MANAGING JOINT PROCESS DEVELOPMENT: A STUDY OF BUYER/SUPPLIER COLLABORATION AT THE PROJECT LEVEL

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Abstract
Excessive project budget overruns is a serious problem that may endanger long-term competitive advantage and financial viability of firms engaged with process development together with equipment suppliers. Joint development of new process technology often span organizational boundaries and are frequently described as both uncertain and equivocal. With the aim to propose better management methods for such projects, we combine case study research with a multi-wave, multiple informant survey study of 52 collaborative process development projects. Our results show that joint problem solving is the key to reduce equivocality, whereas early end-user involvement allows project participants to reduce uncertainty. Uncertainty has a clear negative effect on budget performance, whereas mixed results were obtained for equivocality. These findings provide important implications for both theory development and operations management practice.

Keywords: process development, information processing, uncertainty, equivocality, joint problem solving, early end-user involvement.

Introduction
In 2002, BHP Billiton commenced a feasibility study into opening a nickel and cobalt mine and a processing plant in Ravensthorpe, Australia, at the cost of $1.4 billion. The project was approved in 2004 and construction started shortly afterward. The project was BHP Billiton’s largest ever. The plant was eventually opened in 2008, after massive cost blowouts and excessive delays. Total costs were now reaching $2.31 billion, indicating a 70% cost overrun for the project. In January 2009, BHP Billiton announced that it was suspending production at Ravensthorpe due to significant processing problems. The decision cut 1,800 jobs and had a devastating impact on the local economy as well as on the stockholders (Mills, 2010).
BHP Billiton’s Ravensthorpe experience is not a unique case. A recent study by Ernst & Young (2011) found that such projects are quite commonly plagued by budget overruns of 70% or more. Developing and implementing new process technology is thus a risky endeavour that may seriously endanger long-term competitive advantage and financial viability of firms if not managed proficiently (Fillipou & King, 2011).

Process development projects are typically very large in both monetary size and duration, and entail significant management challenges (Scott-Young & Samson, 2008; Azadegan & Dooley, 2010). The design activities are complex (Schuman & Brent, 2005), addressing simultaneously both manufacturing processes (to identify plant and equipment items along with their required operating ranges and capabilities) and material conversion processes (to determine material characteristics and under what conditions it should be processed). In particular, process development projects often span organizational boundaries, thus requiring joint efforts from large project organizations at both the buyer and supplier side (Hutcheson et al., 1995; Robertson et al., 2012).

Joint development activities between buyer and supplier organizations require significant interaction and exchange of information among team members to develop customized process technology (Athaide et al, 2009; Robertson et al, 2012). Because of idiosyncratic design requirements, a significant amount of information must be gathered, shared and processed by the buyer and supplier members of the project organization in order to reduce uncertainty and equivocality in the early stages of development (Daft & Lengel, 1986; Galbraith, 1973).

In brief, uncertainty refers to the difference between the information available and the information needed to complete a task (Galbraith, 1973). By contrast, equivocality refers to the extent that multiple and conflicting interpretations of the information exist among participants in a project (Daft & Lengel, 1986). Somewhat paradoxically, in an equivocal situation, new information can actually increase rather than decrease equivocality (Weick, 1995).

From a management perspective, recognizing the differences between uncertainty and equivocality is critical because they require different management approaches (Daft & Lengel, 1986; Chang and Tien, 2006). Uncertainty reduction is primarily achieved through information gathering and analysis that, if successful, significantly increases the chances of a fruitful project (Ullman, 2010). Consequently, in joint process development, the project organization has to gather information to answer questions related to the specifications of the equipment, the design of process flowcharts, and the broader manufacturing environment (Schuman & Brent, 2005). By contrast, reducing equivocality presupposes the exchange of subjective views among project participants to define problems and resolve conflicts through the enactment of a shared interpretation that can direct future activities (Daft & Lengel, 1985; Weick, 1979). Accordingly, a project organization may facilitate equivocality reduction by explaining different viewpoints and defining or creating an answer to problems rather than by learning the answer from new information gathering and analysis (Weick, 1995).

On a general level, prior research has highlighted the negative consequences that may arise when project participants in joint development projects fail to manage uncertainty and equivocality (Stock & Tatikonda, 2008; Koufterous et al., 2005). Too much uncertainty and
equivocality can for example lead to difficulties in creating explicit, stable, and robust process designs, causing time delays and waste of resources (Sicotte & Langley, 2000; Song et al, 2007). However, prior research in operations and technology management does not provide detailed advice for how to reduce uncertainty and equivocality in projects (Stock & Tatikonda, 2008; Koufteros et al, 2005). In addition, most prior studies are qualitative with limited generalizability (e.g. Bruch & Bellgran, 2012; Frishammar et al 2011; Song et al, 2007) or not primarily focused on strategies for mitigating uncertainty or equivocality (Chang, 2002; Frishammar et al, 2011; Kouferos et al, 2005). Furthermore, prior research has mostly been conducted in the context of product development rather than process development (Gales & Manseur-Cole, 1995; Koufteros et al, 2005; Sicotte & Langley, 2000; Song et al, 2007). While findings from the product development literature may provide valuable insights also for process development (Kurkkio et al, 2011), the effectiveness of different strategies may vary according to the characteristics of the development work (Daft & Lengel, 1986). Also, due to industrial firms’ heavy investments into process technology and its importance for each firm’s competitive advantage (Robertson et al., 2012) the context of process development deserves attention in its own right. Furthermore, quite few authors address both uncertainty and equivocality in the same study (Song et al, 2007; Sicotte & Langley, 2000), and single-sided studies of uncertainty is indeed much more common (Stock & Tatikonda, 2008; Gales & Mansouer-Cole, 1995; Tatikonda & Rosenthal, 2000; Stock & Tatikonda, 2004; Hong et al, 2004). However, the effects of equivocality may be at least as severe (Daft & Lengel, 1986; Weick, 1995).

In light of the managerial challenges and theoretical gaps described above, this article seeks the answers to two research questions. First, we seek to study the performance effects of both uncertainty and equivocality. Second, we seek to identify the key collaborative activities that allow the reduction of uncertainty and equivocality respectively. In doing so, we draw on a mixed-methods study of joint development projects. After a qualitative pre-study, we rely on data from a multi-wave, multiple-informant survey including 251 responses from 52 joint process development projects involving both buyers and suppliers.

The project-level survey in which both uncertainty and equivocality are explicitly measured along with information processing activities and project performance makes it possible to contribute with vital theoretical and practical implications. First, the study can improve our understanding of how specific information processing activities are related to uncertainty and equivocality. Such understanding is crucial when trying to reduce uncertainty and/or equivocality in order to enhance the success of joint development projects. This study also contributes by investigating a previously neglected empirical context; joint process development in mature industries. This makes it possible develop our knowledge of how identified levels of uncertainty and equivocality affect project performance in this industrial setting.

**Theory and Hypotheses**

**Theoretical background**

Process development projects are increasingly important in process- and other manufacturing industries to increase production yields, cut costs, and keep up with competition (Fillipou & King, 2011). Process development 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). Process development projects in this study concern the development and implementation of new process technology and machinery equipment. Such development projects typically necessitate significant inputs from suppliers of process equipment (Azadegan & Dooley, 2010). The reason for this is that process firms often lack the internal resources and competences to design new process equipment on their own (Arora and Gambardella, 1997; Frishammar et al., 2012; Reichstein and Salter, 2006).

The traditional view of process development with equipment suppliers is mainly a unidirectional process of technology transfer, i.e. an import of technology by the buyer side (Holden & Konishi, 1996). However, today the design and implementation of production equipment is recognized as an integrated process requiring input from members of various functions with different backgrounds and roles (Athaide et al, 2009; Rönnberg Sjödin et al, 2011; Stock & Tatikonda, 2008). Hence, joint process development can be seen as a reciprocal and iterative process requiring significant interaction and integration to balance requirements and capabilities of the participating partners (Abd Rahman et al., 2009; Malik, 2002; Robertson et al., 2012). The need for interaction and integration puts significant emphasis on the processing of relevant and necessary information between the parties involved (Koufteros et al., 2002; Swink et al., 2007).

The information processing perspective is well established within organizational theory (Chang and Tien, 2006; Daft & Lengel, 1986; Galbraith, 1973). It emphasizes the importance of matching organizational information processing to the specific task (Galbraith, 1973; Tushman & Nadler, 1978). Central to the information processing perspective is the idea that organizations seek to reduce potential uncertainty and equivocality arising from the project task context (Daft & Lengel, 1986; Galbraith, 1973). Research in a variety of organizational settings has been supportive of the contention that, to be effective, work units must match task uncertainty (i.e., lack of information needed to complete a task) and equivocality (i.e., multiple and conflicting interpretations of the available information) with appropriate information processing activities (Gales & Mansurer-Cole, 1995; Koufteros et al, 2005; Sicotte & Langley, 2000; Song et al, 2007). In the context of joint process development projects processing information concerning the technical and operational characteristics and requirements of the technology are a key concern (Robertson et al, 2012). To this end, both uncertainty and equivocality and the negative effects they may cause provide critical problems in process development projects (Bruch & Bellgran, 2012; McGovern & Hicks, 2006).

According to prior literature, it is critical to acknowledge that reducing uncertainty and equivocality necessitate different activities and organizational support (Daft & Lengel, 1986; Koufteros et al, 2005). We seek to contribute to this research stream by studying uncertainty and equivocality reduction through collaborative activities at the project level in joint process development projects. Our conceptual model (see Figure 1) identifies two key activities for uncertainty and equivocality reduction, namely early end-user involvement and joint problem solving. It also displays the possible effects of uncertainty and equivocality on project budget performance.
Figure 1. Conceptual Framework

**Early end-user involvement as the key activity for uncertainty reduction**

Studies of industrial product and process development define "users" as those who do not manufacture an innovation but incorporate it into the assembly of a finished product or process (von Hippel, 1988). In the current context of joint process development projects, the user is the buyer firm. However, project participants from the buyer organization is typically sourced from the R&D and project management functions within the firm and are typically not “using” the production equipment in their daily work (Schuman & Brent, 2005). Rather, operations and maintenance personnel in the buyer organization that will work with the equipment as part of regular work duties constitute the end-users. This distinction is widespread in information systems research (e.g Tait & Vessey, 1988), but seems somewhat neglected in the technology management literature (Leonard-Barton & Sinha, 1993). We argue that this distinction is particularly important in process development projects because the output of the projects will be directly implemented and used in the production environment by end-users (Leonard-Barton & Sinha, 1993; Rönnberg Sjödin et al., 2011).

Furthermore, it is important to consider when end-users should be involved in a project. Prior literature has found that end-user involvement in process development projects is associated with greater implementation success (McDermott and Stock, 1999; Stock & Tatikonda, 2008; Tait and Vessey, 1988). However, previous research has typically not explicitly studied when this involvement should take place. From an information processing perspective, the timing of involvement is especially critical. While uncertainty and equivocality may be present during all stages of development projects, they are undoubtedly the highest at the early stages of development (Frishammar et al., 2011). To this end, we highlight the importance of early involvement of end-users in the pre-study, development and design stages where uncertainty and equivocality concerning future production requirements and process technology solutions are key characteristics (Kurkkio et al 2011).

Early end-user involvement is defined as the involvement of operations and maintenance personnel in the early (e.g. pre-study, design) development stages of the project. The involvement of end-users may be more or less intense. We argue that early end-user involvement is an important way of filling key information gaps in joint process development projects and, as such, serves as a vital activity for uncertainty reduction. End-users can supply information about the operational requirements of the equipment (Gales & Mansouer-Cole, 1995) already at an early stage, before significant resources has been committed (Hick & McGovern, 2009). In particular, accessing information from the accumulated production
experience of end-users may provide critical inputs to increase the quality of simulations and process flow charts in the early design stages (Pisano, 1996).

In addition, the involvement of end-users ensures that factors such as operability, maintainability and robustness of the productions process is taken into account (Schuman & Brent, 2005). For example, maintenance personnel can supply critical information about wear of moving parts and suggest alternate and more robust designs and process operators can supply vital information about the actual operation of the equipment in the production environment (Pisano, 1996). Gaining access to such knowledge is therefore a key challenge for the project organization during the design stage (Bruch & Bellgran, 2012). The importance of early end user-involvement is also underscored by the opposite alternative, i.e. late end user-involvement during implementation of a project, which has been shown to cause significant problems in terms of costly late design changes and re-work according to prior research (Assaf and Al-Hejji, 2006; Rönnberg Sjödin et al, 2011).

Furthermore, knowledge of the complex interdependence among material inputs, the specific process technology and the overall production process is typically tacit and gained through processes of learning by doing (Tyre & Hauptman, 1992). Therefore, such knowledge is primarily gained by users of the equipment. To access tacit knowledge concerning production requirements, the project organizations should involve and interact with end-users in order to close information gaps and reduce uncertainty (Leonard-Barton & Sinha, 1993).

However, it may also be argued that early end-user involvement is important for equivocality reduction. Primarily, information about production requirements and equipment functionality is to a large degree rooted in the tacit knowledge of end-users (Von Hippel, 1988). If end-users are not involved, project participants may be forced to enact their own interpretations of the available information, which could lead to a multitude of conflicting meanings. However, the involvement of end-users does not necessarily facilitate a shared understanding of the supplied information within the project organization. In fact, the involvement of end-users means that yet another functional group is involved in the project organization, with their own interpretations of the available information (c.f. Daft & Lengel, 1986). Therefore, gaining additional information from end-users could actually increase equivocality among project participants, along the arguments provided by Weick (1995).

In sum, we argue that early end-user involvement is an important way of filling key information gaps in joint process development projects and, as such, serves as a vital activity for uncertainty reduction but not for equivocality reduction. We thus posit a negative relationship, hypothesizing that higher levels of end-user involvement will lead to lower levels of uncertainty.

H1: Early end-user involvement is negatively related to uncertainty.

Joint problem solving as the key activity for equivocality reduction
Joint problem solving is defined as the process of ongoing mutual effort that the collaborating partners undertake to diagnose and overcome obstacles that are blocking project effectiveness (Bstieler & Hemmert, 2010). In joint problem solving sessions, parties gather and share views
and interpretations and make collective decisions regarding solution alternatives (McElvie & Marcus, 2005).

We argue that joint problem solving is a key activity for enacting shared meaning and shared interpretations of information in joint process development projects and, as such, serves as a vital activity for equivocality reduction. Similarly, Daft and Lengel (1986) suggests that to reduce equivocality firms should adopt practices that enable debate, clarification, and enactment rather than simply providing large amounts of data. Joint problem solving thus provides the forum for rich face-to-face interaction in the project organization and facilitates communication and enactment of shared interpretations from which a development team can move forward with the project (Bstieler & Hemmer, 2010).

In addition, joint problem solving sessions constitute arenas for experimentation with different knowledge and ideas that can result in novel solutions (Dyer & Nobeoka, 2000; Uzzi, 1997). For example, McElvie & Marcus (2005) observed that joint problem solving sessions in which suppliers can demonstrate new solutions in a ‘hands-on’ setting are a highly effective way to solve problems and convey knowledge that is technically complex and difficult to articulate. Partners may provide alternative interpretations of technical problems and solutions, which enable a firm to compare, contrast and triangulate different perspectives and potential solutions (Nonaka, 1994). If the partners participate significantly in decisions and actions, joint problem solving will thus enable shared understandings by drawing on the knowledge and skills of the involved partner firms (McElvie & Marcus, 2005).

However, it is also possible to argue that joint problem solving could reduce uncertainty to some degree when the knowledge of the two partners is shared and communicated. Joint problem solving does not, however, entail the gathering of new information but rather draws on the knowledge and capabilities that the partners already have (Bstieller & Hemmer, 2010; McElvie & Marcus, 2005). Drawing only on the available knowledge delimits the possibility of closing significant information gaps and thus the potential of joint problem solving as a mechanism for reducing uncertainty (Daft & Lengel, 1986).

In sum, we argue that joint problem solving is a key activity for enacting shared meaning and interpretations of information in joint process development projects and, as such, serves as a vital activity for equivocality reduction but not for uncertainty reduction. In other words, we suggest that when the level of joint problem solving is increased, the level of equivocality will be reduced.

H2: Joint problem solving is negatively related to equivocality.

Performance consequences of uncertainty and equivocality

While the activities to reduce uncertainty and equivocality diverge, the negative consequences of these two constructs may actually converge. That is, if not sufficiently reduced, they may lead to a waste of resources, time delays, difficulties in creating explicit and robust process designs, and difficulties in performing feasibility analysis and further project planning (Sicotte & Langley, 2000; Song et al, 2007; Frishammar et al, 2011). Therefore, ultimately, high levels of uncertainty and equivocality could pave the way to a situation where process
development projects enter the implementation stages without accurate design specifications and information (Bruch & Bellgran, 2012). Consequently, this may lead to significant challenges during implementation and will often require re-work and late changes during a time where the project becomes much larger both monetarily and in terms of the number of persons involved (Rönnberg Sjödin & Eriksson, 2010; Schuman & Brent, 2005). In sum, all these factors make the project suffer monetarily. Accordingly, we argue that both uncertainty and equivocality in the early stages of joint process development projects are negatively related to the project budget performance.

In a situation where uncertainty has not been sufficiently reduced, a number of information gaps may occur that significantly increase the risk of budget overruns. In particular, technical information about properties and functions of the production equipment may not be satisfactorily specified (McGovern & Hicks, 2006). If project participants face high levels of such uncertainties (i.e., an inability to close important information gaps) when engaged with development activities, significant resources may be wasted because project participants then lack information concerning the requirements of the equipment (Frishammar et al., 2011).

Both general technical information (e.g., hydraulics and electrics requirements) and project specific technical information (e.g., material loads, throughput) need to be shared among the partners (Bruch & Bellgran, 2012). If such critical information is not shared, development work may be delayed or, alternatively, work may continue based on unclear assumptions rather than clear information, which often leads to mistakes in the design followed by re-work or late changes (Assaf and Al-Hejji, 2006). For example, Chang (2002) found that failure to provide information, providing incomplete or incorrect information and demands for additional work were key drivers for budget overruns in engineering projects. In these situations, the time pressure in the subsequent implementation stages increases and additional resources need to be committed to the project to resolve the problems. In this case the general prediction is that the project organization is likely to face severe costs and project failure (Chang, 2002).

When equivocality is not effectively reduced the situation may be different but with similar outcomes. Project participants then have conflicting interpretations of the information concerning what needs to be done. Differences in experience, assumptions, knowledge bases, values, and problem solving styles of the project participants may cause confusion, distrust, or a lack of understanding (Daft & Lengel, 1984). In this case, development work will be especially problematic because project participants lack a clear and shared view of the path forward. In particular, misunderstandings and conflicting interpretations concerning the production requirements may lead to development of designs that do not match the objectives of the project (Chang, 2002; Hicks & McGovern, 2009). In addition, conflicts among the parties may ensue and resolving these conflicts occupies valuable resources in terms of personnel and time while putting development work on hold (Vaaland & Håkansson, 2002).

In sum, while the characteristics of uncertain and equivocal situations differ, we hypothesize that the consequences may actually converge. Specifically, misunderstandings and conflicting interpretations often leads to late changes and re-work (Chang, 2002) and conflicts may slow down development (Vaaland & Håkansson, 2002). Thus, equivocal situations, just as uncertain ones, will likely lead to increased work load and time pressure during the implementation stage. As a consequence, additional resources need to be committed to the
project to resolve the problems, with budget overruns as the likely result. Based on the discussion above we suggest the following two hypotheses:

\[ H3: \text{Uncertainty is negatively related to project budget performance.} \]

\[ H4: \text{Equivocality is negatively related to project budget performance.} \]

**Methods**

The article combines a case study with a multi-wave, multiple-informant survey of joint development projects. We thus adopt a mixed-methods approach applicable to intermediate theory research, as suggested by Edmondson and McManus (2007).

**The qualitative pre-study**

Data from 45 exploratory interviews conducted at two process firms and eight of their equipment suppliers served as a pre-study to the survey research (See Table 1). This was deemed suitable given the limited knowledge about collaborative practices among equipment suppliers and process firms in joint process development projects (Lager & Frishammar, 2010; Robertson et al, 2012). The case studies were helpful in several ways. First, they provided practical knowledge about the research setting, i.e. joint development projects in the context of process development. Second, the cases aided in identifying relationships among variables in need of study (Eisenhardt, 1989; Yin, 2003). The cases thus complemented our literature study and guided the development of the research model. Third, the case study was important for the operationalization of key variables. The qualitative interviews were thus helpful in choosing among items and composing scales (Edmondson and McManus 2007). Finally, the case study activities and interviews helped to identify suitable projects and in building trust and securing commitment for the survey study.

<table>
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<tr>
<th>Firm Pseudonym</th>
<th>Main products</th>
<th>Employees</th>
<th>Annual turnover (M$)</th>
<th>Country</th>
<th>Interviews</th>
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<td>Automated lifting cranes</td>
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<td>1163</td>
<td>Finland</td>
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</table>

Table 1. Descriptive information about the firms in the pre-study
The multiple informant survey

Sampling of projects and data collection

The multiple informant survey

Sampling of projects and data collection

The sample of projects for this study was gathered from four Swedish process firms within the metal and minerals industry. The sampled projects were identified through discussions with senior managers at these four firms. Projects were selected based on the following criteria: time since completion (< 5 years), project organization size (multiple actors from both buyer and supplier sides should be involved), and relevance to the study (i.e. joint process development projects). This sampling procedure is consistent with published project level studies in leading journals (e.g. Hoegl & Wagner, 2005; Hoegl & Praveen Parboteeah, 2006; Primo & Amundsen, 2002).

For each project, three surveys were sent out: One to the buyer side of the project team and one to the supplier organization. To mitigate source bias, we used multiple key informants on each side (Hoegl & Wagner, 2005). To avoid common method variance (Lindell & Whitney, 2001), the third survey was sent to a project external manager at the buyer firm to rate project performance. Typically, for each selected project, one key informant was identified through the pre-study who subsequently helped in identifying the other respondents that were seen as the most knowledgeable about the specific project.

Data collection for the survey was conducted over a period of six months with multiple researchers involved in the day-to-day data collection. Each respondent was first contacted by phone, briefed about the study’s purpose and content, and asked for participation. In a few cases when a respondent could not participate in the survey (e.g. due to a very heavy work load or a low knowledge level), another suitable person that had participated in the same specific project was identified and subsequently contacted. In total, over 500 phone calls were made to assure participation and over 1000 e-mails were exchanged with respondents during the data collection effort.

The total sample consisted of 52 joint development projects involving four process firms in Sweden and 28 different equipment suppliers from Europe, with headquarters located in Sweden, Finland, Germany, The Netherlands and France. Due to the globalized nature of many of the equipment suppliers, respondents in the supplier firms were also reached in China, Chile, South Africa and Switzerland. In total, 251 completed and usable surveys were obtained: 52 responses from project external managers (i.e. higher level executives in the buyer organization), 100 responses from project participants in the buyer organizations, and 99 responses from project participants in the supplier organizations.

The sampled projects concerned the design and implementation of mechanical process equipment, electrical equipment, control systems for production processes, and entire processing facilities including all the above parts and systems. The project durations varied between 12 and 120 months with an average of 35 months. Moreover, the monetary size of the projects was between 0.2 M$ and 230 M$ with a mean of 45 M$.

Measures

All constructs considered in this investigation take project as the unit of analysis. Accordingly, all measures were specified at the project level. The measurement scales were
primarily based on descriptions and measures in prior literature, while one of the measurement scales were specifically generated for this study. The questionnaires were pretested by 4 academics and 3 practitioners with experience from similar projects. As a result, minor changes were made to eliminate or alter ambiguous questions and phrasings and to remove items not capturing the constructs for which they were designed. This procedure helped increased the face validity of our measures. The complete measurement scales are included in the appendix. Informants rated the dependent, independent, and control variables on 7-point scales.

The dependent and control variables were collected from project external managers. Budget performance was measured using the two-item scale by Rijsdijk & Van den Ende (2011) and an additional item was adapted from Bstieller and Hemmert (2011). The control variables were entered as the logarithm of measures of project size (USD) and project duration (Months).

Data on all other variables were collected from project participants, from both the buyer and supplier side of each project. Data was aggregated on the project level, where the input to the analysis was the mean of the responses, typically including two buyer and two supplier responses for each project. The scales for uncertainty and equivocality draw on the scales used by Park (2011). The measures were adapted to fit the current project context and are aligned with prior theoretical conceptualizations of uncertainty and equivocality (Daft & Lengel, 1986; Frishammar et al, 2011). The scale for joint problem solving was adopted from Bstieller and Hemmert (2011) and Heide and Miner (1992). Early end-user involvement was measured with a new 2-item scale designed to measure the intensity of end-user involvement in the pre-study and development stages.

Analytical procedures

Data was analyzed using partial least squares (PLS), which is a variance-based structural equation modeling (SEM) technique (Wold, 1982). During recent years the use of PLS has increased in several academic disciplines, such as marketing, strategic management, and management information systems (Hair et al., 2012) as well as operations management (Peng & Lai, 2012). There were several motives for selecting PLS. First, the research objectives and, to some extent, the exploratory nature of the study makes PLS an appropriate technique (Hair et al., 2012). Specifically, both the originality of the research model and some of the measures, and the fact that some of the relationships have not been hypothesized before, makes PLS suitable (Chin, 1998, Peng & Lai, 2012). Second, the relatively small size of our sample (52 projects) makes PLS an appropriate analytical technique because prior literature suggests PLS being appropriate for sample sizes of 30 to 100 cases (Chin and Newsted, 1999, Haenlein and Kaplan, 2004).

The software used was Smart PLS (Ringle et al, 2005), which is a PLS path modeling tool that determines relationships between independent and dependent latent variables as linear composites, much like conventional multiple regression techniques. However, as a SEM tool, Smart PLS is capable of simultaneously determining both the indirect as well as the direct path influences among all of the latent variables in a nomological network.

Results
The use and presentation of PLS estimates and results follow a two-stage sequence. To start with, the measurement model is assessed in terms of item and construct reliability, and convergent and discriminant validity. If the measures prove reliable and valid, then the structural part of the model is considered and evaluated in terms of the significance of the construct relationships based on a bootstrapping technique, variance explained of the endogenous constructs ($R^2$), predictive value (Stone–Geisser statistic), and the overall quality of the model in terms of goodness-of-fit (Tenenhaus et al., 2005).

**Measurement model results**

First, we checked the loadings, or item reliability, of each indicator used to measure the constructs. Although one item (JPS3) was below the suggested 0.7 acceptance cut-off value (see Table 2), we kept it because of the suitable construct reliability and average variance extracted (AVE) and because the scale is theoretically well established in prior literature (Chin, 1998). Second, the measures have a high internal consistency in terms of composite reliability above the 0.7 threshold (Werts et al., 1974), i.e. the constructs are reliable (Column 5, Table 2). Third, the amount of the constructs’ variance explained by their respective measures (Column 4, Table 2) exceeds the 0.5 threshold level (Fornell and Larcker, 1981). Fourth, the constructs differ from each other because cross loadings are much lower than the square root of the average variance extracted (AVE), i.e. they demonstrate high discriminant validity (see Table 3). In sum, our measurement model is based on reliable and valid measures.

<table>
<thead>
<tr>
<th>Construct name/items</th>
<th>Factor loading</th>
<th>t-value</th>
<th>AVE</th>
<th>Composite Reliability</th>
<th>Cronbach Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uncertainty</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unc1</td>
<td>0.932</td>
<td>37.761</td>
<td>0.894</td>
<td>0.962</td>
<td>0.941</td>
</tr>
<tr>
<td>Unc2</td>
<td>0.969</td>
<td>141.143</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unc3</td>
<td>0.935</td>
<td>42.060</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Equivocality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eq1</td>
<td>0.956</td>
<td>83.299</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eq2</td>
<td>0.962</td>
<td>110.675</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eq3</td>
<td>0.920</td>
<td>24.846</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Joint Problem Solving</strong></td>
<td></td>
<td></td>
<td>0.642</td>
<td>0.874</td>
<td>0.814</td>
</tr>
<tr>
<td>JPS1</td>
<td>0.907</td>
<td>13.282</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JPS2</td>
<td>0.876</td>
<td>10.657</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JPS3</td>
<td>0.559</td>
<td>2.897</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JPS4</td>
<td>0.816</td>
<td>7.467</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Early End-User Involvement</strong></td>
<td></td>
<td></td>
<td>0.860</td>
<td>0.925</td>
<td>0.844</td>
</tr>
<tr>
<td>EEU1</td>
<td>0.899</td>
<td>14.744</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEU2</td>
<td>0.955</td>
<td>29.194</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Budget Performance</strong></td>
<td></td>
<td></td>
<td>0.809</td>
<td>0.926</td>
<td>0.879</td>
</tr>
<tr>
<td>BP1</td>
<td>0.958</td>
<td>61.053</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BP2</td>
<td>0.965</td>
<td>83.786</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Discriminant validity

<table>
<thead>
<tr>
<th>Constructs</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>BP</th>
<th>EEUI</th>
<th>Eq</th>
<th>JPS</th>
<th>Unc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget Performance</td>
<td>4.58</td>
<td>1.87</td>
<td>0.899</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early End-User Involvement</td>
<td>4.40</td>
<td>.852</td>
<td>0.361</td>
<td>0.927</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivocality</td>
<td>2.62</td>
<td>.767</td>
<td>-0.485</td>
<td>-0.133</td>
<td>0.946</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joint Problem Solving</td>
<td>5.56</td>
<td>.576</td>
<td>0.288</td>
<td>0.380</td>
<td>-0.442</td>
<td>0.801</td>
<td></td>
</tr>
<tr>
<td>Uncertainty</td>
<td>2.77</td>
<td>.844</td>
<td>-0.580</td>
<td>-0.341</td>
<td>0.621</td>
<td>-0.254</td>
<td>0.946</td>
</tr>
</tbody>
</table>

(Note: Bold numbers indicate the square root of the average variance extracted, and numbers below the diagonal represent construct correlations)

Structural model results

The structural model results, based on a 500 sub-sample bootstrap, suggests that H1-H3 are all supported (p < 0.05). In particular, the relationship between joint problem solving and equivocality (b = -0.450) is highly significant. Moreover, the relationships between early end-user involvement and uncertainty (b = -0.260) and uncertainty and budget performance (b = -0.329) are both significant (See Table 4). However, the negative relationship between equivocality and budget performance (b = -0.231) was not supported by the data. H4 is therefore rejected.

Furthermore, the controlled relationships for project duration and size were not significant. The variance explained by endogenous variables (R²) was 0.418 for budget performance, 0.200 for equivocality and 0.182 for uncertainty. This indicates that the model has strong capabilities for explaining variations in budget performance while the explanations of uncertainty and equivocality are less powerful. The Stone–Geisser Q2 statistic (Geisser, 1975; Stone, 1974) had a positive value for all reflective endogenous constructs, suggesting that the model has predictive value. Considering the measurement and structural models together, their goodness-of-fit (GoF) value (Tenenhaus et al., 2005) was 0.468, indicating that the model is of reasonably high quality (GoF ranges between 0 and 1; the higher the better).

Finally, formal hypotheses were not formulated for the effects of early end-user involvement on equivocality or joint problem solving on uncertainty because neither prior literature nor our case research enabled us to posit any meaningful hypotheses regarding these relationships. Nevertheless, we tested for these relationships. As expected our results show no significant effects of early end-user involvement on equivocality (b = 0.029), nor joint problem solving on uncertainty (b = -0.155). Moreover, the direct effects of early end-user involvement (b = 0.200) and joint problem (b = 0.039) solving on project budget performance were not significant.

Table 4. Results of the structural model

<table>
<thead>
<tr>
<th>Effects on endogenous variable</th>
<th>Direct effect</th>
<th>t value (bootstrap)</th>
<th>Variance explained (R²)</th>
<th>Stone-Geisser q2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects on uncertainty</td>
<td></td>
<td></td>
<td>0.182</td>
<td>0.141</td>
</tr>
</tbody>
</table>
### Discussion

In this article we have presented a study on uncertainty and equivocality in joint development projects, and the collaborative information processing activities that enable reduction of uncertainty and equivocality. Our findings highlight the importance of reducing uncertainty and equivocality and underline their negative consequences for project performance. Specifically, our results indicate that end-user involvement reduces uncertainty (but not equivocality) and that joint problem solving reduces equivocality (but not uncertainty). These findings can improve process development practices in industrial firms. Consequently, the findings are practically important because of the inherently strategic nature of process development, which has the potential to support superior firm performance (Teece, 2009). Although the findings origin in the process industry they may extend to other industrial domains as well, especially industry contexts where joint development projects are common, for example product development as well as construction and other manufacturing industries.

### Theoretical implications

Our study provides a couple of important theoretical implications for several literature fields. From an operations management perspective, successful joint development of process technology can provide significant firm-level competitive advantages through improved manufacturing operations (Scott-Young & Samson, 2008; Stock & Tatikonda, 2008). Our
results indicate how early end-user involvement and joint problem solving increase the probability of success in a particular development project by reducing uncertainty and equivocality. By including both concepts in the same study, which is a rare occurrence in prior studies, we were able to distinguish which activities leads to reduction of uncertainty and equivocality respectively, by examining both indirect and direct effects.

For example, the main impact of joint problem solving on budget performance is through the reduction of equivocality, while a potential direct effect is nonexistent in the present study. This is an interesting finding because prior research has neglected to study the effects of joint problem solving on uncertainty and equivocality (e.g. Bstieller & Hemmert, 2010; Mc Elvie & Marcus, 2005). By introducing these intermediate concepts, our study highlight the importance of joint problem solving, suggesting its role as a primary activity for equivocality reduction. However, although the correlation coefficient was negative, equivocality did not have a significant negative effect on budget performance. This could be due to the relatively modest sample size underpinning the analysis or the selection of dependent variable. However, the implication is not that equivocality reduction is pointless. On the contrary, equivocality may be unfavorable for many other things in development projects as well, such as user satisfaction, quality and speed of development. Therefore, more research on the effects of equivocality in joint development projects is needed.

By contrast, the results indicate that early end-user involvement is an effective way of reducing uncertainty, but it simultaneously has a direct effect on budget performance. These results have two relevant implications. First, user involvement is typically cited as an important success factor in industrial development projects (McDermott and Stock, 1999; Stock & Tatikonda, 2008; Tait and Vessey, 1988). However, there is a lack of studies addressing when their involvement should take place. Our study contributes by indicating that early involvement of end-users reduces uncertainty in joint process development projects. Second, the direct and significant effect of early end-user involvement on project performance when controlling for uncertainty is also an interesting finding. It suggests that there may be added advantages of involving end-users early in the project. Prior operations management literature has found that early involvement of end-users instils a sense of ownership in the project by giving end-users the potential to contribute to the project at an early stage (Schuman and Brent, 2005). Enhancing commitment among end-users already in early stages is crucial for facilitating work in the later implementation stages where end-user commitment is critical for preparing a smooth hand-over of the process technology from the project organization to the end-users (Rönnberg Sjödin & Eriksson, 2010; Lager, 2012).

A second area of implications concerns the context and domain of the study. Most prior studies on uncertainty and equivocality have been conducted within product development in high-tech industries where high levels of uncertainty and equivocality are more prevalent (Song et al, 2007; Sicotte & Langley, 2000). Nevertheless, our study indicates that even relatively low levels of uncertainty and equivocality (mean values 2.77 and 2.62) can be problematic in joint process development projects. The effects of uncertainty and equivocality in settings such as process development and “low-tech” industries are therefore relevant and somewhat neglected in prior studies. A reason for negative effects stemming from relatively low levels of uncertainty and equivocality can be the inherently systemic nature of process development (Gopalakrishnan & Damanpour, 1997). Process development often involves many complex and highly interdependent activities and functions that have to be coordinated
and integrated with each other. One activity serves as input to another that is required as input for a third, and so forth. Hence, uncertainty and equivocality in one activity must be reduced before the whole system of activities can proceed without too much flawed information.

A third theoretical implication contributes to stage-gate research. While the conventional stage-gate models were first designed to organize product development, prior research indicates that also process development typically follow some kind of gated process (Frishammar et al., 2012; Lager, 2010; Lim et al, 2006; Pisano, 1997). Stage-Gate models are designed to reduce technical uncertainties as a project progresses (Cooper, 2008). However, the negative effects of equivocality in general suggest that stage-gate models should also include activities and methods for equivocality reduction. Concrete suggestions would be to include activities for equivocality reduction such as joint problem solving sessions in the formalized processes. But also new evaluation criteria in gate reviews, which assure that equivocality levels remain acceptable. These suggestions seem increasingly important since firms are moving towards increasingly open and distributed development processes across organizational boundaries (Robertson et al, 2012).

Finally, the way uncertainty and equivocality was operationalized provides implications for project management literature. Our operationalization measures uncertainty and equivocality as perceived lack of information and the existence of multiple and conflicting interpretations of the information, closely following the conceptual definitions of Daft & Lengel (1986). By contrast, many prior operationalizations measure these concepts by project characteristics such as novelty or complexity (Stock & Tatikonda, 2008) or by environmental influences such as dynamism or hostility (Koufteros, 2005). Although this way of operationalization may have advantages, it is not suitable in a study focusing on how project management can reduce uncertainty and equivocality since it is not possible, nor desirable, for reduction activities to change the inherent characteristics of the project. While novelty and complexity may impose managerial challenges, they may also be desirable characteristics with positive effects since they may lead to better process solutions that are harder for competitors to imitate and thus lead to strengthened competitiveness. By contrast, situations where project management is unable to reduce uncertainty and equivocality are problematic and typically lead to failures. Our operationalization thus recognizes the importance for project management to reduce the negative aspects of uncertainty and equivocality in order to improve project performance (Chang & Tien, 2006).

**Managerial implications**

Our study underlines the importance of selecting distinctive strategies and activities for reducing uncertainty and equivocality. This is especially important since prior research does not provide detailed advice for reducing uncertainty and equivocality in joint projects (Stock & Tatikonda, 2008; Koufteros et al, 2005).

Joint problem solving should be applied with the purpose of reducing equivocality among project participants in early stages. Such activities may be quite costly and resource consuming but still worthwhile when equivocality is reduced. To facilitate joint problem solving an environment of open communication and trust is typically required (Mc Elvie & Marcus 2005). To enable such an environment collaborative activities including joint goal setting, joint project office, and team building activities at the start of the project are often suitable (Rönnberg Sjödin &, Eriksson 2010).
Early end-user involvement should be applied with the purpose of reducing uncertainty but may also be required for enhancing commitment for the project in the end-user organization. It is important to note that at the buyer side it is often the research and development or project function that are running the project whereas there are end-users in the production function that will use the actual equipment, but they are typically not responsible for the performance of the project. One important implication for both project managers and production managers is ensuring that competent and qualified end-users are involved in process development projects as a part of their regular duties. This requires agreements between production and project management at the start of the project specifying when and how specific end-users should be involved in the project.

Recognizing which activities leads to reduction of uncertainty and equivocality respectively is a particularly important implication for managers. This is perhaps best illustrated by the situation where an activity best suited to reduce uncertainty is applied to reduce equivocality or vice versa. For example a manager striving to reduce equivocality could erroneously come to the conclusion that more involvement of end-users would reduce apparent conflicting interpretations among projects participants. As our results suggest, such an approach would provide no reduction of equivocality and would also incur increased costs and negative effects as project participants as well as end-users would feel frustration with such apparently futile involvement activities. Similarly, engaging in joint problem solving to reduce uncertainty rather than gathering information from involvement of end-users or other sources would also incur increased costs to ultimately unproductive activities.

Our results highlight the importance of reducing even relatively low levels of uncertainty and equivocality in joint process development projects. Managers thus need to be highly cognizant of signs of uncertainty and equivocality in joint development projects. Therefore, regular and structured assessment of such problems should be included in the tasks of the project manager. Particularly, identifying areas where lacking information or conflicting interpretations among participants may hinder development work in the project. Including such assessments in stage-gate evaluations would provide further emphasis and legitimacy for project managers to select and implement the appropriate strategies for reducing the risks of uncertainty and equivocality.

Limitations and outlook
Every study has limitations. Some limitations for this study are: Despite the comprehensive data collection, consisting of qualitative pre-study and 251 survey respondents, the total sample of projects for this study was limited to 52 projects from four Swedish process firms. The non-random sample and limited sample size of the present study thus limits the possibility to make generalizations to a larger population outside the scope of the present study. In particular, our cross-sectional research design can only imply, rather than prove causality. To this end, a larger sample and longitudinal design would be beneficial for future research. The negative impact of equivocality on cost was only partially supported in the present study. Nevertheless, we encourage further research to study the concept of equivocality in the context of process development projects. The findings of this study sets the foundation for further research on inter-organizational aspects of process development, a practical operations management concern, that to date has seen little quantitative research.
Appendix - Measures

<table>
<thead>
<tr>
<th>Construct name/items</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uncertainty</strong></td>
<td>The information (e.g. about customer requirements, project scope, technical solution) available in the early stages of the project relationship.</td>
</tr>
<tr>
<td>Unc1</td>
<td>was inadequate for our purposes.</td>
</tr>
<tr>
<td>Unc2</td>
<td>was too vague to be very helpful.</td>
</tr>
<tr>
<td>Unc3</td>
<td>was incomplete for our needs.</td>
</tr>
<tr>
<td><strong>Equivocality</strong></td>
<td>The information (e.g. about customer requirements, project scope, technical solution) available in the early stages of the project relationship.</td>
</tr>
<tr>
<td>Eq1</td>
<td>was interpreted differently by different project participants.</td>
</tr>
<tr>
<td>Eq2</td>
<td>had conflicting interpretations.</td>
</tr>
<tr>
<td>Eq3</td>
<td>was confusing due to different interpretations.</td>
</tr>
<tr>
<td><strong>Joint Problem Solving</strong></td>
<td>In this project.</td>
</tr>
<tr>
<td>JPS1</td>
<td>We jointly planned how this project should be run.</td>
</tr>
<tr>
<td>JPS2</td>
<td>Adjustments to project specific agreements were mutually agreed upon.</td>
</tr>
<tr>
<td>JPS3</td>
<td>We jointly reevaluated the progress of our working relationship throughout the project.</td>
</tr>
<tr>
<td>JPS4</td>
<td>Problems that arose during the project were treated by the parties as joint rather than individual responsibilities.</td>
</tr>
<tr>
<td><strong>Early End-User Involvement</strong></td>
<td>Please indicate the extent to which end-users in the customer organization were involved in the following stages:</td>
</tr>
<tr>
<td>EEUI1</td>
<td>Pre-study/feasibility study.</td>
</tr>
<tr>
<td>EEUI2</td>
<td>Development, engineering and design.</td>
</tr>
<tr>
<td><strong>Budget Performance</strong></td>
<td></td>
</tr>
<tr>
<td>BP1</td>
<td>The actual costs of the project were lower than or equal to the estimated costs.</td>
</tr>
<tr>
<td>BP2</td>
<td>This project has been as costly as or cheaper than expected.</td>
</tr>
<tr>
<td>BP3</td>
<td>The project was undertaken in a cost efficient manner.</td>
</tr>
</tbody>
</table>

References


Filippou, D., & King, M. G. R&D prospects in the mining and metals industry. *Resources Policy.*


Weick, K.E. (1979). The social psychology of organizing (Topics in social psychology series).


