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Uncertainties Experienced by Suppliers Participating in Customers' Product Development Projects

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Abstract: This paper explores uncertainties experienced by suppliers involved in their customers' product development projects. The study introduces a model for classifying different types of involvement, which is used to identify uncertainties and effects across the various types. Empirical data originates from a multiple case study involving four SME suppliers. Four types of uncertainty are identified. These uncertainties stem from both customer and supplier organizations as well as from technology.

Keywords: Supplier Collaboration, Supplier Integration, SME, NPD, Case Study

1 Introduction

Supplier involvement in product development, where the customer organization shares responsibility for the development and design of a subsystem or component with a supplier (Hoegl and Wagner, 2005), can be beneficial for both customers and suppliers. The advantages for customers include access to knowledge (Suurmond et al., 2020), lower costs, and shorter development times (Johnsen 2009), while suppliers can benefit from new knowledge that they can transfer to other projects (Chung and Kim, 2003). However, managing supplier involvement in product development requires dealing with uncertainty (Eslami and Melander, 2019), which is a critical capability in product development (Eisenhardt and Tabrizi, 1995). Uncertainty refers to both the lack of information and the difficulty in accurately predicting something, for example, knowing the outcome of a decision (Duncan, 1972; Milliken, 1987). Several studies have looked at uncertainty in the context of product development (e.g. Eisenhardt and Tabrizi, 1995; Olausson and Berggren, 2010), but not as many in the context of supplier involvement. Based on the media richness theory, which assumes that uncertainty can be reduced by increasing the level of information exchange (Daft and Lengel, 1986), Wynstra and Pierick (2000) present a model that supports customer organizations in deciding on the level of collaboration and communication with the supplier. Le Dain et al. (2010) present a model that supports management in make-or-buy decisions in product development projects. One dimension of the model is project risk, including uncertainty as one of the components to be estimated. Both studies take the customer's approach and do not study uncertainty in detail or from the supplier's perspective. Although several studies suggest that uncertainty can be reduced through communication, it is assumed that both actors perceive the presence of uncertainty or that the actor experiencing uncertainty is powerful enough to persuade the other to communicate (Oosterhuis et al., 2011). Therefore, it is of interest to know what uncertainties suppliers, being less powerful actors in comparison to their customers, experience when deciding on appropriate actions to mitigate the uncertainties that arise when involved in product development. In addition, suppliers are involved in the customer's product development in various ways. For example, in terms of coordination (Lakemond et al., 2013) and the degree of responsibility (Petersen et al., 2005). To fill a gap in the research to date, this study aims to investigate uncertainties that small and medium-sized enterprise (SME) suppliers experience depending on how they are involved in the customer projects as well as which are the potential effects of the uncertainties.

The remainder of the article is organized as follows. First, different sources of uncertainty are described in section 2, followed by a classification model for different types of supplier involvement in product development in section 3. Then, the research method is described in section 4. Section 5 presents four types of supplier involvement identified in the case studies. Section 6 presents the identified uncertainties and their effects and summarizes them in a table that combines the sources of uncertainty with the different types of involvement. Section 7 discusses the findings. Section 8 concludes by summarizing the main contributions, theoretical and managerial implications, the limitations of the study, and suggestions for future research.

2 Sources of Uncertainty

Product development involves several sources of uncertainty, which have been modeled in various ways, for example, Hall and Martin (2005) and O'Connor and Rice (2013). Common to many models is the classification of uncertainty as a result of the organization, the technology, and the market. Sources of organizational uncertainty include gatekeepers in the organization limiting direct communication between the customer's and supplier's engineering departments (Eslami and Melander, 2019), organizational continuity (O'Connor and Rice, 2013), organizational overload, inadequate routines (Martinsuo et al., 2014), and the number of stakeholders (Hall and Martin, 2005). Uncertainty originating from technology is influenced by the unpredictability of technological change (Oosterhuis et al., 2011), and the uncertainty is higher for radical developments involving dramatic changes and new technologies, as the organization is less familiar with them (Hall and Martin, 2005). Uncertainty related to the market refers to the difficulties in predicting customer needs and wants, as well as the lack of information, for example, about competitors' products (O'Connor and Rice, 2013).

3 A Classification Model of Supplier Involvement in Product Development

To compare and contrast the uncertainties, an analytical model for classifying different types of supplier involvement in product development was developed based on models from prior research. Some models distinguish between different types of involvement in relation to the responsibilities assigned to the supplier (e.g. Fujimoto, 1999; Petersen et al., 2005) or different types of resource interfaces (Araujo et al., 1999). There are also two-dimensional models that combine, for example, responsibility and competence (Eggers et al., 2017), or responsibility and development risk (Wynstra and Pierick, 2000). The models often adopt a customer's perspective and address uncertainties emanating from the product. However, uncertainties related to manufacturing, which may be most challenging from the supplier's perspective, are often overlooked. The interdependencies between the product and the manufacturing process are evident. For example, the product shape and material selection can affect the selection of manufacturing processes. Vice versa, the manufacturing processes can constrain the design. The purpose of the classification model used in this study is to classify uncertainties for different involvement types from the supplier's perspective. Therefore, following previous models of supplier involvement that divide responsibilities for product development between customers and suppliers and previous studies that have shown that technological novelty contributes to uncertainty (Tatikonda and Rosenthal, 2000), a classification model for supplier involvement in product development is proposed, as illustrated in Figure 1. Technology novelty is defined as the newness of the technologies used by the customer's and supplier's development organizations, which can be described and differentiated in terms of change (ibid). Technological novelty is subdivided into the dimensions of product and manufacturing process novelty.

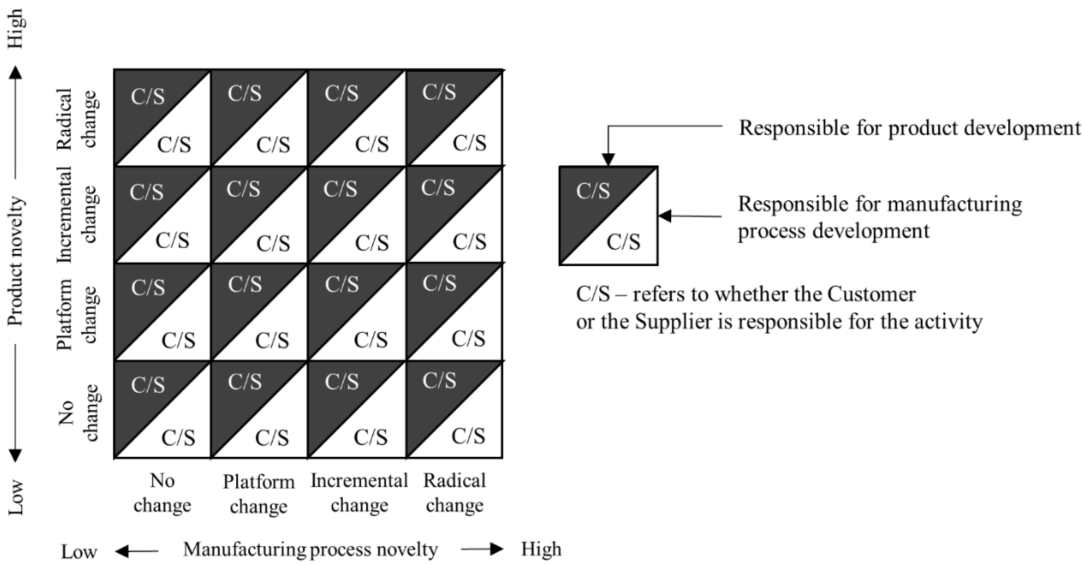

Figure 1. Classification model for supplier involvement in product development types

The model comprises the dimensions of product and manufacturing process novelty and classifies projects according to the degree of change. The degree of change is divided into four categories: no change, platform change, incremental change, and radical change. No change means that existing products and manufacturing processes are used. Platform change refers to the addition of new features to an existing product or manufacturing platform. Incremental changes are the introduction of new products, new materials, and new manufacturing methods or processes for the company. In the category of radical changes, new technologies, materials, or manufacturing processes are introduced that are different from previous products or processes and are unique to the company.

4 Research Method

A multiple case study approach was used to identify uncertainties experienced by SME suppliers in different types of supplier involvement in product development and their effects in a real-life context (Yin, 2018).

Four small and medium-sized enterprises (SMEs), referred to as companies A-D, took part in the study and differed in terms of their size (30 to 210 employees), their customer base, and the technologies used. The SMEs' development tasks varied in terms of product and process novelty. Companies A and B develop and manufacture subsystems for the process industry, for example, for paper mills and water treatment plants. The subsystems are based on mature mechanical technology. Company C manufactures and occasionally designs customer-specific polymer products for various industries such as energy distribution, electronics, and grocery shops. Company D mainly manufactures sheet metal components for heavy automotive manufacturers. What all companies have in common is that the technologies used in the products are mature.

The data were primarily collected through two studies. The primary source of data in the first study was 32 semi-structured interviews with employees representing different roles in the case companies, as shown in Table 1. Three years later, a follow-up study was conducted at Company A on the improvement initiatives since the first study. This second study comprised a further four interviews. The interviews lasted between 21 and 72 minutes in the first study and between 22 and 47 minutes in the follow-up study. Each interview was recorded and transcribed. The quotes in this paper have been translated from the original language into English. Most of the interviews, namely 31, took place in person at the companies' premises; one interview was conducted by telephone, and the four follow-up interviews were conducted by video conference. Workshops were also held with the companies over a period of three years. Three workshops were held individually with companies A-C to develop a better understanding of the design activities and uncertainties of the respective companies. The other three workshops were held jointly with participants from several companies and supplemented the interviews with a cross-company perspective. Documents such as checklists and process descriptions were collected to triangulate and complement the data from the interviews and workshops. The documents deepened the understanding of supplier involvement in product development.

Table 1. Overview of the interviews.

Company & year	No. of interviews	Role of informants
A 2018	8	Engineering Director, Production Manager, Purchasing and Logistics Director, Marketing Director, Product Manager, Quality Manager, Purchaser and Technical Support Engineer
B 2019	9	Managing Director, Production Manager, 3 Design Engineers, Demand Planner, Sales Engineer and 2 Factory Workers
C 2018	9	CEO/Owner, Engineering and Sales Manager, Production Manager, Quality Manager, Design Engineer, Financial Officer & HR generalists, Supply Coordinator, Factory Worker and Toolmaker
D 2018	6	Sales & Purchasing Director, Purchaser, 2 Key Account Managers and 2 Technical Project Leaders
A 2021	4	CEO, Engineering Director, Production Manager, Purchasing and Logistics Director

The data analysis followed the structure proposed by (Miles et al., 2020) with the three simultaneous activities of data reduction, data display, and conclusion drawing. The different types of uncertainties and the effects of uncertainties were matched with the inductively identified characteristics of suppliers' design activities and the theory-driven dimensions of customer organization, technology, and supplier organization. NVivo software was used to code and categorize the transcripts. The data was categorized using data displays to support analytical reflection (Miles et al., 2020).

As the companies operated in a business-to-business (B2B) context and the suppliers had no contact with the product users, or the end customers, there was insufficient data on uncertainty originating from the market. The study focused on the organizational and technical sources of uncertainty.

5 Four Types of Supplier Involvement

To compare and contrast the identified uncertainties for the different types of involvement, the product and process development activities at the studied companies were categorized according to the classification model described in section 3. Four different types were identified: 1) Design reuse, 2) Platform expansion, 3) Design for manufacturing, and 4) New design. See Figure 2 for an overview of the four different types and their classification based on the model illustrated in Figure 1. The left-hand side displays the position of the identified types in the Figure 1 model, whereas the right-hand side shows the names of the identified types. A description of the four types follows.

The first type, *Design reuse*, classified as no change from both a product and process perspective does not involve any new design activities as the supplier delivers a standard product. The supplier is responsible for both product and process development. However, sometimes customers require advice from the supplier's technical expertise. For example, when it comes to the choice of the most suitable product for a specific customer application. This type was found in Company A. The customer's *"process involves chemicals, and he asks which product to choose"* (Product Manager, Company A). The engineers' task is to find a combination of components that matches the customer's process in terms of chemical resistance, particle size, operating pressure, etc.

Platform expansion is classified as a platform change from both a product and a manufacturing process perspective. The supplier is responsible for both product and manufacturing process development. These are based on the customer's product platform including pre-designed product modules and existing manufacturing processes. This type is found in companies A and B. The reasons for the changes can be that the customer has requested more specialized functions or that the subsystems are being used in a new environment. For example: *"Depending on the bulk material being transported, it can be wet, which requires special sealing"* (Sales Engineer, Company B). Company A experiences that *"we suddenly have a customer who wants a new dimension, for example, 800 millimeters. We may be able to supply something that has a diameter of 700, but now the customer wants 800, which means that you reuse a lot of the design for 700 and try to make it bigger"* (Purchasing and Logistics Manager, Company A). It is also common for customers to want to use the product in more demanding situations than originally designed for. These requests often require the company to change the materials, modify the design, and carry out new verifications.

The third type of involvement, *Design for manufacturing*, is classified as an incremental change from a product perspective and platform change from a manufacturing process perspective. The customer is responsible for the product design but involves the supplier to provide feedback from the manufacturing perspective, for which the supplier is responsible. This characterizes the activities at companies C and D. *"The customer has developed a drawing, a model or a concept. We then give our feedback from the production perspective"* (Technical Project Manager, Company D). For example, to simplify the product from a manufacturing perspective so that *"the tolerances and dimensions ensure that it runs smoothly"* in manufacturing (Key Account Manager, Company D). The products developed were, for example, a new product line for heavy vehicles. The suppliers supplemented their existing manufacturing processes with new tools. In this type of involvement, the supplier also provides support in specialized areas in which the customer is weak. For example, it is common for Company C to help with the selection of materials.

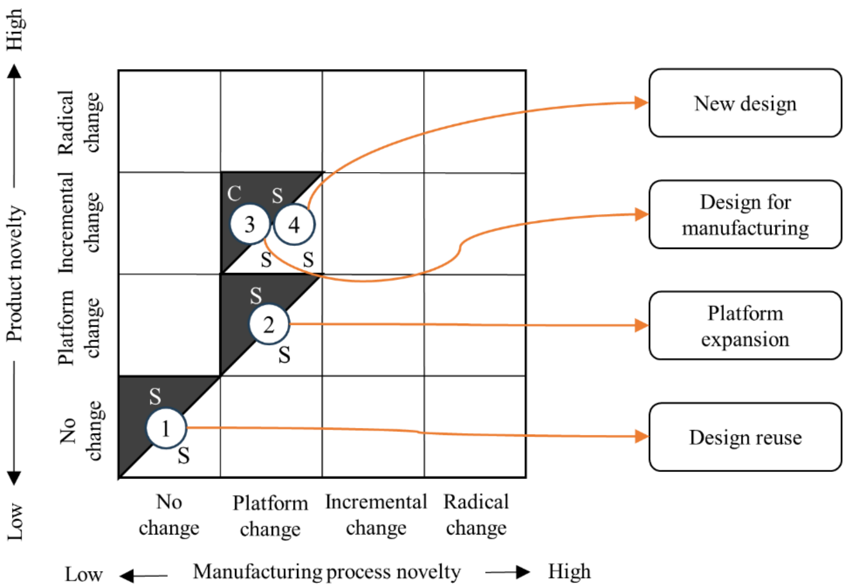

Figure 2. Identified supplier involvement in product development types

The *New design* type of involvement is similar to the Design for manufacturing type in terms of product and platform change. The difference is that the supplier is responsible for product development. This type was identified at Company C, which was involved early in the customer's idea phase with very preliminary product specifications. *"We start with a meeting with the customer, and they present their idea […] I work with the design and there is a constant back and forth* *between the customer and us."* (Design engineer, Company C). The product was new to the supplier in terms of market, product size, and material properties, but other suppliers are producing similar products. The manufacturing of the product is based on the supplier's existing manufacturing capacities but requires new tools and learning how to manufacture products of different sizes and materials.

6 Identified Uncertainties and Effects

This section presents the empirical findings about the identified uncertainties and their effects. Four types of uncertainties were found: product requirements uncertainty originating from the customer organization, manufacturing process uncertainty, project plan uncertainty originating from the technology, and internal handover uncertainty originating from the supplier's organization. These are described in more detail in the following sub-sections. Finally, a table provides an overview of the uncertainties and their effects categorized by where they originated from, and the involvement types described in the previous section.

6.1 Product Requirements Uncertainty

Product requirements uncertainty arises when there is limited access to the specific needs and desires of the customer. This type of uncertainty was evident in all types of involvement. In one case representing the Design reuse type of involvement, the customer had missed passing on information about in which application the component was supposed to be used. This resulted in corrosion problems and led to complaints from the customer, who believed that the supplier was aware of the requirements. One of the interviewees stated: *"We have problems with corrosion on the upper part of the product, the maneuvering component. […] the component is supplied to the fishing industry, and the customer says: 'Do you not know that these products are installed on a fishing boat'"* (Quality Manager, Company A).

In another case, which represented the involvement type Platform expansion, the supplier was aware that it did not have the full information on the physical properties that set the limits for the design. This caused extra work for the supplier's design engineers, who had to search for information that they knew was available from the customer but had not been shared. One interviewee stated: *"This is detective work of an unprecedented kind. […] We receive incomplete information, so we must search for information that is proven to exist. The customer knows what he wants, but we don't get the whole background. We get CAD images where they clearly have 3D models. I need a 3D model to understand quickly and easily what the customer wants. And then we only get a few drawings that are made with little detail. It's detective work."* (Design Engineer, Company B). The fact that the suppliers did not have access to all relevant information resulted in the design engineers having to guess what was requested, which caused rework and a longer design process. The following quote also illustrates the problem of an inconsistent information-sharing process between the customer and supplier. *"Often we make a design suggestion of how we think they want it. We spend a lot of time trying to make something we think they want. Then we get the answer 'No, but that's how we want it'. And then they come up with changes. So, it becomes a very long process. You spend a lot of time at the beginning on something that may end up looking completely different."* (Design Engineer, Company B).

The problems with the unspoken requirements were also reported regarding involvement type Design for manufacturing, as emphasized by one of the interviewees: "*The hardest part is when there are unspoken requirements that you do not know about, or when the requirements come up after the detail has already been manufactured."* (Engineering and Sales Manager, Company C). The same company found that early involvement was better for information sharing. Early involvement usually meant gaining an understanding of the product requirements and identifying unspoken requirements that were often lost when involved late in the development. Without the information that early involvement brings, it was more difficult to make suggestions for improvement, which could ultimately lead to higher manufacturing costs for the product. One interviewee stated: *"The hardest part is when you don't have all the facts early on, for example, if I don't get involved at an early stage. If I am involved at an early stage, I usually get enough information about the product. What it should be able to do, what it should do. […] You have a completely different understanding. If I get involved later and only get a drawing of the details, it can be very difficult to make suggestions"* (Engineering and Sales Manager, Company C).

Product requirements uncertainty could also be a consequence of the customer's poor decision-making. This was reported by Company C about its experience in the New design type of involvement, where there were several customer representatives with different functions. The problem was that the customer representatives had different opinions on the product requirements, but no one took responsibility for making a decision and conveying that unambiguously to the supplier. This led to uncertainty about the requirements and disrupted design activities, as explained by one of the interviewees: *"For example, the assembly department thinks one way, the sales department thinks another, etc. This means that there is no one who can make decisions, no one wants to take responsibility."* (Design Engineer, Company C).

6.2 Manufacturing Process Uncertainty

Manufacturing process uncertainty refers to the supplier's lack of information about the customer's manufacturing processes and the difficulty in predicting the behavior of the developed products in the manufacturing process environment or the outcome of the supplier's manufacturing process. Uncertainty about the customer's manufacturing process was a problem for companies A and B when they were involved in the customers' product development projects, as represented by involvement types of Design reuse and Platform expansion. The performance of the suppliers' sub-systems or components was difficult to predict due to the large number of parameters that could have an impact, making it difficult to select or develop an optimal product configuration for the customer's manufacturing process. One interviewee said: *"There are so many parameters in a process that can affect whether it works or not", "Customers state that certain chemicals are processed and the size of the particles, but that does not tell the whole story"* (Product Manager, Company A). Another effect reported on manufacturing process uncertainty was the unpredictable product service life experienced by Company A. "*Sometimes customers ask for a promise that the product will last for three years. I cannot promise that. Because I do not know how they will carry out their process."* (Product Manager, Company A).

Uncertainty related to the supplier's manufacturing process, which was the case in the Design for manufacturing involvement type, led to unpredictable properties of the product. For example, Company C had to compensate for the variety of polymers used and the differences in material properties when developing the molds for the manufacturing process. The effect of the different properties, in combination with the properties of the developed component and the manufacturing process, made the final measurements of the component unpredictable. One of the interviewees elaborated on this: *"Polymers shrink quite a while after the part is made. A measurement of a part that is hot no longer matches after a day. It shrinks quite a lot. Different polymers shrink differently. Glass fibers make things even more complicated, because the part shrinks differently depending on how the fibers are arranged in the mold."* (Engineering and Sales Manager, Company C).

6.3 Project Plan Uncertainty

Project plan uncertainty refers to the lack of information about the project plan and the difficulty in predicting the reliability of the plan. This type of uncertainty was identified at Company D, involvement type Design for manufacturing. One of their customers developed complex products with multiple interfaces and struggled with design issues that prolonged product development. The product launch had been postponed, and it was difficult to predict a new launch date. One interviewee explained that this impacted on the supplier who had invested time in the project and expensive tools, meaning that they had to wait an unpredictable amount of time for a return on their investment. *"They have a new product with a lot of teething troubles. They must replace some components that do not work. [...] So, we are still in the start-up phase with our products. Now it costs more money than you thought."* (KAM, Company D). The supplier also relied on having new products to be profitable, as the prices of existing products had been reduced over the years. So, if the new products were delayed, it affected the supplier's finances, as stated by one of the interviewees: *"This is the alpha and omega, so to speak, for you as a supplier in order to survive with the rules of the game that exist in the current price agreements. Then you must constantly launch new products onto the market to regain some of the lost ground."* (KAM, Company D).

6.4 Internal Handover Uncertainty

Internal handover uncertainty refers to the lack of information coming from the supplier's internal handovers. This type of uncertainty has been identified in involvement types Platform expansion and Design for manufacturing when information about customer orders is passed on internally. The reason for uncertainty about customer orders was the unclear handover between sales and engineering and engineering and manufacturing. For example, without a proper handover between sales and engineering, the engineers realized that they did not have as much information as the sales staff about the commitments to the customer. This meant that the design engineers at Company B, involved according toPlatform expansion, had to spend more time clarifying what functionality that had been sold. This lack of information also increased the risk of developing features that were not included in the contract, as reported by one interviewee: *"On slightly larger projects, it becomes quite inefficient. The salespeople usually have the most information, and they are the point of contact for the customer if they have questions. We do not have as much information when we are designing, and we have less contact with the customer than the salespeople have. There are often things you don't know. You might assume that the other person knows. [...] Customers ask us to do things, and we produce things for the customer that we end up not getting paid for."* (Design Engineer, Company B).

There were also uncertainties in the handover between engineering and manufacturing as identified in involvement types Platform expansion and Design for manufacturing. Firstly, there were different opinions about whether a handover to the line organization had taken place, which led to confusion about the responsibility for customer orders at Company C, which needed to be clarified as explained by a production manager: *"Too many questions, too much hassle, too much uncertainty"* (Production Manager, Company C). Secondly, manufacturing did not know how to build the products because there was no proper handover from the designer to the manufacturing department at Company A. For example, manufacturing did not have enough information to understand how the product should be assembled, which led to production stops and errors. One interviewee reported that: *"This often leads to inconsistencies that even translate into errors in delivery to the customer and lost time. The worker does not know what to do, so he must stop his work and ask someone, 'How does this work?', to get support from a designer, etc."* (Engineering Director, Company A).

Table 2 summarizes the uncertainties and the effects, classified according to the source of uncertainty and the type of involvement. Empirical data were not found for uncertainties originating from the technology in the New design type of involvement and for uncertainties originating from the supplier organization in involvement types Design reuse and New design. These combinations are marked in grey.

Table 2. Summary of uncertainties and their effects

		Uncertainties originating from:		
		Customer organization	Technology	Supplier organization
Types of involvement	Design reuse	**Product requirements uncertainty:** Effect: Customer complaints.	**Manufacturing process uncertainty:** Effect: Difficult to select or design an optimal product configuration, and unpredictable product service life	
Types of involvement	Platform expansion	**Product requirements uncertainty:** Effects: Extra work, guessing, rework, and longer design process.	**Manufacturing process uncertainty:** Effect: Difficult to select or design an optimal product configuration, and unpredictable product service life	**Internal handover uncertainty:** Effect: Unclarity about customer orders, risk for including features not included in the contract. Production stops and errors.
Types of involvement	Design for manufacturing	**Product requirements uncertainty:** Effect: Higher manufacturing cost.	**Manufacturing process uncertainty:** Effect: Unpredictable properties of the product. **Project plan uncertainty:** Effect: Delayed return on investments, and supplier's finances	**Internal handover uncertainty:** Effect: Confusion about the responsibility for customer orders.
Types of involvement	New design	**Product requirements uncertainty:** Effect: Disrupted design activities.		

7 Discussion

From studying Table 2, it is evident that product requirements uncertainty was present in all four types of involvement. This emphasizes the importance of either ensuring that product requirements are communicated and understood by the supplier when necessary to avoid the identified effects (von Corswant and Tunälv, 2002) or that the suppliers are involved early so that they can access complementary information to understand the requirements put on the product, as shown in this study. The effects seem to vary from type to type, which could be explained by the different responsibilities for product development. The study shows that in involvement type Design reuse, the supplier was consulted when selecting a standard component, i.e., at the lowest level of product and process novelty. In the other three types of involvement, suppliers are more involved in product development, which explains the occurrence of effects on design activities. Interestingly, product requirements uncertainty was the only uncertainty found in the involvement type New design. New design implies the highest degree of product and process novelty, which previous studies have suggested should contribute to higher levels of uncertainty (e.g. Tatikonda and Rosenthal, 2000). However, involvement types Design reuse and New design were the least represented in this study and thus provided the least amount of data, which could be a possible explanation for why less uncertainty was found.

Notably, project plan uncertainty was only found in involvement type Design for manufacturing. One possible explanation for this is that the products developed by the suppliers of the type Platform expansion involved a lower degree of novelty, as the products developed were extensions of the product platform. Ownership of the design, as is the case in the Platform expansion type, may also provide a sense of greater control when compared to Design for manufacturing, where one of the suppliers was involved in a new vehicle development program involving multiple interdependencies and novelty.

When comparing the effects of the manufacturing process uncertainty, the differences between the manufacturing processes and products developed in the various cases should be considered. For example, it could be that the unpredictability of a manufacturing process has a greater impact on uncertainty than the novelty dimension used to distinguish the different types.

Previous studies have recommended intensive communication and using information-rich media, such as face-to-face meetings, when uncertainty is high (Wynstra and Pierick, 2000; Yan and Dooley, 2013). Increased communication can mitigate the uncertainties emanating from customers' and suppliers' organizations, and to a certain extent, technological uncertainties. However, high technological uncertainty also requires several design cycles, prototyping, testing, or the use of more mature technologies (Shenhar and Dvir, 1996).

8 Conclusion

This paper focuses on uncertainties that SME suppliers experience depending on how they are involved in customers' product development projects as well as the potential effects of the uncertainties. Based on a case study comprising four suppliers, different types of uncertainties originating from the customer organization, technology, and supplier organization and their effects were identified. To compare and contrast the uncertainties for different involvement types, a model for classifying different types of supplier involvement in product development was developed.

8.1 Theoretical and Managerial Implications

There is extensive research on supplier involvement (Johnsen, 2009; Suurmond et al., 2020) as well as research on uncertainty in product development (Lasso et al., 2020; Stock et al., 2021). However, less research has been carried out that combines the two fields. Therefore, the study presented in this paper contributes to the literature with new insights regarding different uncertainties that may exist in different relationships between customers and suppliers, here referred to as different types of involvement. The study makes two key contributions. First, it introduces a classification model for identifying different types of supplier involvement in product development. Second, it describes the uncertainties that SME suppliers experience in customer product development, their origins, and their effects. In essence, the study supports that uncertainties in supplier involvement in product development are interrelated (Eslami and Melander, 2019) and that it is important to have well-functioning information sharing and collaboration both internally at a supplier and externally with customers. It also emphasizes the importance of such information sharing and collaboration for both the product and the manufacturing process because of their interdependencies. This is illustrated by the study where internal handover uncertainties originating from the supplier's organization led to uncertainty about customer orders, including product requirements, which indicates that there is a link between product requirements and internal handover uncertainty.

The study also has managerial implications. Although uncertainty is inevitable in product development (O'Connor and Rice, 2013), the study shows that some of the uncertainties associated with the product requirements could have been avoided with a better understanding of the supplier's need of information, as shown in the involvement type Design reuse. The suppliers involved according to Design for manufacturing were in favor of early involvement to ensure that the suppliers had the necessary information. In their experience, they receive critical information about the product to mitigate uncertainties about product requirements if they are involved early in the project. It can be beneficial to get the information over a longer period of time rather than summarizing it at a later stage. The study also shows the importance of the handover of information about product requirements between the supplier's different organizations. Prior research has shown that many SMEs have problems managing requirements because there are no well-defined processes (Schmidt-Kretschmer et al., 2007). Checklists and processes can facilitate the capture of product requirements and clarify responsibilities (Flankegård et al., 2023). Therefore, this study recommends that managers ensure that processes are established for internal communication of product requirements. The classification model for supplier involvement in product development types can also provide a structure for assessing the novelty and change from a design and manufacturing perspective early in the project. Involving those responsible for design and manufacturing in discussing the changes and novelty from different perspectives could provide a mutual understanding of the challenges ahead and an awareness of the integration needed in the development project.

8.2 Limitations and Further Research

This study is limited by its focus on SME suppliers' involvement in their customers' product development. Four different involvement types were identified in the study, but the classification model for supplier involvement in product development indicates the existence of other involvement types. Therefore, it would be interesting to include companies of different sizes, other types of customers, and product development projects, including more novel products and process technologies, to understand whether there are other involvement types, uncertainties, and effects. The relationships between customers and suppliers may be classified in different ways, which means that there are various ways to classify involvement. Hence, further studies could have a closer look at how involvement is classified and potentially use a more nuanced classification to study types of involvement and implications for uncertainties. That is, the classification of supplier involvement types used in this study can be developed. For example, it may be useful to study whether dimensions other than product and process change have a greater impact on uncertainty.

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