Stage-Gate process to incorporate open innovation principles, the project evaluation criteria in gates need to be expanded. In the traditional Stage-Gate model, projects are evaluated in the gates according to a set of “Closed” Evaluation Criteria (CEC), which correspond to the traditional NPD activities of VG (see Table 2). These criteria constitute the basis for the subsequent stop/go decision. In the open Stage-Gate model, a new set of evaluation criteria should be added to each gate, referred to as Open Innovation Evaluation Criteria (OIEC). These should correspond to the inbound and outbound open innovation activities.

**TABLE 2.** Tollgate Activities Complemented by Key Inbound and Outbound Open Innovation Activities

<table>
<thead>
<tr>
<th>Activities According to Stage in the Tollgate Process</th>
<th>Define</th>
<th>Design</th>
<th>Validate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inbound Open Innovation Activities</strong></td>
<td>Business opportunity identification, establish customer needs, create new product concept, evaluate feasibility of product concept, conduct program plan and budget review.</td>
<td>Preliminary design review, risk review, sourcing review, design &amp; test product, finalize product design, establish manufacturing approach, develop new product.</td>
<td>Validation tests, sourcing reviews, manufacturing reviews, verify market readiness, conduct market field test of product, product introduction, measurement and feedback.</td>
</tr>
<tr>
<td><strong>Outbound Open Innovation Activities</strong></td>
<td>Spin-in ideas, knowledge or product concepts from inventors, start-ups, suppliers, customers, research institutions or other sources for internal development, joint development, or application.</td>
<td>Solve technical problems or spin-in external inventions through collaboration with innovation intermediaries, research institutions, suppliers, competitors or firms in other industries.</td>
<td>Acquire already commercialized products or components which provide immediate sources of growth or value added from suppliers, competitors or firms in other industries.</td>
</tr>
</tbody>
</table>

Note: For the sake of parsimony, only the three main phases of the Tollgate process are displayed.
innovation activities in Table 2. The OIEC do not replace the existing evaluation criteria, but simply provide an additional evaluation dimension. The purpose of the OIEC dimension is thus to explore the import and export alternatives for each NPD project in each gate. In sum, the opportunities for continued in-house development that are presented by the traditional evaluation criteria are complemented, in the open Stage-Gate model, by the possibilities of importing important know-how and technology as well as considering external paths to market, or a combination of both.

As such, in the open Stage-Gate model, searching for opportunities to import or export know-how and technology becomes a critical task in preparing the gate deliverables for a NPD team, to ensure that gatekeepers have sufficient information to base import/export decisions on. During the subsequent stage, execution of activities related to import of know-how and technology can typically be performed by the NPD team. Activities related to export of know-how and technology will typically be performed by another set of persons, e.g., a licensing function. As a consequence, the open Stage-Gate model presupposes a need for alignment between NPD and outbound technology transactions.

The OIEC dimension is further concretized as a decision tree, shown in Figure 2. The purpose of the OIEC decision tree is to serve as an easily applicable set of hierarchically arranged questions and considerations that facilitate the import/export of know-how and technology. In addition, the decision tree encourages examination of the firm’s current business model and core capabilities. Therefore, it promotes the idea that neither business models nor core capabilities should be regarded as static entities. We argue that a dynamic view is important for open innovation implementation as firms should continuously experiment with and reevaluate their business models. In addition, firms need a clear view of their core capabilities in order to successfully leverage these when engaging in external collaborations with others.

As already pointed out, NPD projects serve as a forum for identifying the need for adjustment of both core capabilities and business models. Thus, NPD projects may underscore the need for organizational change by highlighting deficiencies in current business models and introducing the need for new or revised capabilities. As NPD is a prime example of a dynamic capability, we argue that gate meetings during NPD projects are a perfect venue for evaluating lower-level capabilities. Acknowledging that core capabilities and business models are established in path-dependent learning cycles, single NPD project cannot dramatically change either capabilities or business models. Nevertheless, the cross-functional make-up of senior managers in gate evaluations provides a forum for rethinking current capabilities and business models, and for modeling or enacting alternative ones.

The OIEC decision tree is made up of four stages. In the first stage, the fit between the NPD project and the current business model and core capabilities is evaluated. Managers here need to consider the extent to which the NPD project is aligned with the firm’s current way of creating and capturing value and to what extent the project leverages the firm’s core capabilities. Stage 1 promotes
FIGURE 2. The Open Innovation Evaluation Criteria Decision Tree

Is the NPD project aligned with the current business model?

Yes

No

Does the NPD project utilize our core capabilities?

Yes

No

Does the NPD project utilize our core capabilities?

Yes

No

Should the business model be redefined?

Yes

No

Should existing core capabilities be redefined?

Yes

No

Initiate a process to rethink current business model

Initiate a process to rethink current core capabilities

Export

Are there any external companies or partners that might be interested in the know-how and technology generated in the NPD project (i.e., can it be commercialized externally)?

Yes

No

Import

Consider importing know-how and technology:
• To complete the product being developed
• To add value to the product being developed
• To speed up the innovation process
• To reduce development cost

Always consider Export options
the idea that business models and core capabilities should be considered at the same time. The outcome of this first stage can result in full alignment with core capabilities and business models, no alignment at all, or partial alignment with either business model or core capabilities. Full alignment leads to a consideration of import activities and, subsequently, export activities. The situation of no alignment at all obliges managers to consider export options only, because development efforts under such circumstances are highly likely to result in failure.

In the event of partial alignment, the second stage encourages management to determine whether core capabilities or business models should be redefined. This step acknowledges that although NPD projects typically should be aligned with both the firm’s business model and its core capabilities, this is not always the case. Moreover, it acknowledges the fact that NPD projects can uncover deficiencies in capabilities and limitations in the current business model, and thus highlight the evolving nature of both business models and core capabilities. If reconfiguration of core capabilities or the business model is decided necessary, the third stage of the decision tree advises managers to initiate a process to rethink current core capabilities and business models to adapt these to future opportunities. This does not necessarily imply that a project suffering from partial alignment is doomed. Rather, if the firm subsequently manages to make the necessary changes to the business model or core capabilities, the project may restart the process and pass the alignment requirement. Moreover, the open Stage-Gate model is not in favor of incremental projects at the expense of more radical ones. Rather, radically new projects may have to restart the process more often because such projects are often outside the scope of current core capabilities or business models.

The fourth and final stage of the decision tree considers the importing of know-how and technology for projects that are aligned with the firm’s business model and core capabilities. The sources of know-how and technology are increasingly widespread and diverse. The decision tree thus encourages managers to take advantage of external know-how and technology to complete the product offering, to add additional value to the product being developed, to speed up the innovation process, or to reduce development costs.

In addition, stage four encourages assessment of exporting opportunities resulting from internally developed know-how and technology to increase rents from NPD. A project that has been decided to proceed in-house may still contain know-how and technology that can be profited from through external paths to market. In addition, external paths to market serve an additional function in the open Stage-Gate model by making it easier for managers to stop unfit projects not suitable for further internal development, thus letting their firms profit from these externally by means of technology licensing. The open Stage-Gate model constitutes a step towards avoiding previously reported problems of gates with no teeth.76

To further highlight the idea of the open Stage-Gate model, case data from four recent NPD projects at VG illustrate some key deficiencies with the current Tollgate process, but also explain how the revised model could aid managers in their efforts to increase rents from NPD efforts.
• **Project 1: Development of a New Pump**—Among the more critical components in a subsea system are the pumps. A subsea pump serves the purpose of increasing the extrusion rate of a reservoir. This is done either by increasing the reservoir pressure by injecting fluids into the reservoir, normally water, or by boosting the upstream flow through the riser that connects the subsea field with the topside module. In order to prevent the pump from corrosion, VG imported a novel coating technology developed by a GE Global Research Centre, originally applied on helicopter engines to protect them from sand failure during the Kuwait war. The project was clearly within VG’s business model and utilized its core capabilities. The imported technology also added value to the application and hence contributed to the success of the project. However, as of today, no attempts have been made to commercialize the accumulated know-how or technology externally, thus overlooking the potential for additional profits from the technology and the product.

• **Project 2: Development of Aqua-Dynamical Pipes**—Subsea equipment is also subject to substantial strain from underwater sea currents. In order to protect subsea piping from fatigue, VG initiated a project to develop aqua-dynamical pipes. During the project, VG designed threads—referred to as strakes in subsea terminology—that would cover the piping like threads on a screw. VG anticipated that this would reduce the strain from sea currents; but since VG did not possess sufficient capabilities in fluid mechanics at that time, the calculations to determine the potential need of the strakes were outsourced. However, when the results of the calculations arrived, the know-how to fully interpret and understand these results was not available within the organization. Due to the tight schedule, the strakes were ultimately designed more as a precaution based on an estimated need than a verified requirement. While attempts to import critical know-how were conducted, they were not performed satisfactorily and with rigor. In addition, no deliberate export options were considered.

• **Project 3: Development of a Subsea Watermill**—A less successful project from a commercial point of view was the development of a subsea watermill. The watermill was designed to operate under the same basic principles as a windmill but with sea currents as the driving force. The project was not aligned with VG’s business model (i.e., not an application for subsea drilling and production) but did utilize VG’s core capabilities—to develop applications suitable for the subsea environment. However, due to a lack of resources and strategic fit, the project was put on the shelf and the current business model was never questioned. A few individuals investigated the opportunities of exporting the concept to another GE business but without success. The lack of success was primarily attributed to a lack of knowledge about where and how to export internally generated technologies. Nonetheless, if the OIEC decision tree had been employed, the export opportunities might have been more systematically explored by management, rather than by lower-level employees in an ad-hoc fashion. With more deliberate attention, another business willing...
to further invest in the concept might have been identified by utilizing GE contacts, as GE is present within a variety of segments in the energy business.

- **Project 4: Development of a New Riser**—In the oil and gas industry, the term subsea refers to equipment resting on the sea bed, while the term offshore refers to equipment found above the surface such as platforms and production ships. The equipment connecting the two areas—i.e., transporting gases and fluids between the subsea field and the offshore module—is called a riser. By definition, it does not belong to either of the two segments. As the exploration depth increases, so do the length and weight of the riser, which soon becomes too heavy to carry its own weight. In order to overcome the weight problem, VG initiated a project together with external partners that aimed at developing a lightweight composite riser. The project was an attempt to cover the subsea/offshore interface, but was neither aligned with VG’s core competences nor its business model. The project was ultimately cancelled after more than a decade of development efforts due to great practical difficulties associated with installation and, consequently, no customers. The possible exporting opportunities of the generated know-how and technology were never thoroughly investigated.

Altogether, these four cases illustrate a couple of important points. First, to diminish the probability of failure, NPD projects should be aligned with a firm’s core capabilities and business model. Second, when such alignment is not present, firms may want to initiate a process resulting in possible future reconfiguration of capabilities and business models to facilitate development efforts into areas of future importance. Third, import of know-how and technology should be considered systematically and carefully, as the success of a NPD project is likely to increase with such a rigorous approach. Finally, export of know-how and technology should always be considered, as firms otherwise run the risk of missing complementary sources of rents.

Overall, the main benefit of the open Stage-Gate model is that it introduces a more externally oriented perspective on NPD. The model helps managers consider opportunities that external know-how and technology and external paths to market present. Moreover, the model supplies the opportunity to take a dynamic perspective on core capabilities and business model issues, thus highlighting the need for possible future adjustments of them. In these respects, the open Stage-Gate model differs significantly from the traditional one. Table 3 illustrates the main differences between the traditional and open Stage-Gate models.

**Discussion**

The open Stage-Gate model makes several contributions. First, it suggests an initial step towards systematically integrating the principles of inbound open innovation with existing Stage-Gate processes. Second, it allows firms to increase their proficiency in outbound open innovation activities, e.g., technology
licensing. As such, it provides a tool for moving from a set of ad-hoc practices to a more systematic application of open innovation principles. Third, to achieve sustained open innovation, the open Stage-Gate model helps managers to continuously assess and adjust their firm’s core capabilities and business model to a constantly changing environment. It therefore enables business model innovation, which is imperative for sustaining open innovation.77

Concerning inbound open innovation the open Stage-Gate model, in contrast to traditional Stage-Gate models like the one employed by VG, allows for systematic reviews and assessment of the potential of importing know-how and technology from outside the firm’s boundaries. As firms have finite resources, they cannot afford to pursue all development efforts in-house, making inbound activities critical.78 Importing external know-how and technology is beneficial for multiple reasons, such as to complete a product, add further value to the product offering, speed up the innovation process, and reduce development costs.

Second, the open Stage-Gate model helps managers to pursue more deliberate outbound open innovation activities. To overcome the limitations of current ad-hoc approaches to commercializing technology externally in the case studied, as well as in other firms,79 the model serves as a device for providing structure to outbound open innovation activities. Consequently, firms may with increased proficiency spin out ideas, know-how, technology, or even products that were internally developed but outside the core business and better developed and commercialized by others.80 Such activities allows extra revenues from ideas, technologies, or products that otherwise would have been left sitting on the shelf.81 However, technology commercialization goes far beyond a marginal transfer of residual technologies in exchange for money.82 Firms may, in addition, reap strategic benefits, such as establishing industry standards or gaining access to external knowledge.83

<table>
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<tr>
<th>Dimension</th>
<th>Traditional Stage-Gate Model</th>
<th>Open Stage-Gate Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation Criteria</td>
<td>Closed Evaluation Criteria</td>
<td>Closed and Open Innovation Evaluation Criteria</td>
</tr>
<tr>
<td>Import of Know-How and Technology</td>
<td>If at all, external know-how and technology are opportunistically reviewed and accessed</td>
<td>External know-how and technology are systematically reviewed and accessed</td>
</tr>
<tr>
<td>Export of Know-How and Technology</td>
<td>Only internal paths to market are assessed</td>
<td>Internal and external paths to market are thoroughly assessed</td>
</tr>
<tr>
<td>Business Model Considerations</td>
<td>Alignment between the NPD project and the business model is considered</td>
<td>Continuous assessment and evaluation of the business model</td>
</tr>
<tr>
<td>Core Capability Considerations</td>
<td>Fit between the NPD project and current core capabilities is considered</td>
<td>Continuous assessment and evaluation of core capabilities</td>
</tr>
</tbody>
</table>
Third, the open Stage-Gate model enables managers to systematically consider whether existing core capabilities are sufficient, or whether new capabilities need to be modeled. As NPD projects pave the way for organizational change by highlighting deficiencies in current core capabilities, the open Stage-Gate model is designed to take advantage of this opportunity. The open Stage-Gate model thus enables managers to systematically consider whether current core capabilities are sufficient, or whether deficiencies in these should trigger a process of modeling new capabilities.

Furthermore, the open Stage-Gate model highlights the importance of distinguishing between which capabilities are core and vital to the firm’s value creation and which are merely necessary to the completion of products being developed. The distinction between core and non-core capabilities is also a reminder to view capabilities in the light of their value-creation potential. Therefore, the increased systematization of importing and exporting practices, as suggested by the model, promotes an increased focus on the core activities of the firm, letting non-core activities take place outside the firm to a larger extent. Explicitly addressing this issue is an important step towards resolving previously reported problems with managers defining core capabilities, often described as “a feel-good exercise that no one fails.” In addition, by continuously evaluating capabilities in relation to value creation in NPD projects—and the potential of letting some NPD activities be performed by external actors—a large step is taken towards avoiding the risk of core capabilities developing into core rigidities.

Finally, the open Stage-Gate model also takes the need for reconfiguring the firm’s business model into account, and thereby serves as a starting point in business model innovation. Chesbrough stated that, for firms to successfully innovate their business model, managers from all units of the firm should take part in the innovation process. The statement gives some further weight to the idea of assessing the business model in the gate reviews, with their cross-functional composition of managers, as the open Stage-Gate model proposes. However, previous research shows that many companies do not have a formally articulated business model. Obviously, an unclear view and understanding of one’s business model will undermine a company’s attempt to successfully open up the NPD process. A clear understanding of the business model is critical to determining NPD project alignment and potential deficiencies and redefinition opportunities as well as to avoiding loss of sensitive IP. When properly managed, the virtues of opening up the NPD process are greater than the risks.

Such assessment may also be valuable for exploring alternative business models for commercialization of know-how and technology. This is a very important step as the business model is a critical part in realizing the value of a particular innovation and a fundamental part of open innovation theory and practice. In fact, Chesbrough points out that “a mediocre technology pursued within a great business model may be more valuable than a great technology pursued within a mediocre business model.”
Managerial and Theoretical Implications

While significant value can be generated by opening up the NPD process, the adoption of open innovation practices is not without challenges. Accordingly, this article has highlighted some of the struggles that many firms are likely to face when attempting to integrate open innovation principles with conventional Stage-Gate methodologies for NPD. In the case of VG, a lack of structures and of a systematized process for open innovation was seen as a major impediment. Consequently, we developed the open Stage-Gate model as a first step to overcome these limitations and deficiencies. The model underscores the need for increased systematization in the process of importing and exporting know-how and technology to leverage the opportunities presented by open innovation.

As such, the open Stage-Gate model represents a more open and dynamic perspective on the NPD process. The model systematizes import and export of know-how and technology and reminds the NPD team as well as gate-keeping managers to pay attention to the opportunities that may arise from opening up the NPD process. In particular, the open Stage-Gate model devotes significant attention to the opportunities of exporting internally generated knowledge to increase rents from internal NPD. By means of the OIEC decision tree, it also systematically allows managers to evaluate whether import of know-how and technology can add value to the firm’s own development activities. Furthermore, by systematically assessing the firm’s core capabilities and business model, a first step is taken towards creating a dynamic and adaptable NPD process that sustains long-term competitive advantage and allows the firm to fully realize the benefits of open innovation. In addition, the open Stage-Gate model reminds managers that the NPD process is an organizational vehicle for uncovering core rigidities and for the exploration of potentially new capabilities and business models. Consequently, the open Stage-Gate model represents a new, more externally aware and dynamic way of viewing the NPD process, and provides a basis for firms seeking to apply the principles of open innovation within their NPD process.

In addition, this article makes several contributions to the knowledge on innovation management. First, the open Stage-Gate model offers a theoretical starting point for integrating the principles of open innovation with mainstream models for NPD. As such, it addresses previously noted deficiencies in the knowledge about open innovation. Moreover, the model is regarded as filling a gap in the development of Stage-Gate methodologies by outlining an open Stage-Gate model, an area where the existing understanding lacks sufficient details. Finally, the model presents a step towards more proficient management of evolutionary business models and core capabilities in the context of increasingly open innovation processes, an area considered ripe for future advancements. Overall, the article contributes to advancing the somewhat abstract theory of open innovation to a more concrete and useful level.

However, further knowledge about open stage models is needed. While this article adds conceptual clarity to this issue, future research would benefit from studying the micro-foundations of these activities. That is, by examining
what happens at each specific stage and gate during an open NPD process more
knowledge about activities, practices, roles, and actors should facilitate further
development of the open stage gate model in the future.

APPENDIX
Interview Guide

A) General Questions
1. What is your formal position?
2. What are your work duties?
3. How much of your work time is dedicated to product development?
4. What is your background and education and how long have you been
   working for Vetco Gray?

B) Questions Regarding the Product Development Process (Tollgate)
1. We are familiar with the Tollgate process currently in use. Are there any
differences between the “conceptual process” put on paper and the one
used in reality? If so, where in the process do these differences exist?
2. On which criteria are projects evaluated, and who participates in the eval-
   uation process?
3. What are the main reasons as to why projects are stopped?
4. What happens to projects that have been stopped? Is there a formal and
documented mechanism for handling stopped projects or is it done on an
ad-hoc basis?
5. In general, when projects are stopped, do you believe that they possibly
are stopped too early or too late? Please explain and elaborate.
6. If you were to change the product development process, what changes
would you suggest? Is there room for improvement in the process? If so,
where?

C) Questions Regarding the Use of External Know-How & Technology
   and External Paths to Market
1. Does Vetco Gray make a practice of bringing in external know-how and/
or technology?
   If yes:
   a. What kind of know-how and technology?
   b. Where do this know-how and technology come from? (E.g., uni-
      versities, start-ups, industry groups, parent company, other business
      units?)
   c. When in the process are external know-how and/or technology
      most commonly used? (Refer to the Tollgate process.)
   d. How are know-how and technology accessed? (Joint ventures,
      acquired, licensed etc.)
e. Are external know-how and technology used on a systematic basis or ad-hoc (opportunistically)?
f. How has bringing in external know-how and technology helped Vetco Gray?
g. How important are external know-how and technology in the NPD process?

2. To what extent are the Global Research Centers (GRC) and other GE businesses used in order to find applicable know-how and technology?

3. Does Vetco Gray practice external paths to market for know-how and/or technology that, for various reasons, have been chosen not to be used internally? (E.g., patents, components, new technologies, blueprints.)
   If yes:
   a. What kind of know-how and technology?
   b. Who buys/licenses this know-how and technology? (Industry groups, public-private cooperation, patent brokers.)
   c. When in the process is this most common? (Refer to the Tollgate process.)
   d. Which modes are most common when know-how and technology are exported? (Joint ventures, sold, licensed out etc.)
   e. Is this done on a systematic basis or ad-hoc (opportunistically)?
   f. What impact has exporting know-how and technologies had on Vetco Gray?

D) Core Capability and Business Model Considerations

1. How would you define Vetco Gray’s core capabilities?
   a. Have the current core capabilities always been core capabilities? Elaborate.

2. How much of your working time is spent on core activities?

3. To what extent are the non-core activities (necessary to complete the offering) sourced from outside the ATO organization? I.e., conducted by someone external to Vetco Gray?

4. Do you believe that non-core activities which are conducted in-house today could be performed by external partners to a greater extent than what is currently the case?

5. How would you characterize Vetco Gray’s business model?

6. What strengths and weaknesses do you see with the current business model? Elaborate.

Notes


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11. Ibid.


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22. Cooper (2008), op. cit.

23. Ibid.

24. Ibid.


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94. Elmqvist, Fredberg, and Ollila, op. cit.
95. Elmqvist, Fredberg, and Ollila, op. cit.
Open Innovation and the Stage-Gate Process: A Revised Model for New Product Development
Johan Grönlund, David Rönberg Sjödin and Johan Frishammar, 2010

**Paper I**

Open Innovation in the Process Industries: A Life-cycle Perspective on the Development of New Process Equipment
David Rönberg Sjödin, Per Erik Eriksson and Johan Frishammar, 2010

**Paper II**

Open Operation: Buyer-Supplier Collaboration in Operational Projects
David Rönberg Sjödin, 2010
*Submitted to IPDM Conference 2011*

**Paper III**
Open innovation in process industries: a lifecycle perspective on development of process equipment

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Abstract: The development and installation of new process equipment in production plants typically requires strong collaboration among a process firm and various equipment suppliers. While incentives to collaborate often are strong, close collaboration also poses significant problems, throughout the lifecycle of process equipment. The purpose of this article is to explore the problems and opportunities faced by process firms and their equipment suppliers throughout the lifecycle stages of collaborative development projects. This paper combines literature on open innovation, collaborative development and buyer-supplier relationships. Empirically, we draw on a large number of interviews in a dual case study of two process firms. Our results show that strong collaboration is neither positive nor negative in general. Rather, opportunities, problems, and collaboration intensity are strongly contingent on the specific stage in the lifecycle of process equipment. Our findings underscore the managerial and theoretical importance of a lifecycle perspective on the development of process equipment, since significant overlaps and interconnections exist across different stages.

Keywords: open innovation; process firms; buyer-supplier relationships; collaborative development; lifecycle stages; process equipment; partnering.


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Johan Frishammar holds a PhD in Industrial Management from Halmstad University and is currently an Associate Professor of Industrial Management at Luleå University of Technology. His research interests centre on open
1 Introduction

Companies are increasingly turning their attention towards external sources of innovation to keep up with the current rapid level of technological change (Chesbrough, 2003). This phenomenon has been characterised as open innovation, which is defined as the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively.” [Chesbrough et al., (2006), p.1]. Previous research into open innovation has mostly focused on new product development in high-tech industries (e.g., Chesbrough, 2003; Christensen et al., 2005). Although some recent studies have established that open innovation practices are apparent also in more mature industrial settings (Chesbrough and Crowther, 2006; Lichtenthaler, 2008), such studies are few. Examples of firms in mature industries are those developing and producing non-assembled products, i.e. process firms. Worldwide, it has been estimated that process firms, which include the metals and minerals, pulp and paper, chemical and food industries, among others, constitute nearly one third of all manufacturing industries in terms of revenues and R&D expenses (Lager, 2010).

Process firms have a long tradition of collaborative development with suppliers of new process equipment, necessitated by the high complexity of the equipment (involving many interconnected components and actors) and the often idiosyncratic constitution of each process plant (Hutcheson et al., 1995). Thus, it is not only advisable but of utmost importance to facilitate collaborative buyer-supplier relationships in order to explore new process innovation opportunities (Lager and Hörte, 2005).

It is, however, important to adopt an unbiased perspective when exploring whether and when to enter into open and collaborative innovation projects (Chesbrough and Schwartz, 2007). The motives and driving forces for getting involved in these projects often differ among process firms and different suppliers of process equipment. Furthermore, potential opportunities and problems arising from open innovation practices may differ among different stages of the equipment lifecycle. Previous literature on open and collaborative development has focused mainly on the early stages of the innovation process (Ro et al., 2008). It may, however, be important to collaborate not only in the early design stages but also later on, e.g., during the installation and post-installation stages (Athaide and Klink, 2009). This research deficit constitutes a significant problem, because previous research has not yet examined collaboration over the full lifecycle of process equipment. Moreover, such an approach appears necessary in order to increase the detailed understanding of collaborative development projects (Langner and Seidel, 2009). Hence, all lifecycle stages of the equipment should be investigated in order to explore the opportunities and problems arising from open and collaborative innovation practices. Therefore, the purpose of this article is to explore the problems and opportunities faced by process firms and their equipment suppliers throughout the lifecycle stages of collaborative development projects.
2 Conceptual background

Collaborative buyer-supplier relationships can be initiated in and maintained over different stages of the lifecycle of process equipment (Lager and Frishammar, 2010). However, as different stages contain distinct problems and opportunities, the collaborating firms may behave differently in terms of routines and practices performed, and utilise different types of mechanisms and artefacts (e.g., contracts and incentive structures) at different stages (Lagner and Seidel, 2009; Sandmeier, 2009). Lager and Frishammar (2010) illustrated a lifecycle model addressing the development of process equipment in the metals and minerals industry. While this model may lack universal applicability, it nevertheless provides a feasible starting point for studying collaboration practices throughout the lifecycle of process equipment. Drawing on their work, this lifecycle in our study has been divided into five stages: fuzzy front end (FFE), process and product development, assembly and installation, start-up, and operation (see Figure 1). Although the stages are presented as sequential, activities performed during the lifecycle are frequently overlapping and heavily interconnected.

Figure 1  The lifecycle of process equipment

The FFE is defined as the period between the arising of an idea, and when a firm decides to proceed to formal development (Kim and Wilemon, 2002). In this stage, process firms and equipment suppliers need to engage in an array of important and interrelated activities. FFE-work is typically exploratory with many iterative loops. It is important to articulate the needs of the process firm(s) and translate these into a product concept (Cooper, 1988a; Khurana and Rosenthal, 1997), which represents the objective of the development process and a statement of both technology and customer benefit issues (Montoya-Weiss and O’Driscoll, 2000). Depending on the project’s character, this is the stage where preliminary experimental tests take place, often complemented by modelling and simulation. Since the activities at this stage strongly affect future equipment performance and costs in the following development stage, it is crucial that the collaborative partners have carefully discussed and agreed upon equipment specifications and preliminary operating and investment costs for such equipment (Cooper, 1988b).

Product development concerns the technical development and marketing of new products to external customers (Gopalakrishnan and Damanpour, 1997). The purpose of process development, on the other hand, is to mediate between inputs and outputs by means of new tools, devices, and knowledge in throughput technology (Ettlie and Reza, 1992; Gopalakrishnan et al., 1999). In the process industries, it is difficult to distinguish between product and process development. That is, process development for the process firm is typically considered to be product development for the equipment supplier.
Regardless of the perspective employed, input from both parties is needed. To facilitate useful supplier input, relationships should preferably be based on long-term collaboration and trust, rather than on short-term competitive bidding practices (Ro et al., 2008). If suppliers are involved at this stage, an overlapped approach (i.e. concurrent engineering) can be performed, making it possible to start the assembly and installation activities before the development is completed (Gil et al., 2008). Early involvement of suppliers in concurrent engineering is often suitable for development projects characterised by high complexity, uncertainty, time pressure, and customisation (Grandori, 1997; Brown et al., 2001; Eriksson and Pesämaa, 2007). According to Errasti et al. (2009) and Song et al. (2009), concurrent engineering increases the suppliers’ understanding of customers’ needs and improves teamwork and joint problem-solving, for which reason it has been shown to improve both cost and time performance. Suppliers can also contribute to the constructability of the product, making it easier to assembly (Errasti et al., 2009; Song et al., 2009). In addition, it is also important to involve end users (i.e. operators, maintenance personnel) in the design stages when high customisation is demanded and end users’ knowledge is high (Athaide and Klink, 2009).

During the assembly and installation of products with challenging characteristics in terms of complexity, customisation, time pressure, and uncertainty (e.g., a piece of equipment or a whole plant) there are typically many suppliers who have to interact. This results in reciprocal interdependence among the different actors (Grandori, 1997). The output of Supplier A is often the input to Supplier B, at the same time as Supplier A requires design information from Supplier B so as to initiate the assembly work. In these cases it is important to establish a broad partnering team in which all key actors interact (Eriksson and Nilsson, 2008). Furthermore, collaboration during installation accelerates effective use of the process equipment in the operation stage (Athaide and Klink, 2009).

When the equipment has been installed, the start-up activities are initiated. Due to the complexity and strategic importance of the process equipment, the start-up stage is a key part of these development projects (Lager and Frishammar, 2010). In particular, complete transfer of the technology and know-how related to the equipment, from the equipment supplier to engineers and operators of the process firm, is essential for effective utilisation in the operation stage (Lee et al., 2010). This can apply to commissioning and transfer of technology developed in-house as well as to the introduction of external technology (Lager and Hörte, 2002). Due to this fact, it is important already during the contract negotiations that both parties agree on how the equipment is to be put on stream.

In the operation stage, when a plant is up and running, collaboration can provide a number of benefits. During this stage, buyers can provide suppliers with rich information on the idiosyncratic characteristics of their operating environment (Athaide et al., 2003), which can be fed back to the FFE-stage in future development projects. Moreover, drawing on the work of Von Hippel (2005), users are increasingly regarded not just as passive adopters of equipment innovations – they may develop their own fine-grained adjustments of the equipment during operation, which suppliers can imitate. Users can, for example, regularly modify their current machines, equipment, and software to better satisfy process needs, if these needs are not met by the market (Von Hippel, 2005). This practice is common in process firms because process equipment often requires continuous fine tuning for many months or even years before it is working optimally (Lager, 2010). Therefore, interaction between buyer and supplier in this post-installation work may enhance the innovation’s operation performance (Athaide and Klink, 2009).
3 Method

Given the limited knowledge about collaborative development within the process industries (Hutcheson et al., 1995), an exploratory case study strategy was adopted (Edmondson and McManus, 2007). In such a research setting, gathering rich information is expected to help identify new aspects and phenomena (Eisenhardt, 1989; Yin, 2003). Furthermore, case studies are especially appropriate for examining and articulating processes (Edmondson and McManus, 2007; Pratt, 2009). In more detail, qualitative data often provide a good understanding of the dynamics underlying uncovered relationships within empirical data (Eisenhardt, 1989). To investigate collaborative practices within the process industries, two process firms in the metals and minerals industry were selected by means of judgement sampling (Denzin and Lincoln, 1994), henceforth referred to as Alphacorp and Betacorp. Both have their main R&D departments and their centre of gravity of operations in northern Europe, but sell their products on a global market. Table 1 provides some further information about the case firms. Moreover, the case setting is particularly interesting as development of process equipment for the metals and minerals industry provides several challenges. The operations include heavy materials that wear and tear the equipment, idiosyncratic process needs, and a critical need for reliable equipment. Furthermore, both of the studied firms strive to maintain market leadership positions within their segments, and thus put significant efforts into having the best process equipment possible. In addition, collaboration is often a necessity as the equipment bought must be customised to the idiosyncratic needs of each firm.

Table 1 Information about the case firms

<table>
<thead>
<tr>
<th>Firm pseudonym</th>
<th>Areas of activity</th>
<th>Number of employees</th>
<th>Annual turnover (M$)</th>
<th>R&amp;D percentage of turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alphacorp</td>
<td>Mining of iron ore and development/production of iron pellets</td>
<td>4,100</td>
<td>3,092 M$</td>
<td>Approximately 1%</td>
</tr>
<tr>
<td>Betacorp</td>
<td>Development/production of metal powders</td>
<td>1,600</td>
<td>816 M$</td>
<td>Approximately 2%</td>
</tr>
</tbody>
</table>

Data for the study were gathered primarily through individual, in-depth interviews at these two firms, due to the fact that interviews can provide insightful information and can be focused directly on research topics (Yin, 2003). Moreover, our focus on understanding problems and opportunities with collaboration in different phases of development underscores the importance of being able to discuss back and forth with the respondents and being able to ask follow up questions. Twenty-eight semi-structured interviews underpin this paper, ranging from one to two hours in time, with an average of about 90 minutes. Two thirds of the interviews were conducted at Alphacorp, which was motivated partly by the fact that Alphacorp is more than twice as large as Betacorp, in terms of employees and turnover. More importantly, Alphacorp have made a number of major investments into new process equipment over the last years. To mitigate bias in the data collection, we selected knowledgeable informants from both the strategic and operational levels who viewed the collaborative relationships from diverse perspectives (Eisenhardt and Graebner, 2007). As such, the respondents were selected carefully in dialog with key informants at the participating firms, based on their involvement in and knowledge of collaborative innovation projects among equipment suppliers and process
firms. The respondents varied in age, years of employment, academic training and position, and were therefore able to contribute with diversity in perspectives (see Table 2).

Table 2  Information about the interviewees

<table>
<thead>
<tr>
<th>Alphacorp Respondent</th>
<th>Position</th>
<th>Bethacorp Respondent</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Department manager facilities</td>
<td>R20</td>
<td>Department manager tech support</td>
</tr>
<tr>
<td>R2</td>
<td>Project manager</td>
<td>R21</td>
<td>Engineer tech support</td>
</tr>
<tr>
<td>R3</td>
<td>Sub-project manager, start-up</td>
<td>R22</td>
<td>Marketing manager</td>
</tr>
<tr>
<td>R4</td>
<td>Department manager R&amp;D</td>
<td>R23</td>
<td>Vice president global development</td>
</tr>
<tr>
<td>R5</td>
<td>Company controller</td>
<td>R24</td>
<td>Process development specialist</td>
</tr>
<tr>
<td>R6</td>
<td>Sub-project manager, Development</td>
<td>R25</td>
<td>Senior vice president</td>
</tr>
<tr>
<td>R7</td>
<td>Department manager R&amp;D</td>
<td>R26</td>
<td>Manager global IT development</td>
</tr>
<tr>
<td>R8</td>
<td>Sub-project manager, Assembly</td>
<td>R27</td>
<td>Production manager</td>
</tr>
<tr>
<td>R9</td>
<td>Purchasing manager</td>
<td>R28</td>
<td>Global supply coordinator</td>
</tr>
<tr>
<td>R10</td>
<td>Product manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R11</td>
<td>Project Manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R12</td>
<td>Plant manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R13</td>
<td>Project Manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R14</td>
<td>Partnering facilitator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R15</td>
<td>Human resource manager</td>
<td></td>
<td></td>
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<tr>
<td>R16</td>
<td>Minerals technology expert</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R17</td>
<td>Project coordinator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R18</td>
<td>Education manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R19</td>
<td>Project manager</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The interviews were semi-structured and guided by a list of questions designed on the basis of the literature review in order to capture a lifecycle perspective of the collaborative development process. Departures from the specific questions were permitted; the format of the interviews was accordingly adapted and changed slightly to pursue interesting and particularly relevant new facets as they emerged (Eisenhardt, 1989). Two of the authors conducted interviews in order to obtain investigator triangulation (Denzin, 1978). Additionally, approximately 30 hours of document studies were performed, both regarding company reports and project documents of incentive arrangements, partnering charters, and tendering and contractual documents, with the purpose of augmenting the interview data.

To create overlap between data collection and data analysis, frequent discussions among the authors were held as well as the continuous taking of field notes. Each
The spreadsheet was summarised and transferred into a spreadsheet for further analysis. The spreadsheet was structured as a conceptually ordered display (Miles and Huberman, 1994). Moreover, iterations between results, theory, and empirical data was performed to enact emergent conclusions (Eisenhardt, 1989; Yin, 2003). To further increase reliability (transparency and future replication), a case study protocol was constructed together with a case study data base, containing case study notes, documents, and the narratives collected during the study, all with the aim of facilitating retrieval for future studies (Yin, 2003). As the current study is of new rather than of replicated nature, pattern matching (a comparison between observed patterns and those established in previous studies) proved difficult, which might have affected internal validity negatively (Denzin and Lincoln, 1994). Construct validity was addressed mainly by trying to establish a clear chain of evidence to allow readers to see how the research purpose match with key conclusions (Yin, 2003). Although case studies are not devoid of generalisations (Gibbert et al., 2008), external validity (generalisability) is problematic with a research design like the current one. Nevertheless, the main objective is to employ analytical generalisation – from empirical observation to theory – rather than extension to a population. Hence, no claim is posed to generalise the findings beyond the sample investigated.

4 Empirical findings

4.1 Fuzzy front end

The FFE-stage is considered critical in order to make sure that a good ‘product concept’ for the equipment is developed, which forms the basis of the process firm’s decision to proceed or not with the development of the equipment. If the equipment is highly complex and customised (e.g., an entire production plant), it is important to establish collaboration with key suppliers already during this early stage. However, the process firms studied typically also want to uphold some degree of competition and keep their options open, wherefore they were reluctant to contract only one supplier for a certain piece of equipment unless necessary. At the same time, it is impossible to agree upon a purchase price for the equipment already at this early stage due to the high uncertainty. An option employed by Alphacorp is then to contract one or two key suppliers as consultants during this stage. After the concept has been developed, the process firm enters formal supply contracts for the final development and delivery of equipment with the supplier that has performed best during the FFE stage.

A problem with collaboration in this early stage is that the buyer organisation has not yet been formally established, since the formal purchasing decision is taken when the concept has been developed and an approximate price can be estimated. Hence, the process firm lacks the human resources to collaborate intensively with many suppliers at the same time. Interaction mechanisms, such as meetings, workshops, and teambuilding activities, were therefore limited at this stage compared to subsequent stages. Consequently, the collaboration intensity is not very high at this stage. A drawback with this is that too small investments in workshops and teambuilding activities in early stages may result in strained relationships, which can not be recovered at later stages. Accordingly, many respondents suggested that more resources should be spent in this early stage – primarily because it is much easier and cheaper to make changes to the equipment during early development than in later stages where development costs and
commitments rise significantly. For the process firms, the critical challenge during the FFE is going from fuzzy and ambiguous project descriptions to establishing and communicating clear and explicit goals and objectives. Failure to communicate effectively during this stage was seen as a major contributor to problems in later stages. A product manager at Alphacorp (R10) described this challenge; “The FFE is usually the most important stage to invest time in. It’s about understanding each other, so that the equipment supplier understands that this is the problem or opportunity that we wish to address, and making sure that we describe what we want.” Furthermore, a plant manager at Bethacorp (R17) described a tendency for myopia concerning early investment decisions; “Unfortunately, sufficient work is not always put into the early stages. When we make investment decisions it is usually because of a need for increased capacity, and when we need it we need it fast, it is almost like investing in panic.”

4.2 Process and product development

When new process equipment is developed, the process firm typically views this as process development whereas the equipment supplier views it as product development. This difference in view has a couple of important implications. First, the supplier needs to reflect upon how the equipment delivered is to fit into the process firm’s production process. This interdependence can be a challenging and constraining factor in what kind of equipment can be developed. A department manager at Bethacorp (R20) described this challenge; “If a piece of equipment is part of an extensive process flow, you have to think about what this equipment should do, what is the demand. A frustrating thing in development projects is that you can be developing a Ferrari engine and still end up with a Volvo car – that is, other equipment is constraining the process. In essence, our main goal is never to improve a piece of equipment; our goal is to improve the process to get better performance.” Secondly, adapting the equipment to suit the process firm’s needs often entails idiosyncratic investments for the equipment supplier.

After the formal purchasing decision has been taken, more and more resources are continuously allocated to the development activities. During the development stage, the collaborative process is therefore gradually intensified. Interaction and joint problem-solving in meetings and workshops become crucial and part of the daily routines. It also becomes increasingly important that different suppliers interact and collaborate, since they are dependent on input from each other to be able to finalise the selected design. If time is a crucial factor, concurrent engineering is sometimes used, making it possible to start assembly and installation work before the design is finalised. Concurrent engineering is effective but it also increases the need for intensive and demanding collaboration among all key actors.

A critical aspect in the development stage is to involve end users (e.g., operators and maintenance personnel) in order to obtain their valuable insights about the final product as early as possible. However, many respondents suggested that the end users were not particularly committed to engaging in development projects until the equipment was ready to be put on stream. A minerals technology expert at Alphacorp (R16) described this problem; “It is hard to engage the production people in the early stages of the project before it is ‘real’. It is only when they see that we have started building and the project is nearing completion that they wake up and start thinking; is this good or is it not good? The end result is much better if production people are involved from inception. Then they
feel a greater responsibility for the project.” Therefore, communicating the need for internal collaboration was seen as a crucial activity at this stage. Moreover, equipment manufacturers were perceived to be reluctant to collaborate intensively during the product and process development stage, as they might lose core knowledge that could be spread by the process firm to the supplier’s competitors. The vice president at Bethacorp (R25) highlighted this issue; “A reason why we might not collaborate as much as we should at this stage may be that the equipment supplier wants to protect its knowledge. They are not interested in letting us in and letting us understand what is unique in their development process, as they perceive the risk of us using this knowledge to develop our own equipment.” This issue is important despite the formation of non-disclosure agreements as the people at the process firm may still pick up tacit knowledge from the equipment manufacturer and use it in collaboration with the latter’s competitors.

4.3 Assembly and installation

The assembly and installation stage is the most complex in terms of interdependence and interaction among various suppliers. If the project involves an entire production plant, the amount of people and firms involved in the project is peaking during this stage, making it very difficult to coordinate a large number of heterogeneous activities. In a project at Alphacorp, this coordination and interaction among many different suppliers was facilitated by involving them in one broad partnering team. When suppliers were involved in the same team, participating in workshops together and sharing risks and rewards among all actors in the team, they were more concerned about each other’s situations instead of sub-optimising. A department manager at Alphacorp (R1) elaborated upon this issue; “In one project we used a common time bonus for everyone during installation even though we knew that electricity and control people are the ones that in the end put everything together. The equipment supplier had to deliver the equipment at a particular point, but was also dependent on the installation crews and everyone else to get the time bonus. This requires that everyone collaborates.”

Due to the large amount of actors involved at this stage, the collaboration with the process firm was somewhat less intensive than in the development stage, but the collaboration among suppliers was intensified. In particular, the involvement of the technology development departments at the process firms decrease during this stage. In opposite, end users show increased commitment during the assembly stage, as it is getting easier for them to picture the final result of the project and to come up with ideas of how to improve the equipment. This is, however, often too late since design changes at this stage cost a lot of time and money. Hence, the design is mostly ‘frozen’ at some point, after which design changes are not allowed.

4.4 Start-up

The start-up of production processes in the process industries is very complex and difficult. Hence, this stage is considered critical, as problems during start-up might impact the performance of a whole plant and impose high costs due to production disturbances. Consequently, the respondents pictured the intensity of collaboration as high. Personnel from the equipment supplier are usually very involved in the start-up process at the plant to get the equipment working properly, transfer operational
knowledge, and make sure that an efficient start-up is achieved. Moreover, the equipment suppliers usually hold extensive educational programs for operators and maintenance personnel. A project manager at Alphacorp (R19) described the commitments in the start-up stage; “On a recent project we had 20,000 education hours. The equipment supplier was there to help with the start-up from December till the end of February; they had people in the control room 24–7 to assist the operators.” In order to facilitate the planning and organisation of the start-up stage, Alphacorp found that a start-up manager should be appointed already after the FFE-stage, when the formal purchasing decision had been taken. The respondents suggested that it is important to be proactive and initiate the organisation and the planning of the start-up activities already during the development stage. From a more long-term perspective, this stage is also strategic in terms of learning, since it is a golden opportunity for knowledge transfer from suppliers to the process firm concerning operational competence.

4.5 Operation

During the operation stage, the intensity of collaboration typically drops significantly, mostly due to a fear in the process firms that the equipment suppliers can learn too much about their processes. The vice president at Bethacorp (R25) highlighted this issue; “In the operation stage, collaboration tends to decrease. This can be caused by our unwillingness to have equipment suppliers in the factory where they can pick up knowledge about our production process.” A department manager at Alphacorp (R4) further elaborated on this issue; “We do things in our maintenance and we do things in our process to adapt the equipment to suit our process. The critical matter is really how we run our process, and that is something that we do not want anyone to know about.” Nevertheless, providing access to the operational knowledge about the equipment is seen as a very important factor for further improvement of the equipment. Additionally, the possibility of testing the equipment in real-life settings is an important benefit for the equipment manufacturer. Moreover, process firms typically make some modifications and adjustments to improve the equipment in their production, and knowledge of these is often transferred to the equipment suppliers when discussions of upgrading the equipment are initiated in the FFE-stage of a future development project. Consequently, this input of customer knowledge could enhance the quality of the equipment not only for the current customer, but also in other markets. In sum, the process firms struggle with decisions concerning what they can and cannot share during this stage, recognising that their operational knowledge of the processes is their main source of competitive advantage.

5 Analysis and discussion

By focusing on the process industries, this study has shown the prevalence of open and collaborative innovation practices outside the high-tech industries, and further shown how open innovation can facilitate not only product innovation but also process innovation, by means of developing new process equipment. Furthermore, our empirical findings identified several potential opportunities and risks in collaboration, for both the process firm and the equipment supplier, during the different stages of the equipment
lifecycle. Consequently, the collaboration intensity also differs according to stage. In Table 3, data concerning opportunities, problems and the intensity of collaboration at different lifecycle stages are summarised.

**Table 3** Opportunities, problems, and collaboration intensity in lifecycle stages

<table>
<thead>
<tr>
<th>Lifecycle stage</th>
<th>Main opportunities</th>
<th>Main problems</th>
<th>Collaboration intensity</th>
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<tbody>
<tr>
<td>FFE</td>
<td>Early establishment of collaborative relations facilitate joint development work at this and later stages. Sharing ideas and visions enhance creative solutions. Joint generation of clear concept definitions enhance development of customised equipment to meet process firm’s needs.</td>
<td>Lack of human resources for collaboration before purchasing decision. Difficult to agree on price due to high uncertainty. Difficult for process firms to describe and communicate what they need to equipment suppliers. Poor collaboration and communication may cause problems in later stages.</td>
<td>Medium</td>
</tr>
<tr>
<td>Process and product development</td>
<td>Larger investments possible after formal purchasing decision. Concurrent engineering improve constructability by drawing on both parties’ knowledge and experience. Further improving collaborative relationships for later stages. Testing prototype equipment in operating environment.</td>
<td>Costly idiosyncratic investments for equipment suppliers. Lack of involvement from end users may cause costly late changes. Equipment suppliers fear potential losses of core knowledge. Interdependencies between product and process development cause uncertainty and confusion.</td>
<td>High</td>
</tr>
<tr>
<td>Assembly and installation</td>
<td>Avoiding sub optimising among various actors through collaboration enables faster and less costly assembly and installation.</td>
<td>Difficulties in coordinating collaboration between a large number of actors. Late changes initiated by end-users cause cost and time overruns.</td>
<td>Medium</td>
</tr>
<tr>
<td>Start-up</td>
<td>Transfer of operational knowledge to process firms enables efficient operation. Significant joint learning opportunities on the operation of the equipment.</td>
<td>Failures may lead to delayed production start and conflicts among actors. Efficient start-up requires detailed planning and appropriate organisation.</td>
<td>Very high</td>
</tr>
<tr>
<td>Operation</td>
<td>Benefiting from equipment manufacturers’ knowledge in optimising and upgrading the equipment. Transferring knowledge of modifications and improvements in the equipment to equipment manufacturers. Suppliers may have the opportunity to test the equipment in real life setting and learn from operational data.</td>
<td>Process firms fear potential losses of core knowledge and there is a lack of facilitating routines to know what should and should not be shared.</td>
<td>Low</td>
</tr>
</tbody>
</table>
A number of interesting facets emerged during the analysis. First, our findings have highlighted the importance and the challenges of the FFE stage. Before engaging in open and collaborative innovation, the process firms describe a need to establish clear and explicit goals and objectives in order to communicate these effectively to their collaborating partners, thus highlighting a critical issue for firms engaging in inbound open innovation activities (Slowinski et al., 2009; Witzeman et al., 2006). Moreover, it is equally important that needs and expected outcomes are effectively communicated within the internal organisation. An important aspect of this is to involve end users, to obtain also their input to the design work (Gassman et al., 2006; Athaide and Klink, 2009). If end-users’ input to design is acquired early, the design can be ‘frozen’ early in order to avoid late changes. Previous research has found that late client-initiated design changes are a common cause of both time and cost overruns (Assaf and Al-Hejjji, 2006; Oladapo, 2007), which underscores the importance of early end user involvement.

Moreover, risks during the assembly and start-up stages were not perceived to be significant. Rather, the respondents indicated that the most severe risk in these stages was to collaborate insufficiently. Since the process equipment often is very complex and of high strategic importance, start-up problems will lead to high costs. Despite the critical nature of the start-up stage, it has been neglected in previous research. The process firms found that one way of handling problems during these stages is to set up a broad partnering team in which all key actors interact and share the rewards arising from collaborative efforts in the network, rather than sub-optimising their performance in dyadic contracts (Eriksson, 2008; Caldwell et al., 2009). Thereby, our results support previous research, stating that buyers can proactively influence the collaboration intensity between suppliers (Wu et al., 2010). However, Wu et al. (2010) found that increased collaboration between competing suppliers in buyer-supplier-supplier triads is detrimental for supplier performance. A potential reason for our contradicting results is that the suppliers in our study are interdependent and have complementary competences and products, rather than being direct competitors.

The limited collaboration during the operation stage suggests that the inputs from suppliers are of somewhat less value at this stage, whereas the risk of knowledge leakage is greater. Since the production process constitutes a core capability of the process firms, the benefits of collaboration may thus be smaller than the risks. The low level of collaboration is then logical and in line with the reasoning presented by Chesbrough and Schwartz (2007), arguing that core capabilities should be developed in-house and shared only sparingly. From the supplier perspective, collaboration may be more interesting since the process technology suppliers can expand their business by also marketing after-sales services (Hicks and McGovern, 2009; Ivory and Alderman, 2009). Additionally, transfer of operation knowledge to the suppliers may enhance development and upgrading of equipment in future projects.

Finally, our empirical findings underscore the importance of a lifecycle perspective since the collaboration intensity is interconnected across different stages. Deficient collaboration in early stages can be difficult to improve significantly in later stages. Moreover, collaboration in the FFE, start-up, and operation stages, is primarily of a dyadic nature – whereas the development and assembly stages involve collaboration in a network of suppliers, especially when concurrent engineering is adopted. These differences bring about a need for process firms to tailor their collaborative practices and mechanisms to changing contingences in different stages.
6 Conclusions

This paper complements earlier open innovation research, by investigating product and process development in mature industries. In order to reap the benefits of open innovation, it is important to address both potential opportunities and problems that may arise in collaborative development projects. However, the potential for collaboration at each stage is different because process firms struggles with different technical, organisational, and managerial activities at each stage. Hence, the content and the intensity of the collaboration should be tailored to the different stages of the equipment’s lifecycle. As such, we highlight the fact that being totally open in development activities is not always the most suitable option (Enkel et al., 2009; Lazzarotti and Manzini, 2009). Instead, different degrees of ‘openness’ may be suitable at different stages. The main theoretical contribution of this paper is therefore the adoption of a lifecycle perspective on the development of process equipment, making it possible to assess all development stages in terms of idiosyncrasies and interconnections. Furthermore, we have found that although intense collaboration among competing suppliers may be detrimental for performance (Wu et al., 2010), it is beneficial to facilitate intense collaboration among suppliers with complementary products and resources in a broad partnering team.

Managers in process firms should recognise the importance of adapting a lifecycle perspective on their development projects due to the significant overlaps and interconnections among different stages, in terms of activities performed and resources required. As such, it is important to underscore that collaboration intensity is interconnected across stages. Although the collaboration intensity may vary across stages, early collaboration paves the way for collaboration in later stages. Process firms should therefore adopt a strategic lifecycle perspective on procurement procedures and project management activities in order to address problems, opportunities, and collaboration intensity at all stages. In line with this argument, the start-up stage should be planned in detail and organised purposefully from the outset of the project, since it is particularly difficult and of strategic importance in process firms. Moreover, risks of losing core knowledge may be particularly high in specific stages for the collaborating partners (e.g., in the development stage for suppliers and in operations for process firms). Consequently, managers from both sides must carefully think through why, when, and to what extent collaboration is needed, and make sure that the advantages outweigh the disadvantages. Thus, a more formalised collaboration process is likely to help both parties to reap the benefits from organisational routines to maximise the outcomes of collaborative development efforts. Such a process should be organised to be explicit, widely known, characterised by clear decision-making responsibilities, and contain explicit performance measures (Khurana and Rosenthal, 1998). In addition, open innovation requires a focus on internal aspects as our empirical findings revealed the importance of suitable internal organisation and coordination. Therefore, successful collaboration with suppliers requires coordination among the internal functions of R&D, procurement, project management, and operation during the entire lifecycle.
References


Open Innovation and the Stage-Gate Process: A Revised Model for New Product Development

Johan Grönlund, David Rönnberg Sjödin and Johan Frishammar, 2010


Open Innovation in the Process Industries: A Life-cycle Perspective on the Development of New Process Equipment

David Rönnberg Sjödin, Per Erik Eriksson and Johan Frishammar, 2010


Open Operation: Buyer-Supplier Collaboration in Operational Projects

David Rönnberg Sjödin, 2010

Submitted to IPDM Conference 2011
ABSTRACT: The purpose of this article is to explore the problems and opportunities faced by equipment suppliers during collaboration with firms in the process industries, throughout the different stages of operational projects. Empirically, results are obtained from 22 interviews in a multiple case study of eight equipment suppliers. The results show that strong collaboration is often required in operational projects to facilitate technology transfer and better operational performance. In particular, collaboration is essential to transfer knowledge about the equipment from the equipment supplier to the process firm in the start-up stage where intimate educational activities are typically required. However, these projects are often very complex to manage, as interdependences among a number of actors and activities create problems for both buyer and supplier. By focusing on the collaborations between process firms and equipment suppliers in the operational stages, this study shows how open innovation can facilitate not only product innovation but also process innovation, by means of collaborative selection and installation of new process equipment – i.e. “open operation”.

KEY CONCEPTS: Open Innovation; buyer-supplier relationships; process equipment; operation.

1. Introduction

In the era of open innovation, firms are experiencing increased advantages of inter-firm collaboration (Chesbrough, 2003). However, the risks of collaboration should not be underestimated, as firms risk spreading core knowledge by collaborating openly with external actors (Enkel et al., 2005). In this study, opportunities and risks of open innovation are investigated by studying collaborative efforts between process firms and equipment suppliers. The process industries (e.g. metals and minerals, pulp and paper, chemical and food industries) add value to materials by mixing, separating, or inducing chemical reactions. Despite their significant financial contribution to national economies, and their numerical strength as a group, the process industries have largely been ignored by prior innovation management research (Lager, 2011; Hutcheson et al., 1995). These industries typically involve considerable capital investment in production equipment with high complexity (involving many interconnected components and actors) and often idiosyncratic constitutions of each process plant (Hutcheson et al., 1995). As a result, development and installation of new process technology frequently necessitate major input from equipment suppliers (Lager & Hörte, 2005).

While incentives to collaborate are often strong, close collaboration also poses significant challenges depending on the stage of the collaborative project. Previous literature on open innovation has focused mainly on collaboration during the early stages of development.
projects (Enkel et al., 2009; Chesbrough & Crowther, 2006). It is, however, important to collaborate not only during development of new equipment, but also during the purchasing, installation and post-installation stages of already developed equipment, as the activities performed in these stages have a strong impact on the operational performance of the equipment (Athaide & Klink, 2009). A project that extends through purchasing to installation and post-installation is in this paper regarded as an operational project. An operational project is thus a project with the purpose of designing and implementing customized process equipment. While collaborating during development projects may be seen as open innovation (Chesbrough, 2003), one may also refer to collaboration in operational projects as “open operation”, conceptualising a more externally open approach in these projects (Lager, 2011).

These kinds of operational projects are very common in the process industries. Indeed, collaboration in operational projects in this setting is of critical importance (Lager, 2005; Lee et al., 2010) because the high complexity and customization of the equipment for each process plant can create significant challenges for buyers and suppliers (Stump et al., 2002). For example, a lack of communication can lead to mistakes in the design of the equipment, and poorly planned start-up activities may lead to problems and high costs for both parties (Rönnberg Sjödin et al., 2010). As a result, these projects often have prolonged start-up periods before the equipment is working as expected (Lager, 2011). To handle these problems, collaborative relationships between equipment suppliers and process firms are often essential over the course of the project. However, research on collaboration in operational projects is limited, and more knowledge is necessary to facilitate improved methods and work-practices for collaborative efforts between process firms and equipment suppliers (Lager & Frishammar, 2010). In particular, the need to study collaboration from the equipment supplier’s perspective has been highlighted in order to identify problems and opportunities faced by these actors in strategically important activities (Rönnberg Sjödin & Eriksson, 2010). Therefore, the purpose of this article is to explore the problems and opportunities faced by equipment suppliers in collaboration with process firms throughout the different stages of operational projects.

2. Conceptual Background

In an operational project, collaboration between equipment suppliers and process firms facilitates technology transfer and better operational performance. Collaborative activities in operational projects include: careful joint selection and design/development of proper process equipment for the process firm’s specific production applications, mobilisation of joint resources for a smooth installation and start-up, and subsequent efficient operation utilising the combined expertise of both parties. Drawing on the work of Lager & Frishammar (2010), operational projects in this study have been divided into five stages: pre-study, purchasing and development, assembly and installation, start-up, and production (see Figure 1). Although the stages are presented as sequential, activities performed during the life cycle are frequently overlapping and heavily interconnected.
Figure 1. The five stages of an operational project

The *pre-study* is usually conducted by the process firm before it decides to proceed to formal purchasing discussions. Here it is important to articulate the needs of the process firm and translate these into equipment or process concepts (Cooper, 1988a; Khurana & Rosenthal, 1998). Moreover, since the activities at this stage strongly affect future equipment performance and costs in the following development stage, it is crucial that the process firm has vigilantly discussed and established equipment specifications and preliminary operating and investment costs for such equipment (Cooper, 1988b). As such, the pre-study should state the objective of the project and make a statement of both technology and end-user benefit issues (Montoya-Weiss & O'Driscoll, 2000).

During the *purchasing and development* stage, the process firm and the equipment supplier jointly decide on the specifications of the equipment and the contractual agreements. It has been shown that trusting and early collaboration with the technology supplier enables firms to make the right technology selection and avoid misspecification and expensive mistakes during purchasing (Abd Rahman et al., 2009). In addition, to facilitate useful supplier input, relationships should preferably be based on long-term collaboration and trust, rather than on short-term competitive bidding practices (Ro et al., 2008). Moreover, the selected contractual forms and conditions will to a large extent impact how future collaboration and technology transfer may be executed even in the later stages of the operational project (Lager & Frishammar, 2010). During this stage, end user involvement (i.e. operators, maintenance personnel) in collaborative development tasks is critical when high customization is demanded and end users’ knowledge is high (Athaide & Klink, 2009). In addition, collaboration at this stage can facilitate concurrent engineering, which makes it possible to start the assembly and installation activities before the development is completed (Gil et al., 2008).

The *assembly and installation* of the equipment are typically performed by the supplier, often in collaboration with various subcontractors. It may however be important to engage the process firm in collaboration at this stage too, because buyer-supplier integration during installation accelerates effective use of the process equipment (Athaide & Klink, 2009). This stage typically involves many suppliers and sub-suppliers who have to interact. This results in mutual interdependence among the different actors (Grandori, 1997). As such, close collaboration among the different actors is often needed to avoid sub-optimization (Eriksson & Nilsson, 2008).

When the equipment has been assembled, the *start-up* activities are initiated. Due to the complexity and strategic importance of the process equipment, the start-up stage is a key part of an operational project (Lee et al., 2010). Once a piece of equipment has been
installed, the sellers must train buyer personnel on its use, and help incorporate it into the buyer’s daily routines to ensure successful implementation (Hausman and Stock, 2003). In particular, complete transfer of the technology and know-how related to the equipment, from the equipment supplier to engineers and operators of the process firm, is essential for effective utilization in the production stage (Lee et al., 2010). In contrast, buyer mismanagement of the equipment often leads to subsequent requests for product redesign or modification (Meldrum and Millman, 1991). Due to this fact, it is important already during the contract negotiations that both parties agree on how the start-up stage is to be conducted.

In the production stage, when a piece of equipment or plant is up and running, collaboration is vital as process equipment often requires continuous fine tuning for many months or even years before it is working optimally (Lager, 2010). In this case, the equipment supplier’s knowledge about the equipment may enhance the equipment’s operation performance (Athaide & Klink, 2009). Moreover, since learning a technology proficiently is typically associated with operating the process equipment, the supplier of the equipment should always have a strong interest in obtaining information from production about operation performance (von Hippel and Tyre, 1995) as well as the idiosyncratic characteristics of the customer’s operating environment (Athaide et al., 2003). As a result, collaboration in the production stage can lead to new knowledge that can be fed back to the early stages in future development projects. Moreover, many equipment suppliers are complementing their product offerings with after-sales service innovations (i.e. maintenance, optimization) in order to generate new revenue streams and capitalize on their experience (Hicks and McGovern, 2009; Ivory and Alderman, 2009; Shelton, 2009).

3. Method

In this study, an exploratory multiple case study strategy was employed. This was deemed suitable given the limited knowledge about collaborative practices within the process industries (Edmondson and McManus, 2007; Hutcheson et al., 1995). In addition, multiple cases are effective because they enable collection of comparative data, and so are likely to yield more accurate, generalizable theory than single cases (Eisenhardt, 1991; Yin, 1994). Furthermore, information-rich real-life case studies are expected to help identify new aspects and phenomena (Eisenhardt, 1989; Yin, 2003) and are especially appropriate for examining and articulating processes (Edmondson & McManus, 2007; Pratt, 2009) such as the different stages of an operational project.

To investigate collaborative practices within the process industries, eight equipment suppliers operating in the metals and minerals industry were selected. The selection was done in collaboration with process industry professionals in leading roles by means of judgement sampling (Denzin and Lincoln, 1994) based on the equipment suppliers’ involvement in collaborative projects with their customers. Table 1 provides some further information about the case firms. Moreover, studying equipment suppliers in the metals and minerals industry is particularly interesting as development of process equipment in this setting provides several challenges. In particular, the operations handle heavy
materials that put significant strain on the equipment, enforcing the need for robust design. Customers also often have idiosyncratic equipment needs, and a crucial need for reliable equipment. In addition, the industry has undergone large changes in the recent decades due to consolidation and increasingly globalized customer markets (Lager & Frishammar, 2010).

Table 1: Information about the case firms

<table>
<thead>
<tr>
<th>Firm Pseudonym</th>
<th>Main Products</th>
<th>Number of employees</th>
<th>Annual turnover</th>
<th>Country</th>
<th>Respondents (* = phone)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Griffin</td>
<td>Sieves</td>
<td>200</td>
<td>21 M€</td>
<td>United Kingdom</td>
<td>Marketing Director*</td>
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<td></td>
<td>Manager Electronics*</td>
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<td></td>
<td>Sales Manager</td>
</tr>
<tr>
<td>Nippon</td>
<td>Blenders</td>
<td>170</td>
<td>25 M€</td>
<td>Netherlands</td>
<td>Application Manager</td>
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<td></td>
<td>Sales Engineer</td>
</tr>
<tr>
<td>Tiger</td>
<td>Automated lifting cranes</td>
<td>8</td>
<td>6 M€</td>
<td>Sweden</td>
<td>Vice President</td>
</tr>
<tr>
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<td>Project Manager</td>
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<td>Project Manager</td>
</tr>
<tr>
<td>Alpine</td>
<td>Press tools</td>
<td>50</td>
<td>6 M€</td>
<td>Switzerland</td>
<td>Managing Director*</td>
</tr>
<tr>
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<td></td>
<td></td>
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<td>Sales Director</td>
</tr>
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<td>Delphi</td>
<td>Presses</td>
<td>450</td>
<td>60 M€</td>
<td>Germany</td>
<td>Sales Manager*</td>
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<td>Production Manager*</td>
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<td>Department Manager*</td>
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<tr>
<td>Gold</td>
<td>Mill linings</td>
<td>200</td>
<td>112 M€</td>
<td>Sweden</td>
<td>Global Technology Manager</td>
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<td></td>
<td></td>
<td></td>
<td>Development Manager</td>
</tr>
<tr>
<td>Silver</td>
<td>Separation equipment, and slurry pumps</td>
<td>240</td>
<td>100 M€</td>
<td>Sweden</td>
<td>Project Manager</td>
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<td>Project Manager</td>
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<td>Sourcing Manager</td>
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<td>Lakeland</td>
<td>Mineral processing equipment</td>
<td>3200</td>
<td>878 M€</td>
<td>Finland</td>
<td>Product Line Manager</td>
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<td>Manager Deliveries</td>
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<td>Sales Director</td>
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Data for the study were gathered primarily through individual, in-depth interviews at these seven firms, due to the fact that interviews can provide insightful information and can be focused directly on research topics (Yin, 2003). Moreover, the focus on understanding problems and opportunities with collaboration at different stages underscores the importance of being able to discuss back and forth with the respondents and being able to ask follow-up questions. The 22 interviews underpinning this paper ranged from 30 minutes to 2.5 hours in duration, with an average of about one hour. Due to time and budget constraints, six of the interviews were conducted over the phone (denoted by an asterix in Table 1).

To diminish bias in the data collection, knowledgeable informants from both the strategic and operational levels were selected, who viewed the collaborative relationships from diverse perspectives (Eisenhardt and Graebner, 2007). As such, the respondents were selected carefully in dialogue with key informants at the participating firms, based on their involvement in and knowledge of collaborative projects among equipment suppliers and process firms. In addition, the respondents varied in age, years of employment, academic training and position.
The interviews were semi-structured and guided by a list of questions designed on the basis of the literature review in order to capture activities, problems and opportunities in the different stages of operational projects. Data were gathered on the organizational level, but examples from recent projects were encouraged. Departures from the specific questions were permitted in order to explore particularly interesting findings that emerged during the study. Accordingly, the format of the interviews was adapted and changed slightly to capture the emergent themes (Eisenhardt, 1989). In addition, approximately 15 hours of document studies were performed, regarding both company reports and project documents, thus allowing empirical triangulation of the findings from the interviews.

To create overlap between data collection and data analysis, patterns in the empirical data was reflected on as they were discovered, together with continuous field note writing. To facilitate data analysis, each interview was transcribed and transferred into a spreadsheet which was structured as a conceptually ordered display (Miles and Huberman, 1994). Furthermore, iterations between results, theory, and empirical data were performed to enact emergent conclusions (Eisenhardt, 1989; Yin, 2003). In addition, a case study data base was constructed containing case study notes, documents, and the recorded and transcribed interviews collected during the study, thus facilitating retrieval for future studies (Yin, 2003). Construct validity was addressed mainly by trying to establish a clear chain of evidence to allow readers to see how the research purpose matched with key conclusions (Yin, 2003).

4. Empirical findings

4.1 Pre-study

In operational projects, formal purchasing discussions are usually preceded by a pre-study conducted by the process firm, to determine future process needs and expected outcomes. As such, collaboration intensity during the pre-study is often low. However, the respondents agreed that the pre-study was of critical importance to the overall collaboration, indicating that problems may occur in later stages when the process firm initiates purchasing discussions without having a complete picture of what it wants.

The pre-study was also seen as a stage where the potential of recently developed equipment could be explored. Still, the respondents felt that the process firms typically look for proven equipment when investing in new equipment or a new plant. On the other hand, the respondents noted that equipment which previously has been used in one process might not work so well in a different process, suggesting that sometimes the conservative nature of their customers was not in their best interest.

In some cases, the equipment suppliers may be contracted as consultants during the pre-study. This allows them to contribute with their competences in designing production lines. A sourcing manager at Silver elaborated on how the outcome of the customer’s pre-study was used in the design of the equipment: "We usually make the dimensions and the design of the plant based on the customer’s pre-study. They tell us ‘this is the material we
have, these are the tonnages we will run and these are the parameters we want', and then we develop a process model to determine the equipment needed.” However, the involvement during the pre-study does not guarantee that the equipment supplier will get the individual order. A sales director at Lakeland provided an example from a recent project: “We conducted the pre-study and thought we had a good chance of getting the whole project, but in the end they decided to purchase our competitor’s equipment for a large part of the plant.”

4.2 Purchasing and development

During the purchasing and development stage of an operational project, a bid invitation, based on the pre-study, is typically sent out to several equipment suppliers which have to compete. After a supplier has been selected, the equipment supplier and process firm typically engage in careful joint selection of proper process equipment for the process firm’s specific production needs.

During this stage, communication and collaboration are very important. The vice president of Tiger accentuated the need for communication before the final order is placed: “If you haven’t talked enough before the order is placed, you often end up in a situation where the customers say ‘I thought you were going to do like this’, and then you get misunderstandings and arguments. Therefore, the most important thing before signing any order is that both parties know what we have sold and what they have bought.”

In operational projects, it can often be hard to estimate the price of the project beforehand, as a result of the complex nature of the assembly and installation and start-up stages. This is especially true in large projects. Because of this, Silver had recently been engaged in a project where the customer had requested open books on some of the value of the order. A sourcing manager at Silver explained the rationale for open books: “It is very hard for us to forecast all the costs. When it comes to our equipment we have a pretty clear picture of the cost, but when it comes to other equipment, installation costs and raw materials it can vary quite a lot. Without open books it would be likely for us as a supplier to add a little on the price to handle this uncertainty, and this is what the customer doesn’t want.”

Provided that a common agreement has been found, the development activities can often start, although all the details of the purchase may not have been finalized. After the formal purchasing decision has been taken, development activities are intensified at the equipment supplier. Frequent contacts with the process firms are often required to get feedback and discuss different solutions. A problem at this stage might be that the process firms are slow to respond to questions from the equipment suppliers, which can make it impossible for the development team to continue with the design without sufficient information. A critical aspect in the development stage is thus to involve end users (e.g. operators and maintenance personnel) in order to obtain their valuable insights about the final product as early as possible. Moreover, involving end users early during development is important for creating commitment. It decreases problems at later stages,
as they take more responsibility for equipment that they have been involved in developing.

In addition, development work usually involves a significant element of customization to get the equipment to fit with the customer’s process needs. An application manager at Nippon highlighted why customization is so important: “If the customer wants the equipment with ten openings to fill it with different products, or only with one or with none, or if he wants it easily cleanable, or even if he wants to have it in gold, we are open. If you are not open to customization in our business you will never sell equipment, because the customer always wants something different.”

Moreover, development typically involves a lot of collaboration and exchange of information with the process firms, which may lead to knowledge leakage. A sales manager at Griffin highlighted the fact that some customers could not be trusted: “From a commercial point of view some customers are always unfaithful, which you learn quite fast, and in these cases we won’t give out more information than we have to.” Indeed, the risk of losing core knowledge sometimes restricted what the equipment suppliers were willing to share openly. A product manager at Silver explained what they were reluctant to share: “What we avoid giving out is manufacturing drawings and things like that, so that our competitors won’t get access to these and go out and manufacture our equipment. This is an important part of our know-how, how we manufacture our equipment and how it looks.”

4.3 Assembly and installation

Assembly and installation are usually conducted by the equipment supplier. However, the process firm is responsible for making sure that the facilities are in place to install the equipment. A production manager at Delphi stressed the importance of the customer’s preparation: “It is critical that the customer knows exactly what they need when the installation starts at the customer site and what they have to prepare.”

Furthermore, this is a stage where mistakes in the design of the equipment and/or facilities are often discovered. In these cases it can often be hard to determine who was responsible for the problem. Therefore, the respondents stressed that a good collaboration was critical when problems occurred, as disagreements at a stage where both parties have people waiting to get to work can be very costly and detrimental to the future collaboration.

If the project involves an entire production plant, the amount of people and firms involved in the project is peaking during this stage, making it very difficult to coordinate a large number of diverse activities. In this case, managing the assembly and installation stage can be very complex in terms of interdependence and interaction among various suppliers. Under such circumstances, Silver had good experiences from a recent project where a contractor firm had been appointed as project manager with a set deadline for the project. This proved successful as it allowed the project manager to put pressure not only
on the equipment suppliers but, more importantly, also on the process firm to complete their parts on time during this stage.

Moreover, end users are naturally more involved at this stage as the work is conducted in their plants. In cases where the end users have not been involved during development, this might lead to late changes proposed by the end users, that can cause cost and time overruns.

4.4 Start-up

The start-up of production processes in the process industries is very complex and difficult to manage. This is especially true during large projects as several pieces of equipment may be put on stream at the same time. A project manager at Lakeland bluntly put it: “The start-up stage is normally characterized by chaos.” Hence, this stage is considered critical, as problems during start-up might impact the performance of a whole plant and impose high costs and decreased revenues, due to delayed production start and disturbances in production. Therefore, the respondents viewed this as a very intense stage in terms of collaboration.

Depending on the type of equipment that is to be put on stream, highly competent people may be needed to facilitate the start-up from the equipment supplier’s side. As an example, the technical director of Alpine is usually in charge of all its start-ups. A sales director at Alpine explained why this is the case: “We used to have three people that had the technical competence to do the start-up, but one guy left and the other retired, so now our technical director is the only one left with experience and know-how, and it is something that takes a lot of time to learn.”

Furthermore, the respondents suggested that it is important to be proactive and initiate the organization and the planning of the installation and start-up activities already during purchasing. A project manager at Silver recounted a successful example of this from a recent project where the customer had appointed a start-up manager from their side: “The start-up manager was at every project meeting from the start of the project, and we wondered what he was doing there so early. But it was completely right, because when the start-up stage came he already knew everything and everything worked perfectly.” In other words, the early appointment of the start-up manager had significantly improved the start-up stage of that particular project.

Personnel from the equipment supplier are usually very involved in the start-up process at the plant to get the equipment working properly, transfer operational knowledge, and make sure that an efficient start-up is achieved. Moreover, the equipment supplier usually holds extensive educational programs for operators and maintenance personnel. A sales manager at Delphi elaborated on why these issues are so important: “All these trainings and support during start-up are a very important part of our sales because we do not sell a press or a machine. We sell a technology, and this technology needs to be understood. To really benefit from this technology they need to understand a lot of features and this is why it is so important to help them, to support them, and to supply training.” As such, it
was noted that operators at the process firm cannot learn all of the capabilities of the equipment by merely studying the equipment's operation manuals and other written documentation. Rather, the tacit knowledge often has to be transferred through close education, such as direct, first-hand observation and operation in collaboration with knowledgeable personnel from the equipment supplier. Moreover, a critical part of the start-up stage is the knowledge transfer from the equipment supplier to the process firm concerning operational competence. Indeed, in a recent project Lakeland educated 100 people from the customer’s organization about the equipment. In this case, the educational commitments represented 5% of the overall order value.

4.5 Production

During the production stage, the process firms run the equipment in their plant and continuously fine-tune the equipment to obtain an improved process. However, even in the production stage, further development of the equipment may be needed to get it functioning as stated in the contract. A frustrated project manager at Lakeland remarked: “It has been four years since the project started and we are still in the plant from time to time to fix some problems in the design.” Cases like this, where mistakes in the design of the equipment cause prolonged projects, are problematic because they decrease the profitability for the equipment suppliers.

In contrast, the equipment suppliers are in general trying to be more involved at this stage through after-sales services, as their technical knowledge is useful in optimizing the performance of the equipment. In this sense, sharing of operational knowledge about the equipment from both sides is seen as a very important factor for further improvement of the equipment. Moreover, the equipment suppliers are generally interested in taking an increased responsibility for the equipment in the production stage (e.g. maintenance contracts, supply of spare parts). In addition, the equipment suppliers may take responsibility for running the equipment in production. In this case, already established customers are rarely interested in letting the equipment suppliers run part of their processes, as they want to keep the operational competences in-house. However, the respondents noted that new entrants in the metals and minerals industry that have not yet developed any competences in operation have a stronger interest in letting the equipment suppliers run part or all of their production process.

Additionally, collaboration in this stage allows the possibility to make further tests of the equipment over the long run and in real-life settings, which is an important benefit for the equipment supplier. Moreover, the process firms typically make some modifications and adjustments to improve the equipment in their production, and knowledge of these is often transferred to the equipment suppliers when discussions of upgrading the equipment are initiated or in future development projects. Accordingly, this input of knowledge from the process firms could enhance the quality of the equipment not only for the current customer, but also for other customers.

For the equipment suppliers, collaborative relations in this stage were also seen as very important for generating new ideas for future development projects. However, finding customers that can come up with these kinds of ideas is not always an easy task. A
marketing director at Griffin elaborated: “If I were to go to a customer and ask them to evaluate their industry and where their business is going in terms of our kind of equipment and what needs to be developed to make their life easier generally, the end customers haven’t got much of an idea. They just say that everything is okay.” However, some customers seemed to be more adept at coming up with ideas and suggestions for further development. A common denominator of these firms was that they had employees dedicated to dealing with process development issues during their daily work, rather than as an additional task on top of day-to-day operations.
5. Discussion and analysis

This study has shown the importance of collaborating in operational projects for equipment suppliers and process firms. Furthermore, the empirical findings from the equipment suppliers identified several potential opportunities and problems in collaboration, for both parties, during the different stages of operational projects. In Table 2, data concerning opportunities and problems at the different operational stages are summarized.

Table 2: Opportunities and problems in the different stages of operational projects

<table>
<thead>
<tr>
<th>Life cycle stage</th>
<th>Main opportunities</th>
<th>Main problems</th>
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<tr>
<td>Pre-study</td>
<td>A proficient pre-study significantly improves the projects’ chances of success in later stages. Equipment suppliers may be engaged as consultants and contribute with their knowledge and experience.</td>
<td>Problems can occur in later stages if the process firm has not clearly established what it wants. Customer preference for proven equipment can restrict potential improvements.</td>
</tr>
<tr>
<td>Purchasing and development</td>
<td>Open books decrease risks for both parties. Involving end users gives vital input to the development and increases their commitment to the project in later stages.</td>
<td>Hard to estimate price as unforeseen problems often occur in later stages. Process firms are slow to respond to questions, which delays development. Equipment suppliers fear potential losses of core knowledge.</td>
</tr>
<tr>
<td>Assembly and installation</td>
<td>Engaging a contractor to manage the coordination of the assembly and installation activities. Avoiding sub-optimizing among various actors through collaboration enables faster and less costly assembly and installation.</td>
<td>Difficulties in coordinating collaboration between numerous actors. Late changes proposed by end users lead to cost and time overruns.</td>
</tr>
<tr>
<td>Start-Up</td>
<td>Technology transfer to process firms enables efficient operation. Education of operators enables technology transfer and improves performance in the production stage. Significant joint learning opportunities on the operation of the equipment. Early appointment of start-up manager increases start-up performance.</td>
<td>Several simultaneous activities lead to high complexity and “chaos”. Failures may lead to delayed production start and conflicts among actors.</td>
</tr>
<tr>
<td>Production</td>
<td>Equipment suppliers can use their knowledge in optimizing and upgrading the equipment. Lead users can be a source of new developments. Opportunity to test the equipment in real-life settings and learn from operational data. After-sales commitments enable new revenue streams for equipment suppliers.</td>
<td>Mistakes in design may lead to long lead times before formal transfer of equipment and to additional development work.</td>
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A number of interesting findings were uncovered during this study. Collaboration during the pre-study was generally limited, although in some cases strong involvement from equipment suppliers as consultants was employed. However, the respondents highlighted the critical importance of the customer’s pre-study before engaging in operational projects. In particular, it is important to establish and communicate clear and explicit goals and performance objectives for the project before engaging in formal purchasing discussions. Thus, the respondents gave prominence to a critical issue for firms engaging in inbound open innovation activities (Slowinski et al., 2009; Witzeman et al., 2006).

Moreover, the results underline purchasing as a vital stage in the collaboration, as this is the stage where plans and contracts for later stages are drawn up (Lager & Frishammar, 2010). Accordingly, the respondents underlined that trust and early collaboration between the process firm and the equipment supplier during purchasing enable firms to make the right technology selection and avoid misspecification and costly mistakes, in accordance with earlier theory (Abd Rahman et al., 2009). Nevertheless, purchasing discussions may be quite tough, as it is hard to estimate the total price of the equipment. An interesting finding in this stage was therefore the use of open books, which can reduce some of the risk for both parties.

During development, the respondents underlined the involvement of end users, as they can give critical inputs to the project based on their knowledge. Furthermore, early involvement of end users increases their commitment to the project in later stages. Similarly, the importance of end-user involvement has been highlighted in previous literature (Athaide & Klink, 2009). Moreover, in this stage the equipment suppliers were sometimes reluctant to share too much information, especially with customers that were not deemed to be trustworthy, fearing that core knowledge could be spread to competitors. Accordingly, the equipment suppliers usually neglected to share core knowledge such as manufacturing drawings, in accordance with Chesbrough & Schwartz (2007) who state that core knowledge should be kept in-house.

In the assembly and installation stage, a lot of diverse activities need to be managed. This often results in mutual interdependence among the different actors (Grandori, 1997; Eriksson & Nilsson, 2008). In this case, appointing a contractor firm as project manager was helpful in establishing close collaboration among the different actors and avoiding sub-optimization in this stage.

The start-up stage is typically very challenging and even chaotic as one of the respondents put it. Nonetheless, previous literature has neglected to study this important phase. An interesting way of countering this problem was the early appointment of a start-up manager, allowing an early start on planning these critical activities. Furthermore, collaboration during the start-up stage is critical in order to fully transfer the process equipment to end users (Hausman and Stock, 2003). While formal mechanisms are appropriate for capturing and transferring the explicit part of technology, other approaches are necessary to share the tacit component, which is non-codifiable in nature (Lynskey, 1999). As indicated by the respondents, this is particularly true for the
operation of complex process equipment. In particular, it was noted that operators at the process firm cannot learn all of the capabilities of the equipment by merely studying written documentation about the equipment. Rather, the tacit knowledge often has to be transferred through hands-on education, such as direct, first-hand observation and operation in collaboration with knowledgeable personnel from the equipment suppliers. As such, this study further highlights the need for collaboration and knowledge management during the start-up stage as essential for the technology transfer of process equipment (Lager & Frishammar, 2010).

During the production stage, the equipment suppliers were generally trying to increase their life cycle commitments by complementing their product offerings with service innovations (i.e. maintenance, optimization). This corresponds with reports from previous literature (Hicks and McGovern, 2009; Ivory and Alderman, 2009; Shelton, 2009). Moreover, these developments are in line with the ideas of open services innovation (Chesbrough, 2011), where business models are expanded as firms find new revenue streams in a services-based economy. However, the respondents noted that it was hard to convince customers of the merits of their services, especially when the customers had similar internal competences. Furthermore, for the equipment suppliers, collaborative relations in this stage were also seen as very important for generating new ideas for future development projects. However, the equipment suppliers noted that sometimes customers had a hard time coming up with suggestions for improvement. The equipment suppliers generally countered this problem by identifying and collaborating extensively with process firms that had employees working explicitly with process development issues and capable of coming up with new ideas. These firms can thus be regarded as lead users (Von Hippel, 1988).

6. Conclusion

By focusing on the collaborations between process firms and equipment suppliers in the operational stages, this study has shown how open innovation can facilitate not only product innovation but also process innovation, by means of collaborative selection and installation of new process equipment – i.e. “open operation”. As such, the study complements earlier research on open innovation that has mainly focused on collaboration during the early development stages.

Moreover, production plants in the process industries are extremely costly, so a high utilization of the equipment with minimal maintenance shutdowns is necessary to maximize throughput and business returns (Lager & Frishammar, 2010). Therefore, equipment suppliers play an increasingly important role in refining existing technologies and improving equipment reliability and capabilities. Such efforts are facilitated by close cooperation with the process firms, which can contribute process knowledge that the equipment supplier might otherwise lack. Hence, collaboration in operational projects is critical.

An interesting conclusion that can be drawn is that a main difference between a development project and an operational project is the direction of knowledge flows. In a
development project, the equipment supplier is typically very interested in obtaining information from the process firm on potential improvements to the equipment (Athaide et al., 2009), as well as the potential of testing the developed equipment in the customer’s plants (Lager & Frishammar, 2010). In an operational project, however, the flow of knowledge is typically the reverse. In these projects it is the process firm that wants to benefit from the equipment supplier’s knowledge when attempting to upgrade their production process.

The findings of this paper can be used to remind managers in equipment suppliers of the problems and opportunities that arise during the different stages of operational projects. In particular, it is important to recognize that failure to address problems in early stages will often compound and create bigger problems at later stages. A main example of this is the purchasing stage, during which it is critical that the two parties create a common objective for the project, as failure to do so can create disagreements and deficient collaboration in later stages. However, if the process firm has not clearly established its objective with the project during the pre-study stage, these discussions during purchasing will typically be unproductive. Managers in both process firms and equipment suppliers should thus become conscious of the significant overlaps and interconnections among different stages that typically characterize these operational projects.

In addition, the start-up stage should be a prime concern for managers in equipment suppliers. As the problems are greatest in this stage, the potential for improvement should also be immense. This requires close collaboration. To this end, managers in these firms should make sure already at an early stage during purchasing discussions that the start-up stage is planned to suit the requirements of the projects. As such, end users should be involved at an early stage to enhance commitment, while clear responsibilities among the collaborating parties should also be outlined. In particular, collaboration is essential in order to transfer knowledge about the equipment from the equipment supplier to the process firm in the start-up stage, where intimate educational activities are typically required. In addition, collaborative activities during production are on the rise as the equipment suppliers expand their business models to be service providers. However, to succeed in these efforts the equipment suppliers may have to find ways of selling these services as complimentary performance enhancements, rather than as a treat to the process firm’s internal competences. The equipment suppliers are thus encouraged to involve their customers not only in their product development activities, but also in their service development activities to facilitate the development of complimentary services.

References


