Managerial Complexity in Process Industrial R&D Projects: A Swedish Study

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ABSTRACT

Process industries often have features that differ from other businesses, such as round-the-clock production and costly and specialized production processes—features that have not been dealt with in the project management literature. We highlight and identify the complexity of R&D projects in the Swedish process industry and its interrelated process development and product development activities based on results from interviews and a case study. The different competence areas in which a project manager must integrate and manage R&D projects is illustrated. We conclude that a project manager needs both production and product-related competence, including customers' processes.

KEYWORDS: project complexity; project manager; process industry; R&D project

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INTRODUCTION

In general, project management is associated with planning, scheduling, and controlling all activities required to reach project objectives (Lewis, 2001; Söderlund, 2002). Over the years, the interest in project management has grown as projects have become important for many organizations' strategic and operations management (Söderlund, 2005a). A review of the literature concerning project management (see the Appendix) reveals that effective outcomes of projects and the value of different project management practices are emphasized (Besner & Hobbs, 2006; Jacques, Garger, & Thomas, 2008; Shim & Lee, 2001; Turner & Müller, 2005). Further, the review shows that exploration of factors that generate successful project outcomes is highlighted in the literature (Cooke-Davies, 2002; Ives, 2005; Kanter & Walsh, 2004). These success factors can be linked to collaboration (Barnes, Pashby, & Gibbons, 2006), team communication (Hirst & Mann, 2004), project leadership (Barber & Warn, 2005), and managing global projects (Chiesa, 2000). Research concerning project management also reveals that projects are becoming increasingly "complex," and there is thus a need for understanding this complexity (Williams, 1999).

One source of complexity in projects is that every aspect of project management has two dimensions that need to be managed: the technical dimension (those groups of practices or processes that are integral to project management) and the human dimension (including the people who are operating these processes and the expertise they bring to the project) (Cooke-Davies & Arzymanow, 2003). These dimensions must be integrated and managed by crossing functions and knowledge bases in, for example, R&D projects (Carbone, 2005; Clark & Fujimoto, 1991; Dong, 1994). Several models visualize these integrated activities in R&D projects and innovation: for example, the funnel, the waterfall, the vat, and the cyclical models. However, these models have been criticized for being too static to allow for innovation (Schoen, Mason, Kline, & Bunch, 2005). Even though research yields new models and tools in project management, many R&D projects exceed planned unit cost, project cost, or time-to-market, and miss product reliability objectives (Naveh, 2007). Therefore, we argue that too little attention has been paid to describing and illustrating the areas that create project complexity and the need for integration of product development (ProdD) and process development (ProcD) in R&D projects. ProdD is defined as the process of bringing a product to market and ProcD as the development of new production processes and improvement of existing ones. The process industry (PI) is a branch where production processes are costly and interconnected, and have a high level of complexity (Hild, Sanders, & Cooper, 2000). Often, the expensive production processes are specialized to produce one product type. The difficulties related to complexity and integration of ProcD and ProdD in these special settings may have to be dealt with differently, or need other solutions than, for example, parts production. All types of R&D projects in the PI imply an integration of both product and process (production) development. A change in one of the development processes will have implications for the other. The purpose of this article is to identify the areas of complexity in R&D projects in the PI and to illustrate the different competence areas in which a project manager must integrate and manage R&D projects in the PI. However, this study is limited to R&D work encompassing integrated product development and process development where there is no need for new plants or for entire production process lines to be developed and constructed. Nevertheless, the continual improvement of work projects together with plant modification projects have been found to account for more than 80% of the development projects in the Swedish and Norwegian PI (Lager, 2002).

The article is structured with a literature review, where we discuss the current research concerning project management in relation to project complexity and project managers. The review continues with a brief discussion of the overall complexity of ProdD and ProcD in the PI—that is, the management of interrelated activities. Then research methodology is presented, describing the content of development work in the PI, and therefore of project complexity. This description results in a conceptual model highlighting interrelated areas that must be managed by project managers in the PI.

Literature Review

From a study of papers in project management journals published between 2000 and 2009, we conclude that general project management research can be divided into four major categories (see Appendix):

1. Project management practice and perspectives (Bryde, 2003; Kolltveit, Karlsen, & Gronhaug, 2007),
2. Project performance (Chen & Lee, 2007),
3. Project success factors (Cooke-Davies, 2002), and
4. Project complexity (Baccarini, 1996; Vidal & Marle, 2008).

These categories indicate multifaceted areas that a project manager must handle to reach project success. Since the focus of this article is on innovation and R&D projects, we add a fifth category in the literature review of project management: innovation and R&D projects. The special tasks and uncertainty of R&D and innovation projects encompass complexity that can differ from other projects discussed in the project management literature. The research shows that R&D projects become increasingly complex, owing to, for example, cross-functional teams, globalization, and shorter product life cycles (Olson, Walker, Ruekert, & Bonner, 2001; Sherman, Souder, & Jenssen, 2000). Lenfle (2008) emphasizes the need to distinguish different solutions and ways of managing innovation projects.

Shenhar and Dvir (1996) argue that project management literature generally seems to assume that all projects are fundamentally similar. Therefore, they developed a two-dimensional typology according to the degree of technology uncertainty (from low-tech to high-tech) and the level of system scope in the project (for example, complexity in planning, control, etc., of the project). This typology highlights the need to adapt managerial attitudes to select managerial tools. Further, they pinpoint the difference between the project types and the complexity in handling project management aspects in projects with a wider scope (interlinked with other projects in a program). We argue that their contribution adds to one dimension of complexity but conclude that research is still lacking regarding project complexity in R&D projects. We agree with Shenhar and Dvir (2007) that the project management field is still evolving, and we particularly lack research on which areas project managers need to integrate and manage in R&D projects.

Project Complexity

Research about the concept of complexity has been conducted for years, but there is little consensus on what project complexity is. Vidal and Marle (2008) identify two main scientific kinds of complexity: (1) descriptive complexity, which incited researchers to try to quantify or measure complexity, and (2) perceived complexity, where complexity is considered subjective, because the observer may not perceive all interconnected parts that contribute to the overall complexity. For example, the complexity in a project consists of interdependent elements: the organization, the stakeholders, the team and how the project is delivered (that is, the project management methodology used) (Maylor, Vidgen, & Carver, 2008), and simultaneous events, which preclude an observer from seeing the full picture of the complexity of a project. These two kinds of complexity can be applied to project complexity and project management complexity.

In the project management literature, project complexity is a multifaceted concept that is often used to describe various areas that can be difficult to manage. Examples are coordination of complex sequences of actions (Banerjee, Carrillo, & Paul, 2007; Pich, Loch, & De Meyer, 2002), projects in complex and dynamic settings (Maaninen-Olsson & Müllern, 2009), and joint R&D projects with several parties (Arranz & Fdez de Arroyabe, 2009). According to Baccarini (1996), project complexity is subjective, and the complexity can be interpreted to encompass anything characterized by difficulty and uncertainty. Therefore, Baccarini proposes a definition of project complexity as "consisting of many varied interrelated parts" (p. 202), which he then operationalizes in terms of differentiation (the number of varied elements) and interdependence (the degree of interrelatedness between these elements). Baccarini (1996) suggests that this definition can be applied to different types of project complexity related to the organization, the technology, the environment, the information, the decision making, or the system. The major source of project complexity, emphasized by Williams (1999), is so-called structural complexity (variety of tasks and the degree of interdependence among these tasks) and uncertainty (in goals and in methods).

With regard to the more "perceived complexity" in a project, which is more dependent on the relationship between the project's types, project managers' personality, and the project's success (Dvir, Sadeh, & Malach-Pines, 2006), there should be a fit between the project managers and the project assigned to them to ensure project success (Maylor et al., 2008).

We conclude that researchers view project complexity as an elaborate function of project size, project variety, project interdependence, and elements of context. We also agree with Vidal and Marle (2008) that there is a need to explore project complexity further. This complexity is further elaborated upon by Bredillet (2010), who proposes a "meta" approach of the project management field, illustrating the interaction of the multiple variables forming complexity, ambiguity, and uncertainty in project management.

Project Managers

As discussed previously, project managers need to deal with uncertainty and complexity, so what type of complexity do project managers specifically encounter in project management? From the literature review, we find that research with a focus on the project manager falls into three main categories (see Appendix):

- Project managers and leadership (Barber & Warn, 2005; Turner & Müller, 2005),
- Characteristics of project managers (Aronson, Reilly, & Lynn, 2006; Dolfi & Andrews, 2007), and
- Project managers' interaction with team members (Bohlen, Lee, & Sweeney, 1998).

However, the literature review reveals research illustrating the complexity of R&D projects and its consequences for the project manager in the process industry is lacking (Turner & Müller, 2005). The increasingly complex role of project managers is one example. Further, we argue that there is a need to "prepare" project managers to handle increased project complexity, but, in agreement with Thomas and Mengel (2008), we have not found any recognized development paths for project managers that encompass coping with project management complexity. Early research indicates that there is a relationship between project manager's competence and the outcome of the project (McDonough III, 1990). Specifically, Müller and Turner (2010) state that leadership competencies should be considered when assigning project managers to projects.

Various studies also emphasize complexity as the principal cause of project failure—that is, failures are caused by multiple interactions, internal contradictions, and the geographically dispersed and "multi-nodal" (with multiple sites of control and influence) nature of projects (Ivory & Alderman, 2005). Zwikael and Globerson (2006) argue that even though critical success factors are well known, the rate of failed projects remains high. They further suggest that current critical success factors may be too general and do not contain knowledge specific enough to support project managers' decision making. This is in line with a growing stream of literature suggesting that standardization of project work and project management is problematic since contextual factors need consideration (Balachandra & Friar, 1997; Shenhar & Dvir, 1996; Wheelwright & Clark, 1992).

In this article, we look at project management in the PI, where, traditionally, the project manager, according to Ludwig (1974), has been a process engineer with a chemical or mechanical engineering background. Therefore, the view of a project manager has been associated with engineering-related activities by both business leaders and other engineers (Ludwig, 1974). That is, the role of a project manager corresponds to the role of a process engineer. Ludwig (1974) concludes that in the PI, a project manager should have a broad perspective and must recognize the close and essential interrelations between a myriad of simple or complicated functions and problems. Therefore, managers of R&D projects need other competences such as business economics, motivation abilities, good judgment, practical understanding of operating the equipment, and an interest and ability to see the relationship between the company and project goals.

Product Development and Process Development in Process Industry

To understand project management complexity in R&D projects in the PI, there is a need to view the content of product development and process development and their symbiotic relationship. The properties of PI products are usually dependent on the production conditions. As mentioned, production processes are normally specialized to produce one product type (Lager, 2002). When new products are proposed, production process issues therefore quickly surface. Changes in process settings will affect product properties such as durability, strength, color, and appearance.

The different goals of R&D projects put different demands on project members and shape the projects differently. In general, ProdD has an extrovert focus, often starting with customer dialogues,

Type of Industry	Size of the Company: Small (No. of Employees < 100)	Medium (No. of Employees 100 to < 500)	Large (No. of Employees ≥ 500)	Total
Steel	0	1	8	**9**
Paper	0	0	7	**7**
Mining	0	0	2	**2**
Chemicals	6	6	3	**15**
Rubber	1	2	3	**6**
Plastics	2	2	0	**4**
Food/Dairy	0	1	6	**7**
Total	**9**	**12**	**29**	**50**

Note. Steel, pulp and paper, and mining industries were selected for further analysis because these branches represent large organizations having a broad range of development projects with various degrees of ProdD and ProcD.

Table 1: Overview of companies in sample.

whereas ProcD has an introvert focus of improving company processes. Since ProdD is usually extrovert, product developers may focus on monitoring the progress in materials science, processing and simulation methods, and work with designers and customers.

The corresponding ProcD projects may, for instance, have the scopes to produce products to specifications as efficiently as possible to improve productivity, by cutting costs and eliminating waste, making processes more flexible, minimizing variation, or improving flow. Further, ProdD is often concentrated in an R&D unit and ProcD is often decentralized to a production unit—especially for large businesses near the consumer (Lager, 2002).

Although considerable progress has been made in project management research, we conclude the complexity of PI R&D projects is great. We propose that some of the complexity may be reduced by reducing the uncertainty component of managing and assembling a competent R&D project team. This article therefore aims to present a model describing project complexity by enabling product and process integration.

Research Methodology

This study is based on an inductive approach and starts by exploring how development work is conducted in the Swedish PI. The following areas were of interest in the study: content of development work, project work, cooperation, changes, and future needs of development work. The principal empirical study involved a total sample of 50 companies from the steel, paper, mining, chemical, rubber, food/dairy, and plastic industries. The criterion for selecting the companies was production of non-assembled products where the different production process steps are connected into a continuous flow. Industry lists identifying PIs were the basis for the company sampling, along with suggestions given by representatives of Swedish branch organizations.

We initially contacted company representatives by telephone to ensure that the companies were or had been involved in development projects. The telephone contacts also aimed to identify the key respondents and to solicit cooperation. Out of the 55 companies that were contacted, 50 companies agreed to participate in the research. To increase reliability, respondents were given the chance to review and adjust their interview transcripts. The purpose of the study was to investigate current development work, to study how product and process development had been conducted since 1990, and to explore future needs and trends concerning ProdD and ProcD projects. The respondents therefore had to have deep insight into development work, and most respondents were for that reason R&D managers, and, in smaller companies, some were project managers or members of ProdD projects.

Table 1 presents an overview of the companies for each sector and their size. We have divided the companies into three groups: small, medium, and large, depending on the number of employees.

Data were gathered from structured telephone interviews with open-ended questions. The interviews were recorded and transcribed, then coded with the software package "Non-numerical Unstructured Data Indexing Searching and Theorizing" (N5). The texts were coded with nodes and organized into a tree structure, which enabled thorough qualitative analyses. These analyses indicated that complexity, extent, length, and the need to involve different types of competences of R&D projects have changed. Therefore, these changes were explored with a specific focus on project content, project management, and integration of product and process development. Steel, pulp and paper, and mining industries were selected to deepen the analysis regarding the changes since these branches represent large organizations that have a broad range of development projects with various degrees of ProdD and ProcD. Eighteen respondents from these industry branches were selected (see Table 1). The transcriptions from the 18 respondents were then coded and analyzed for R&D project management needs. Furthermore, we used secondary data such as company reports and Internet homepages with descriptions of the various products. These homepages were also additional sources of "non-assembled" product descriptions.

Regarding development focus at the companies in the study, the majority of the respondents stated that ProdD and ProcD are integrated in R&D projects. It was difficult for them to state the proportion of ProdD and ProcD at their company. However, Table 2 shows the distribution of the respondents' view of the companies' development focus. The column "Equal" shows that the respondents regard the company to have an equal focus on both ProdD and ProcD in their R&D projects.

The respondents in the study had varied project experience. Most respondents had different roles at the company and had experience with both small and large projects. At the time of the study, the respondents worked in projects with characteristics as shown in Table 3.

	Company Focus in Development Project			
	Product	**Process**	**Equal**	**Total**
Steel	2	1	6	9
Paper	3	0	4	7
Mining	0	1	1	2
Total	5	2	11	18

Table 2: The companies' development focus.

Type of Industry	Respondents' Project Experiences
Steel	Product and metallurgical projects
	Centralized R&D projects (two respondents)
	Product development and service
	Product development projects
	Majority in process development projects
	Product development projects; material and components
	Technical projects and application projects
	Product development projects
Paper	Product development according to specifications
	Centralized R&D projects (two respondents)
	Product development projects; laboratory and technical service
	R&D projects
	Centralized R&D projects and process development
	R&D projects and product development projects
Mining	Technical development and process development project
	Centralized R&D projects

Table 3: The respondents' project experiences.

Moreover, we conducted a literature review of some selected journals (see Table 4) within the years 2000–2009 to analyze the contemporary research on project management, and specifically on innovation and R&D projects. The keywords used for the literature search were *project management* or *project* and *leader*, *manager* and *complexity*, and *model*. The articles were selected for the review if the keywords were contained in the abstract.

The researchers in this study have cooperated with process-based companies in various projects. Their pre-understanding may thus have had implications for the analyses of the initial study, and enhanced patterns matching the authors' original views of the demands put on project managers in R&D projects in the PI.

The primary data used in this article was mainly based on a limited amount of sources (presented in Table 1). However, other data have contributed to the pre-understanding of complexity in R&D project in the PI. A prior study, focusing on complexity of product development in the process industry, indicated a need to further explore the complexity of managing interrelated processes in development projects. This previous study included a review of product development literature in manufacturing industry and a prestudy consisting of four case studies of how companies in the Swedish steel and paper industry organize and manage their product development work. Together with the data presented in Table 1, the total amount of the data contributing to the pre-understanding was derived from multiple sources:

Selected Journals
Business Horizons
California Management Review
European Journal of Innovation Management
Human Resource Management Journal
Harvard Business Review
IEEE Transactions and Engineering Management
International Journal of Innovation Management
International Journal of Operations & Production Management
International Journal of Project Management
International Journal of Technology Management
Journal of Engineering and Technology Management
Journal of Business Research
Journal of Production Innovation Management
Management Decision
Omega
Operations Research
Project Management Journal
R&D Management
Research Technology Management
Sloan Management Review
Technology Analysis and Strategic Management

Table 4: Selected journals in the literature review.

interviews (71 in total) and industry reports with the primary purpose of exploring development work in the process industry.

R&D Projects in the Process Industry

The purpose of this section is to provide insights into the complexity of R&D projects in the process industry—that is, to describe the complexity consisting of interrelated parts in R&D projects and the requirements this complexity imposes on the project managers. We specifically highlight the content of development work and the requirements it places on project management due to the coupling of ProdD and ProcD work in the PI. The descriptions that follow are taken from interviews with R&D engineers working in the steel, pulp and paper, and mining industries.

The Content of Development Work in the Process Industry

The focus of PI R&D projects has not traditionally been on ProdD but on ProcD, on increased production capacity, and on the search for cost-effectiveness. Production processes are capital-intensive, and capital is tied up in the production processes. A dilemma in the PI is that the production processes are inflexible, since their settings have large effects on the final product properties—for example, durability and tensile strength.

To appreciate the complexity of R&D projects, the content of development work must be understood. The studied companies' products are often semi-manufactured to be further processed by their customers. For example, one may produce steel (such as sheet) in a variety of grades and strengths that, in turn, affects the weight and the material costs of the customers' products and production complexity. Customers of steel products may have specific demands about cost, life expectancy, appearance, strength, weight, environment-friendly properties, and the like. The project manager must incorporate these diverse requirements into the R&D projects. This is difficult to accomplish because the dimensions of customers' wants and requirements often require a transformation of product properties to be manageable for developers. Cardboard boxes that lose their shape and strength when exposed to water are an example of an ill-defined problem that must be transformed into measurable requirements for moisture resistance or wet strength of paper.

In the paper industry, some of the most important characteristics of paper are low cost, high performance to weight, and convenience of use. As in the steel industry, development work in the paper industry has a focus that concerns both ProdD and ProcD. ProdD concerns improving material properties such as strength, brightness, moisture absorption, or the papers' ability to be run at customers' production processes. ProcD is predominantly about cost reduction since it is difficult to increase the price of paper even if it is of higher quality; as one interviewee put it, "no one wants to pay for paper."

In the mining industry, the R&D projects are primarily initiated by production needs—that is, to develop and improve production processes and to increase productivity. Development aspects can be hardness, grade of fine granular, impurities, and metal content of ore. The project goals can include

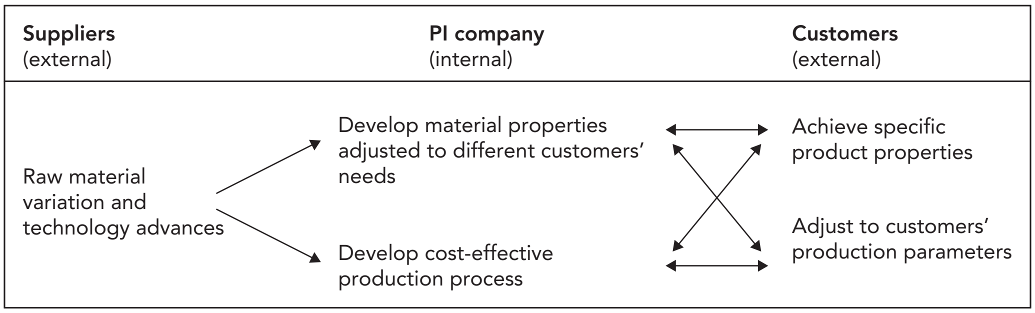

Figure 1: Interrelated processes in R&D projects.

development of products that perform better in customers' production processes—typically productivity improvements or energy consumption reductions. ProdD can consist of mineral extraction and producing high-quality metals in a cost-effective and environmentally friendly way. One ProdD difficulty is that some ores are more diluted with gangue minerals. This raw material variation also makes the production and R&D tasks different from similar work in manufacturing. Another difficulty is that the mineral products react differently depending on the customers' production processes. Therefore, a new product needs to undergo tests before launch. These tests are made first in laboratories, then often in pilot scale production, and finally in full production.

To summarize, challenges in the PI that the R&D team needs to overcome often include large variation of raw material properties, inflexible production facilities, often-vague customer demands that may be related to customer-specific production processes, or customer-specific products. The main complexity in R&D projects is the interrelated processes linked to (1) raw material variety at suppliers and (2) incorporation of a range of customers' needs in developing material properties, thus simultaneously balancing cost-effectiveness in the production processes, as well as the customers' production processes (see Figure 1). It is therefore important to identify the competence areas linked to these processes.

Since the PI products often are considered to be bulk products, the sales prices are often non-negotiable but set globally. The team needs to monitor technological developments of industrial raw materials and of processing equipment. Since the PI may have little influence over product prices, world market price fluctuations may also boost or cripple any R&D project.

Project Complexity in Process Industry

Over the last 20 years, project durations in the PI have been shortened, usually to less than two years. ProdD has also become more important. Nowadays product developers must consider aspects other than just the desired properties; they have to assess how producible and transformable the product is in different customers' production processes, regardless of whether specifications are met. These changes require information to be handled faster and incorporated from both suppliers and customers, both initially and during the ProcD and ProdD. Different interlinked information processes need management by both the project team and the project manager. The information sources may be of different character, and mechanisms to combine sources are often lacking. Our interviewees recognize that, for example, sales personnel possess valuable information about the customers and the competitors on the local market that is not always distributed to the team.

The number of project members can range from a few up to a hundred, and the larger project groups result from the need for inclusion of different competences. Large projects generate several subprojects and naturally have larger coordination needs. When development work concerns complex products, several disciplines have to cooperate (for example, a technical service organization and the experienced developers). Therefore, developers need to grasp the comprehensive purpose of the specific R&D project and its interrelationships to other subprojects. To be able to grasp specific subproject purposes, including how one subproject relates to another, can be difficult, since much of the development work is performed informally. Another challenge is that participants seldom work on projects full-time and thus cannot devote time to seek the core of problems.

The main project complexity in R&D projects in the PI is due to the interconnectedness of ProdD and ProcD. Changes in production parameters cause changes in the properties of the material (the product). Even so, if the objective of a project comes from external demands—for example, customer requirements—the project is classified as "product development." If, on the contrary, production objectives are in focus, the project is denoted "process development."

Another project complexity concerns integrating sources of valuable knowledge and competence. Product developers need to know the limits and possibilities of the customers' production processes, and to predict customers' use of the product to generate new product applications. This entails an extensive and continuous dialogue with those responsible for the company's own production process, as well as those responsible for customers' processes. Customer collaboration in projects has therefore increased to gain insight into customers' problems and their ProdD. This collaboration calls for team members to be more flexible and responsive to customers' requirements. The customers demand various things of the product, requirements that often imply costly changes of the production process, but the producers are often unable to compensate for higher costs with higher prices. The respondents also indicate that it is difficult to gain access to, and obtain time from, customers' staff. Developers increasingly view raw material suppliers as resources that can reduce ProdD time when included in development projects.

To summarize, the identified areas of competences needed in R&D projects are:

- **Project-related:** Management of subprojects with cross-functional teams; identification and incorporation of various information sources (external and internal).
- **Customer-related:** Management of customer involvement, identification, and integration of a range of customers' needs, each with a specific production process and restrictions that transform the material differently; improvement of product performance in customers' production processes; identification of new application areas of the product.
- **Supplier-related:** Management of supplier involvement; knowledge of implication of variance in raw material; incorporation of technology development.
- **Product-related:** Knowledge of material property transformation; maintaining high quality despite raw material variance.
- **Production-related:** Knowledge of achieving cost-effectiveness; production flexibility; reduction of production restrictions.

Discussion

The complexity in R&D projects consists of a web of competences and activities to be integrated within ProdD and ProdC. The content of R&D work and the need for various types of cooperation among several internal and external actors in the PI are making the project management environment and the role of project manager increasingly complex. This environment demands adjusted project management for dealing with the complexity. However, as also indicated in the literature, project management research still treats every project similarly (Söderlund, 2002), and the role of a project manager must be developed further to meet today's requirements (Kloppenborg & Opfer, 2002). We believe that this article highlights a research area that needs to be further explored—the complexity of project management in the PI. Further studies are required that include both in-depth and more general survey-capturing methods and means to manage complex projects, specifically integrating competence areas. In accordance with the Contingency Theory (for instance, Balachandra & Friar, 1997; Keller, 1994), we also conclude that there is no one best way of managing development projects in the PI; the success of one way depends on the tasks at hand, the technology, the nature of the environment in which the project is run, and other factors. Project management standards should therefore be applied cautiously in these settings.

The study indicates that there is a mix of different foci in R&D projects in the PI—the extrovert focus coexists with the introvert. Several activities need to be managed simultaneously, such as monitoring technology progress of the processes of the entire supplier-customer chain and the development of new materials. Thus, the project manager in the PI should have a systemic view and handle multitasking of many simple and complicated problems. His or her responsibilities and control include various areas such as business planning, economics, engineering, construction, and components of plant operations. Further, the project manager should have the ability to identify competence needs, identify and assist external cooperation, and handle geographically distributed team members, all within a limited project time.

Working in different fields also makes it difficult to excel in any of these, and large variability of how ProdD and ProcD are performed is likely since R&D work does not consist of a series of routine tasks. It is also likely that this variation, taken together with the complexity of the processes, reflects a large improvement potential.

The focus of the producer is mostly on meeting product and delivery specifications as economically as possible and minimizing the operational staff. R&D activities are directed at improvement of existing processes to reduce variations of products, lower production costs, increase yield, and so on. The ProdD is linked to ProcD; improving processes often leads to improvements of current products, and the success of new products depends on the contribution of the process engineering expertise. New products that differ greatly from the previous products usually involve new machinery and a new production layout. The processes are therefore limiting the range of producible products and of most R&D project scopes.

In the analysis of how development work is conducted in the PI, we found a complexity in project management and

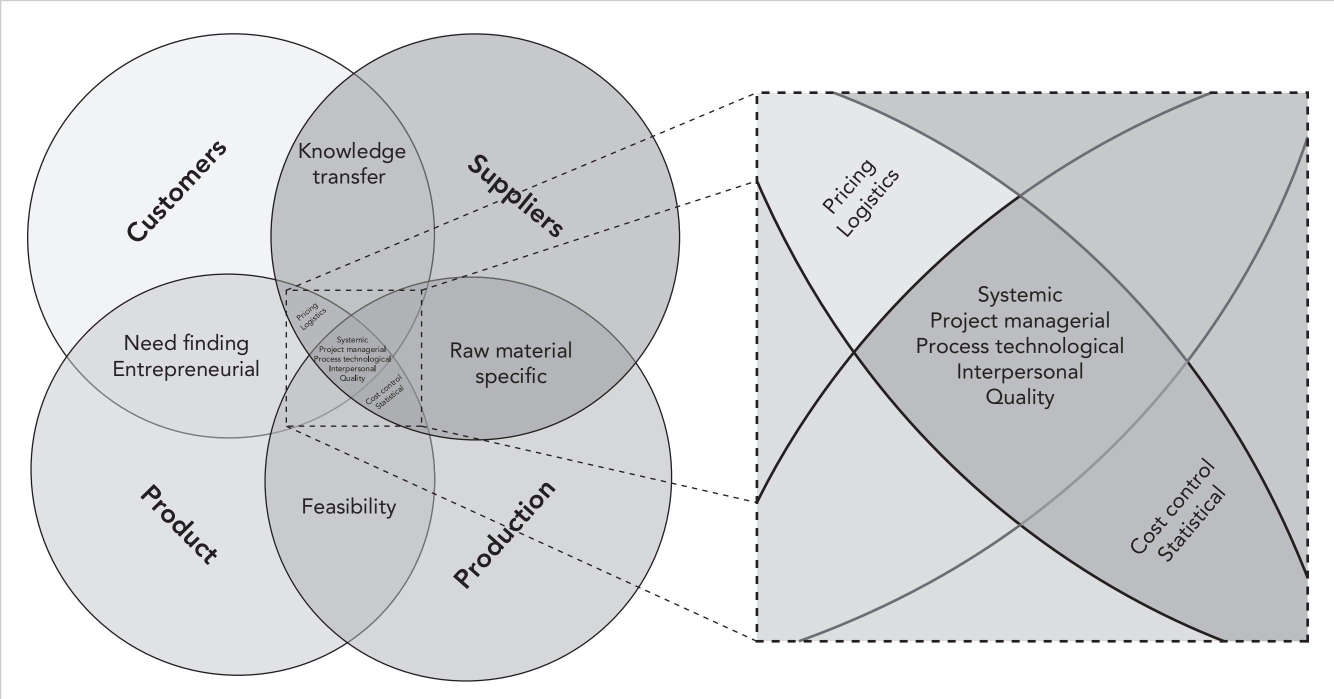

Figure 2: Competence areas that a project manager must integrate and manage in an R&D project.

a need for multifaceted project managers in the development projects in the PI. This complexity and need have led to the aim of creating a conceptual model to describe the underlying structure of the competences that integrate product and process development.

Figure 2 summarizes the identified abilities that constitute the current complexity of R&D project management in the PI that a project manager should be able to integrate. The competence areas should derive from various competence sources and incorporate them in the development work.

The skills in our model are respectively categorized as internal (associated with the product and the company's own production process) and external (competence and knowledge related to the customers and the suppliers). For a product to be developed, the project manager needs access to both material-related and process-related skills. Moreover, to have only access to competence about one's own production process, and how different production parameters affect and transform the product (material properties), is often insufficient; the R&D project also needs to know how these changes affect the customers' processes. Further, the study indicates that development projects must develop products and new application areas simultaneously. In addition, R&D projects need to incorporate suppliers, as they possess knowledge about future technological advances. The overall need to incorporate many stakeholders opens a link toward another research base—stakeholder management (see Follett, 1941; Freeman & Reed, 1983; Klefsjö, Bergquist, & Garvare, 2008).

This research has had an inductive approach, working from observations and interviews to the formulation of an understanding of the engineering environment in process industries. Therefore, the quality of the work requires a discussion related to research validity and reliability. The purpose of this research has been to generate understanding rather than to test a ready-made hypothesis—therefore, the research results are both situation-dependent and dependent on the interpretations of the researchers. The validity of the research (that is, if what was measured is what was intended to be measured) is improved when the data are good, and the interviewees were able to review the transcripts to improve the validity. However, the purpose of the work was to learn from the interviews rather than to measure something, and the reliability question is thus irrelevant (Stenbacka, 2001).

Although the respondents may have answered structured telephone interviews, one interviewer may have received slightly different answers than the other interviewers, and the analysts, having different insights, may well have come to different conclusions. However, we saw a pattern in the results and thereafter analyzed this in relation to previous research of complexity in project management. We believe that the different backgrounds of the researchers and the triangulation with results obtained from literature performed after the interview analysis does imply that the results are trustworthy.

The data collection is based on Swedish process industry engineers and the relative similarity of the answers of engineers in a particular branch makes the data representative of a Swedish setting. Although the technical processes are similar for engineers working in the steel industry in a developing country, the organizational culture, country legislation, and the like may make a project manager's job different from our informants. We do therefore avoid stating that our results are generalizable to other contexts, to let the reader judge if our conclusions are valid outside Swedish process industries.

Conclusions and Future Research

The conceptual model promoted in this article is based only on 18 respondents in process-based companies representing the mining, steel, and paper industries, and is not a generic model suitable for all types of companies and industries. However, this study is aimed at obtaining a greater understanding of project complexity in the PI, and we conclude that more empirically based research is needed to further develop guidelines for managing project complexity.

Ontologically, this study applies to a more analytical perspective, assuming that the management of R&D projects in process industries is a system that can be understood and explained through its actors and processes—that is, through the information and competence needed by those who are involved in the projects. Our goal with this article was to create an understanding of the complexity in R&D projects in the process industry and thus to illustrate the interrelated processes that constitute this complexity. Epistemologically, our presumptions originate from existing research within the field of innovation and R&D project literature. We then empirically explore the complexity in development work in the PI and the requirements that the development work places on project management due to the coupling of ProdD and ProcD work. These presumptions are, along the research process, complemented by specific project management literature (for instance, related to practice, complexity, and the project manager) highlighted during the years 2000–2009. This knowledge enabled a further elaboration of complexity in R&D projects in process industries, which a project manager may encounter and should be able to integrate.

Compared with the typology developed by Shenhar and Dvir (1996), our conceptual model adds to the theory of project management by highlighting the aspects that create project complexity in R&D projects in the process industry—that is, the need to interlink process development and product development. Nevertheless, it is not just the project scopes that create complexity; complexity is also created when competence areas need to be bridged. These areas are related to (1) the product developed and its customer(s), (2) the production process and the supplier(s) of raw material and equipments, (3) the customer of the product(s) and supplier(s), and finally (4) relationship between the product(s) and the production process.

We have established that since development is multifaceted, a project manager must rely on several sources of competence to manage project complexity, as follows:

1. Identify the critical competence areas.
2. Find sources for the competence areas.
3. Gain access to the sources.
4. Build suitable mechanisms of integration with the sources.

Our conceptual model (see Figure 2) proposes the core competences required by the project manager, as well as the core competences required in R&D projects. This model includes a holistic system view of the R&D project and its value-added sources. Further, the project manager should have communicative skills and the means to distribute and transfer the goals of the project to subprojects. The project manager must be able to retrieve, evaluate, and use data from various sources correctly.

By identifying the competence areas in R&D projects, the project manager can link carriers of the internal sources with external actors to facilitate integration of product and process development—that is, to develop and adjust integration mechanisms to critical sources in the project. For example, technicians can be the intermediary between R&D and the market.

Some companies emphasized that their projects are increasingly extensive, with several subprojects. The wider range and coordination of subprojects will have implications for the project manager's ability to visualize the main objective and determine how the subprojects are interlinked. Further, coordination mechanisms need to be adjusted and formalized.

The creation of effective mechanisms for bridging different competence areas needs more work. However, this study indicates that a developer's knowledge of the customers' processes helps the understanding of customers' needs and requirements. One means to build bridges is to rotate personnel between the product development and process development for a specific industry, since ProdD requires process technical competence and ProcD requires product technical competence. To clarify the demand, developers may need to cooperate with customers and possibly with end users. It is especially important to visit customers and demonstrate the product in an application development.

Since much of the data in R&D projects concerns statistical measures, a project manager must understand how statistical methods can be used, and the special considerations needed when using them on data generated from continuous processes. Box (1957) commented on process improvements in the PI and noted that adjustments are made when plants are installed, but that the process of discovering optimal operational conditions—as results of experimental efforts, chance discoveries, and new ideas—usually continues over many years. Little evidence suggests that this improvement process has itself been much improved in practice during the last 50 years.

Previous research (Söderlund, 2002) shows that project management is more developed in certain industry branches, and that a key problem is that every project is treated similarly by project management research. This article shows that there is a need for further research concerning how project management should be developed in the process industry, specifically as to how to integrate and manage ProdD and ProcD projects. Other areas of importance are to investigate how to integrate the technical dimension and the human dimension in project management, and with which mechanisms. We believe that our model is a first attempt to integrate product and process development and that integration mechanisms should be built in the intersection among the identified competence areas, but deeper empirical studies considering other aspects of groups of practices and processes are needed.

In summary, our conceptual model describes the competence areas that are important to integrate in complex R&D projects in the process industry, and adds to the knowledge of what makes projects complex or difficult to manage. We believe that this article opens the way to further explore the contingency factors that must be identified and understood to manage complex R&D projects successfully. We agree with Bredillet (2010) that project management should not be seen as just a set of methods, techniques, and tools, but should also be viewed through the lens of contingency theory—that is, project management should not be seen as a "one-size-fits-all" approach (Maylor et al., 2008). Managerial R&D complexity has a wide and diverse set of meanings that should be further explored. Besides contingency theory, stakeholder theory (Elias, Cavana, & Jackson, 2002; Follet, 1941), where different stakeholders with different means of power affect project outcomes and bring insights into managing, valuing, and responding to various stakeholder needs in these types of R&D projects. Areas for further research could include:

- refining the identification of competence areas and exploring the key drivers in project complexity in other type of industries,
- exploring the possibility of managing interrelated processes and complexity,
- identifying the role of the project manager in complex R&D environments, and
- pursuing quantitative studies including falsifiable hypotheses regarding R&D project work with different levels of competences integrated in the process industry. ■

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Appendix: Selected References Within Project Management (PM) and Project Leader/Manager

Reference	Research Strategy	Research Area and Findings
Project Management Practice and Perspectives		
Bryde (2003)	Literature review and in-depth interviews with 63 people across 22 organizations	Investigates PM practice. Describes characteristics of an emergent PM approach concerning attitudes and opinions of people involved in projects.
Cooke-Davies and Arzymanow (2003)	Qualitative research, 31 in-depth interviews in 21 organizations	Studies variations between PM practices in a search for an optimum PM model. States a need of identification of how superior practices can be developed over time.
Kloppenborg and Opfer (2002)	Literature review of PM trends (1960–1999)	Investigates the PM research. Predicts evolution of the project manager's role to demonstrate more leadership than PM and, hence, advanced training for project managers.
Kolltveit, Karlsen, and Gronhaug (2007)	Literature review of perspectives in PM	Investigates current perspectives in PM. Project managers have to address numerous issues and perspectives.
Shenhar and Dvir (1996)	Multiple case study of 26 projects and a questionnaire ($n = 127$)	Addresses some of the theoretical issues of PM. Proposes a project empirical classification scheme of management styles based on the degree of technical uncertainty and complexity of the project.
Söderlund (2005b)	Two in-depth case studies and one ethnography	Studies perspectives on PM practices. Stresses the role of PM in integrating the various knowledge bases of a project and the need for skillful combinations of knowledge processes.
Project Performance		
Besner and Hobbs (2006)	Large-scale survey; 753 respondents	Discusses the value of different PM practices and the need of clarification of the distinction between the project phases and project processes.
Chen and Lee (2007)	Classification of 14 managerial practices of leadership behaviors	Develops project managers' performance evaluation model with five phases.
Hirst and Mann (2004)	Survey of 56 R&D teams in 4 organizations	Focuses on R&D leadership and team communication and its relationship to performance. Develops a five-factor model of team communication.
Project Success Factors		
Cooke-Davies (2002)	Analysis of 136 projects executed 1994–2000 by 23 organizations	Studies success factors in projects. Identified 12 success factors and discussed their link to the "people" side of PM.
Elmquist and Le Masson (2009)	A case study in a collaborating setting, 23 interviews	Introduces a conceptual framework for evaluating R&D projects in the context of innovation.
Ives (2005)	Literature review of PM, four interviews	Identifies contextual elements of PM within organizations linked to project success, his/her responsibility to negotiate, existence of an imbalance of power and authority between the organization and the project manager.
Kanter and Walsh (2004)	Two workshops with 30 people	Discusses five success factors linked to PM.

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Appendix: **(Continued)**

Project Complexity		
Baccarini (1996)	A literature review of the concept of project complexity	Indicates a need to further explore project complexity and its influence upon the PM process.
Clift and Vandenbosch (1999)	In-depth interviews of 20 leaders of NPD projects	Explores the cycle-time reduction strategies used by project teams involved in projects with varying complexity.
Geraldi (2008)	Literature review on the edge of chaos in organizations	Applies a model that enables a holistic view of the company's current organizational design and its respective range of complexity of project portfolio.
Philbin (2008)	Survey ($n = 25$)	Develops a conceptual framework—the four-frames systems view of managing complex technology projects.
Pich et al. (2002)	Development of a conceptual model	Shows that ambiguity and complexity are factors that explain the coexistence of different approaches to project management.
Söderlund (2002)	Case studies of two development projects	Demonstrates the importance of various global arenas, such as testing activities and PM forums.
Vidal and Marle (2008)	Literature review	Develops a project complexity framework.
Williams (1999)	Paper in opening session in workshop	Discusses what constitutes project complexity.
Innovation/R&D/Product Development Projects		
Barnes, Pashby, and Gibbons (2006)	Six case studies	Develops a framework that illustrates the key issues affecting the success of collaboration in R&D projects.
Chiesa (2000)	A sample of 12 multinational companies	Studies the management and organization of global R&D projects. States the importance of a global attitude of the R&D managers.
Lenfle (2008)	Case study	Explores PM in innovation projects. Emphasizes the need to distinguish different solutions and different ways of managing innovation projects.
Olson, Walker, Ruekert, and Bonner (2001)	Interviews and survey of 34 project teams	Demonstrates the importance of cooperation between specific functional dyads.
Leadership		
Barber and Warn (2005)	Literature review of leadership literature	Finds that project managers who focus on proactive leadership behavior will be more successful in completing projects.
Jacques, Garger, and Thomas (2008)	Survey of 151 graduate PM and MBA students	Argues that leadership skills and behavior necessary for successful PM differ from those necessary for other leadership situations.
Kaulio (2008)	Broad multisite approach; 48 critical incidents from 28 respondents in 48 different projects	Identifies critical incidents for project leaders working in multiproject settings. The frequent issues are technical difficulties, dyadic leadership, and group dynamics, as well as external relations.

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Appendix: (Continued)

Shim and Lee (2001)	Questionnaire to 88 R&D projects consisting of 419 professionals	Proposes and tests a model that the influence styles used by project leaders are affected by personal, task, and relational factors and hence performance. R&D project leaders differ not only in general level of influence, but also in how to mix various influence tactics.
Turner and Müller (2005)	Literature review on project success factors	Provides a review of literature focusing on the possible impact that project maangers have on project success and calls for evidence of the impact by direct measurement.
Characteristics of Project Managers		
Aronson, Reilly, and Lynn (2006)	Questionnaire consisting of 143 NPD projects	Examines the effect of leader personality on new product development (NPD) project performance under differing conditions of uncertainty. Supports the importance of teamwork as a process variable linking leader personality to NPD performance.
Dvir, Sadeh, and Malach-Pines (2006)	Questionnaire to 89 project leaders	Examines relationships among project types, project managers' personality, and project success. For three types of projects, there are different patterns of correlations between certain aspects of managers' personalities and certain dimensions of project success.
Maylor, Vidgen, and Carver (2008)	Workshops with project managers	Investigates project managers' perceptions of managerial complexity and provide a framework for description of the level of managerial challenge or difficulty, and the assessment of it in the future.
McDonough III (1990)	Questionnaire and interviews of leaders of 41 new product development projects in 13 firms	Supports the notion that performance of a project is affected by the cognitive style, career orientation, and background characteristics of the project leader.
Project Manager and Team Members		
Bohlen, Lee, and Sweeney (1998)	Questionnaire ($n = 103$)	Studies the influence reasons and influence strategies of project managers. Suggests how frequently project managers may expect to apply certain types of influence strategies.
Dunn (2001)	Survey ($n = 222$) in 18 matrix-type organizations	Studies behavioral aspects of multi-managers and motivation. Finds that project managers bear a significant responsibility for the well-being of project team members.
Aspects of Concern for a Project Manager		
Blackburn (2002)	Interviews of 20 project managers	Investigates what project managers do, and how they understand and talk about what they do. Shows how PM processes act as allies, enabling the project manager to interest and enroll team members.
Eskerod and Skriver (2007)	One in-depth case study	Studies knowledge transfer between project managers. Finds that organizing by projects may restrain knowledge transfer because a project orientation facilitates knowledge silos.