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How to Identify Possible Applications of Product Configuration Systems in Engineer-to-Order Companies

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Abstract *Product configuration systems (PCS) play an essential role when providing customised and engineered products efficiently. Literature in the field describes numerous strategies to develop PCS but neglects to identify different application areas. This topic is particularly important for engineer-to-order (ETO) companies that support gradual implementation of PCS due to large product variety and, several times, higher complexity of products and processes. The overall PCS process can thereby be broken down, and the risk minimised. This paper provides a three-step framework to identify different applications of PCS including the following steps: (1) identifying potential PCS, (2) aligning IT development, and (3) establishing an overview of PCS application. The study is supplemented by results from a case study in which the proposed framework was tested. The results from the testing confirm that the framework is applicable, as it leads to strategic and smart decisions regarding the implementation of PCS.*

Keywords: product configuration systems (PCS), *engineering-to-order (ETO) companies, applications*

1. INTRODUCTION

In response to increased global competition, companies are pressured to improve the capabilities of their products without compromising on price and time of delivery [1]. To cope with these challenges, companies are applying mass customisation strategies to greater extent.

Mass customisation strategies are applied both to mass producers that aim to increase variety and to engineering-to-order (ETO) companies that aim to increase the standardisation of their product offerings without limiting their customers. Product configuration systems (PCS) are a key element for achieving the benefits of mass customisation strategies [2] and represent some of the most successful applications of artificial intelligence [3]. PCS support in the product configuration process, which consists of activities that involve gathering information from customers and generating the required product specifications [4,5].

The literature describes numerous benefits that can be gained from implementing PCS, including preservation of knowledge, use of fewer resources, less routine work, reduced lead time, improved quality, and improved certainty of delivery [1,5–7]. However, there are also several challenges, such as applying PCS to complex products that become more expensive than anticipated and suffer from lack of acceptance due to insufficient scope [8]. For highly complex products with a large solution space, it can be infeasible to include all the requirements, as they can be very customer specific [9,10]. Other challenges include lack of documentation [11], updates and maintenance, knowledge acquisition, testing of knowledge, high dependency on configuration experts, and specification errors [12].

The implementation process for PCS is highly dependent on companies' manufacturing strategies and the degree of customisation. The degree of customisation offered by companies can be determined based on the customer order decoupling point, or the time when the customer becomes involved in the customisation process [1]. External factors such as dynamism in market and customer demands can also push these companies towards higher degrees of product customisation [13].

Traditional order fulfilment strategies, a highly characterizing component of the manufacturing strategies, are ETO, make-to-order (MTO), assemble-to-order (ATO), and make-to-stock (MTS) [14]. As there is no product customisation in MTS companies, this paper does not address them further. In MTO and ATO companies, there is a defined solution space where modules and components are combined according to pre-defined constraints. Solution space includes all the product attributes a company offers to cover diverse customers' needs [15]. The solution space is undefined in ETO companies and thus the number of possible configurations can be close to infinite [3]. PCS in ETO companies are, therefore, created with a high level of abstraction, as it can be too time consuming to define the solution space in a more detailed way [16]. Furthermore, due to the undefined solution space and the complexity of processes and products, multiple PCS are often implemented [17] to support specific parts of the sales and engineering processes. This raises challenges in identifying and prioritising different projects when implementing PCS in ETO companies.

The current literature describes different strategies for the development of PCS [1,5,8,18,19] but neglects to identify different applications for PCS. This is the step before the development process where potential PCS are identified, and it is especially important in ETO because of the vast product variety and process complexity that result in numbers of PCS. Thus, identifying the possible applications of PCS in a structured way is important to align the stakeholders and prioritise PCS projects. This paper aims to contribute to the literature and help practitioners by providing a framework that ETO companies can use to identify different applications of PCS. More specifically, this paper aims to answer the following research question (RQ):

How can ETO companies identify possible applications of PCS?

A framework based on the experience of the research team and the literature in the field of PCS is proposed to answer the RQ. The study then validates this framework in a case study within an ETO company.

The remainder of the paper is organised as follows: Section 2 discusses the relevant literature, and Section 3 explains the research method. Section 4 proposes the framework. Section 5 presents the results from the case study. Section 6 discusses the results, presents the conclusions, and provides a direction for future research.

2. LITERATURE REVIEW

The literature is divided into three sections. Section 2.1 elaborates on the structure of PCS and interactions with other IT systems. Section 2.2 discusses the application of PCS. Section 2.3 describes development strategies for PCS and highlights the research gap.

2.1. **Structure of PCS and integrations**

The underlying IT structure of a PCS consists of configuration knowledge representation and reasoning, conflict detection and diagnosis, and, finally, a user interface [20]. The knowledge base, which represents the actual product data and the configuration logic, is the most fundamental technical component of PCS [3]. The configuration processes for complex products can be overwhelming in terms of the number of solutions that can be selected, and this can result in optimal solutions being ignored [21]. Therefore, a recommendation system is suggested in the IT architecture [21]. These recommendation technologies can be integrated into the PCS to support the end-user in the configuration process [22].

PCS can be applied as standalone software and as data-integrative and application-integrative systems [3]. Data-integrative PCS can be used to avoid data redundancies, as application-integrative PCS allow communication across different applications (e.g., CAD drawings can be generated from the output of the PCS) [3]. In terms of data integration for PCS, common sources for master data can be found in Enterprise resource planning (ERP) systems that often define a production-relevant view of the material. This is required for the assembly process and for product data management (PDM) and product lifecycle management (PLM) systems. It is also used for maintaining production-relevant data and for product information management (PIM) systems used to maintain sales-relevant data [19].

Different PCS can be integrated to increase the level of automation in the overall process (commercial and technical PCS, for example) [5]. Finally, PCS can be integrated into suppliers' systems to retrieve the required data from the configuration processes [23,24]. Numerous have explored the hypothesis that "the higher the degree of integration across the supply chain, the better a company performs" [25–28]. Having PCS integrated across supply chains (e.g., retrieving the information directly from suppliers in the configuration process) increases the accuracy of the specifications of highly customised products [17].

2.2. **Application of PCS**

The product configuration process can be defined as "all the activities from the collection of information about customer needs to the release of the product documentation necessary to produce the requested variant" [5]. The overall product configuration process can then be divided into sales and technical configuration processes [29]. The sales configuration process identifies products that fulfil customers' needs and determines the main characteristics of the products [29]. The technical configuration process generates documentation for the product based on the input gathered during the sales phase [29]. Customers may use PCS as a system that allows them to configure a product (e.g., on the Internet) and visualise the changes and impacts of specific selections. Alternatively, the system can be used as an internal tool to support the company's employees during the product configuration process [3].

The configuration process is more complex in ETO companies than in MTO and ATO companies due to the defined solution space [3]. PCS in ETO companies are normally used for design on a high level of abstraction, as defining the solution space on a more detailed level can be extremely time consuming [16]. This is in contrast to the solution space in MTO and ATO companies, which is better defined for different product configurations and enables detailed designs to be generated in the sales phase [1]. PCS can generate quotes for more detailed designs in MTO and ATO companies than it can for ETO companies [30]. The main output types generated by the PCS can divide the process of generating the products' specifications into three phases: (1) initial specification, (2) further product specification, and (3) quote creation [16]. Figure 1 illustrates how the level of detail for the PCS can be determined based on the output generated.

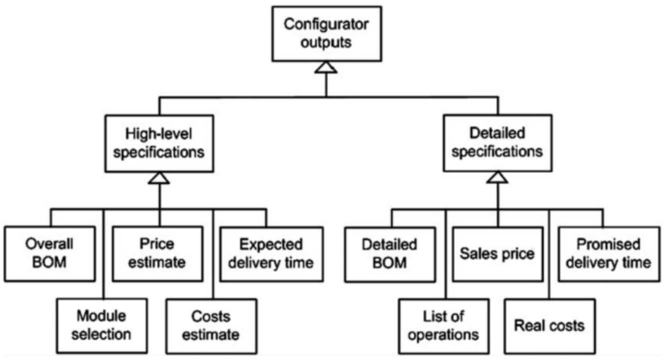

Figure 1. The main output from the PCS and level of detail required [16].

2.3. **Development strategies for PCS projects**

Studies in the field of PCS have proposed frameworks to guide the development of PCS projects [1,5,8,18,19]:
Shafiee et al. [18] propose a framework for scoping PCS projects in ETO companies. The framework helps companies to identify the users, IT architecture, prioritisation of products and product features, and project plan.
Haug et al. [8] have defined strategies for PCS in ETO companies by focusing on the involvement of different experts (product, knowledge representation, and configuration software) in the development and implementation processes of PCS.
Felfernig et al. [19] propose a development strategy based on the standard Unified Modelling Language (UML) design language to develop and cope with increasing complexity of the knowledge base. The three main components of the configuration environment are defined as knowledge acquisition, configuration, and reconfiguration. The authors propose a diagnosis at each stage [19].
Hvam et al. [1] provide a seven-phase framework that includes analysis and redesign of business processes, modelling of the product range, selection of PCS software, and modelling, implementation and maintenance of the plan.
Forza and Salvador [5] provide guidelines for the implementation of PCS, including benefit and cost analyses, planning of the implementation processes, and aligning the execution of the implementation with best practices.
These frameworks aim to increase efficiency of PCS projects, but none provides guidelines on how to identify different applications for PCS. In addition, only two of the frameworks mentioned above [8,18] are specifically aimed at ETO companies. Authors of a few studies [1,5,19] propose comprehensive frameworks that describe different processes involved in PCS projects. However, the literature does not provide instructions on how to identify different applications for PCS. As mentioned previously, this is especially important in ETO companies due to vast product variety and complexity. Thus, there is a need to create a structured framework to identify different applications for PCS in ETO companies.

3. RESEARCH METHOD

The research method in this paper is structured in two phases. The first phase explains the development of the framework that aims to provide a structured approach to identify different applications for PCS in ETO companies (Section 3.1). The second phase explains the validation of the framework that was achieved with a case study of an ETO company (Section 3.2).

3.1 **Framework development**

The framework is based on the literature in the field of PCS and the experience of the research team. More specifically, the literature enabled a better understanding of (1) PCS and their interaction with other IT systems, (2) application of PCS with a special focus on ETO companies, and (3) development strategies for PCS. The literature provides an input for the individual steps of the framework. The framework was developed in an iterative process and was improved based on feedback from the case company and discussions within the research team.

3.2 **Validation of the framework**

To validate the framework, a case study was conducted in an ETO company. A case study was selected for this purpose to allow this phenomenon to be studied in its natural setting [31]. Case studies also provide researchers with a deeper understanding of the relationships between variables and phenomena that are not fully examined or understood [32]. Further, they can be used to understand IT-related innovations and organisational contexts [33].
The company selected for the case study has worked with PCS since 2012, and the PCS projects have been selected mainly based on stakeholders' interests. There are numerous possible applications of PCS in the company, but an overview and a clear framework for implementing PCS were lacking. The company was selected based on its alignment with the focus of this study: to identify different applications of PCS in ETO companies.
To validate the framework, a project team was formed that included both researchers and the manager of the configuration team at the case company. The research team organised five workshops over a five-month

period, each of which lasted an average of 1.5 hours. The first two workshops aimed to apply the proposed framework to the company's settings to identify different applications of PCS. These two workshops resulted in a report that drew on the proposed framework steps to demonstrate different PCS applications for the company.

These results were presented to the managers of the IT department in the third workshop. Feedback received at this stage was used to improve the generated report.

In the fourth workshop, the revised results were presented to managers of the different business units (BUs) at the company. Approval to further involve employees, which was needed to verify the proposed applications of the PCS, was received in this workshop.

In the fifth workshop, managers at different levels from one of the BUs identified possible application areas for PCS. A valuable discussion arose among the managers. The first draft of the overall configuration process was aligned according to feedback received from these discussions. The final version of the report was then sent to all workshop participants for approval.

Section 5 provides examples of the results from the individual steps of the framework. Following the case study, we revised the framework—including a realignment of the proposed steps—to increase its clarity.

4. FRAMEWORK

This research proposes a three-step framework to guide the implementation process of PCS in ETO companies. The framework builds on related research fields and attempts to include the main aspects that must be considered when identifying possible applications of PCS in ETO companies. The steps of the proposed framework are: (1) identifying potential configurators, (2) aligning IT development, and (3) establishing an overview of PCS applications. Figure 2 shows the steps of the framework. The following sections provide further details of the individual steps.

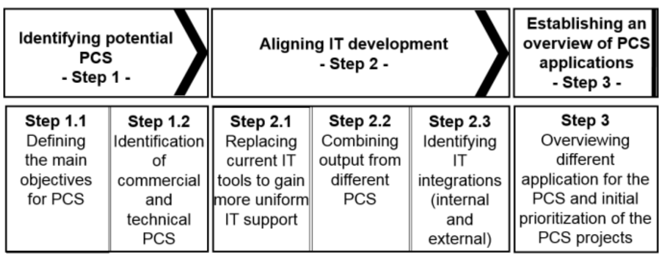

Figure 2. The proposed framework to identify applications of PCS.

4.1 **Step 1: Identifying potential PCS**

Step 1 aims to identify potential PCS. This step is divided into two sub-steps: step 1.1 defines the main objectives for PCS, while step 1.2 identifies potential PCS (commercial and technical).

4.1.1 *Step 1.1: Defining the main objectives for PCS*

The literature describes numerous benefits achieved from using PCS, including reduction of man-hours and lead time when making product specifications [4,9,12,16], improved quality of product specifications [4,12,34,35], more on-time delivery [4,34,36], improved control of product variants [1,4,29,34,36], increased sales [30,37], improved knowledge management [4,30,38], improved accuracy of cost calculations, and, thus, increased profitability [39]. It is important that the objectives or benefits to be achieved are clear from the start, as they influence decision-making when evaluating commercial and technical PCS separately (Section 4.1.2) and when evaluating the complete overview of different PCS applications (Section 4.3.1).

4.1.2 *Step 1.2: Identifying commercial and technical PCS*

In this step potential PCS to support both the sales and engineering processes, or commercial and technical PCS [29] are identified. The objectives determined in step 1.1 serve as guidelines in this process. The following questions can be used as guidelines but can change depending on the objectives defined.

- Where are a considerable number of man-hours used when making product specifications?
- Are there quality issues related to specific product specifications?
- Where are the long lead times or bottlenecks? (For example, long waiting times can result from lack of work on product specifications, redesign loops, and lack of information).
- When are critical decisions made to avoid unnecessary complexity and increased cost?
- When are there delays (e.g., late delivery)?
- Where are there deviations between estimated and realised costs?

4.2 Step 2: Aligning IT development

Step 2 aims to provide an understanding of current IT systems used to generate product specifications, interactions across PCS, and other IT system interactions with PCS. This step is divided into the following three steps: 2.1 replacing current IT tools to gain more uniform IT support, 2.2 combining output from different PCS, and 2.3 identifying IT Integrations (internal and external).

4.2.1 *Step 2.1: Replacing current IT tools to gain more uniform IT support*

This implies a more standardised way of applying the IT systems needed to generate proposals and different product specifications. Actions can include replacing current tools or IT systems (e.g., Excel sheets) to create more uniform IT support for generating product specifications. This, in turn, allows for interactions across PCS used in different departments, as explained in Section 4.2.2. More uniform IT support can also be valuable in terms of: maintenance, user acceptance, and quality [39].

4.2.2 *Step 2.2: Combining output from different PCS*

Combining different PCS [1,5] means that different PCS within a company can interact. This helps to avoid data redundancy, as the same information does not have to be included in multiple PCS. Combining different PCS also streamlines the communications across different departments, where the PCS are used as platforms to exchange data and to give input (e.g., sales to engineering, and vice versa). This also implies that the outputs from one PCS are used as inputs for the other PCS (e.g., sequential process such as pre-sales, sales and engineering).

4.2.3 Step 2.3: Identifying IT integrations (internal and external)

The configuration process is highly dependent on retrieving information from both internal and external IT systems. Redundancy can be avoided by having integrations with other IT systems [3]. This step is thus concerned with identifying required IT integrations, both internal and external, in the configuration processes. Internal integrations include IT systems used within the company. These can include CAD, ERP, PDM, and PLM [1,3]. External IT systems integrations can retrieve information (prices, sizing parameters, etc.) needed during the configuration process from a supplier's database or even a PCS [17,23,24].

4.3 **Step 3: Establishing an overview of PCS applications**

Step 3 draws on analysis of the previous steps to establish an overview of different applications for PCS and create an initial prioritisation of the identified PCS.
This step takes into account the analysis performed in the previous two steps. The company's complete specification process is mapped based on the analysis performed in steps 1 and 2. This should provide a clear overview of how the specification process can be supported with PCS. After the overview is established, the overall specification process is evaluated based on the objectives defined in step 1.1. This provides initial input for the prioritisation of the identified PCS.

5. CASE STUDY

The case company is a world leader in catalysts and surface science. It offers a variety of catalysts and a complete range of proprietary equipment, spare parts, and consumables. The first PCS in the company was launched in 2013; since then, five new PCS have been introduced. The PCS cover some of the main product categories offered, such as catalysts, equipment, and processing plants. The approach of expanding the application of PCS has focused primarily on implementing new PCS, with little consideration for creating an optimised workflow based on overall objectives and aligning the different stakeholders. This approach served its purpose by quickly establishing the application of PCS and demonstrating the benefits the company can achieve. As the company recognised its expansion of PCS applications, an overview of the specification process was required where the potential PCS were identified. The results of implementing the individual steps of the framework at the case company are presented in the following sections.

5.1 **Step 1: Identifying potential PCS**

5.1.1 *Step 1.1: Defining the main objectives for PCS*

This step provides an understanding of the main objectives to be achieved from using PCS. The objectives are based on discussions with different stakeholders in the company and their experiences using PCS.
The case company has a high-level focus on increased digitalisation and automation of the sales and engineering processes. The following are the main objectives the company aims to achieve from increased use of PCS:

- Reducing routine work in the sales and engineering processes
- Decreasing the lead time to generate proposals and other specifications
- Increasing the hit rate as a result of shorter lead time to respond to customers' requests
- Improving the quality of the product specifications by reducing errors and increasing accuracy
- Empowering the global sales offices to generate product specifications

The importance of these individual objectives differs from project to project. For instance, a processing plant with a very low sales rate would invest in PCS to empower sales offices around the world and extract implicit knowledge from employees to make the information more explicit. The objectives are determined at the company level. However, since the following analysis was conducted on the BU level (as explained in Section 3.2), the following examples from the case study are based on one of the BUs.

5.1.2 *Step 1.2: Identifying commercial and technical PCS*

In this step, the sales and engineering processes were analysed based on the objectives in step 1.1 to identify processes where PCS can add value.
The BU already uses one commercial PCS that supports the sales process. The analysis revealed three potential new PCS: one commercial PCS and two technical PCS. Using both commercial and technical PCS enables the engineers to base their work on the output from the commercial PCS and to further work with the data inside the technical configurator. This optimisation of workflow means that the relevant data for configuration is stored in a single system: a setup that allows both sales persons and engineers to work in a more optimal way. Figure 3 summarises the setup of the users, output documents, and interactions between the commercial and technical PCS identified. The interactions between the PCS are further discussed in step 2.2.

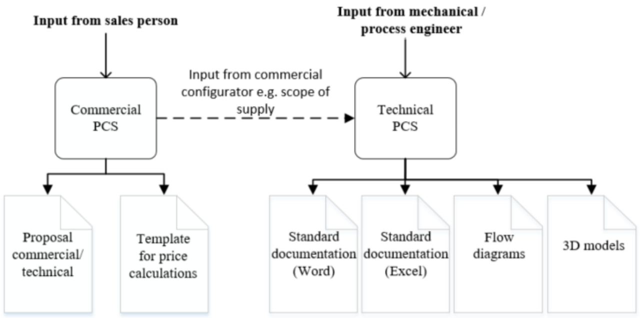

Figure 3. Setup for the identified commercial and technical PCS.

5.2 **Step 2: Aligning IT development**

5.2.1 *Step 2.1: Replacing current IT tools to gain more uniform IT support*

This step establishes an overview of different IT systems used to create product specifications with the aim of gaining more uniform IT solutions to support the sales and engineering processes.

The analysis revealed three Excel-based tools used in the sales process to generate quotations. These tools number more than 30 in the engineering processes. The reason for so many Excel-based tools is that specification processes are designed on a component level. In almost all cases, the Excel-based tools used by the engineers have interfaces to interact with other IT systems (e.g., calculation and simulation tools, CAD). They require expert users and are very department specific. This means that cross-department input requires an expert user in that department to operate the Excel-based tool.

The identified PCS (Section 5.1.2) can replace some of the Excel-based tools used to generate product specifications. The commercial PCS can replace the three Excel-based tools used in the sales process. The two technical PCS are not able to replace all Excel-based tools, but they can reduce them by about 80%. The reason for incomplete replacement is that the requirements in about 20% of the cases are too complex to include in the PCS.

5.2.2 *Step 2.2: Combining output from different PCS*

This step focuses on listing dependencies across departments, data sharing, and identifying how PCS support that process.

The analysis revealed great dependency across the different departments. When a project/plant is sold, input data for different equipment are required from the relevant sales departments. This requires stakeholders to attend time-consuming meetings; often, the input data is received late. In response, a project/plant commercial PCS that can retrieve information from the other departments was identified. Figure 4 shows the interactions between the identified project/plant PCS and the other commercial PCS used for equipment configurations.

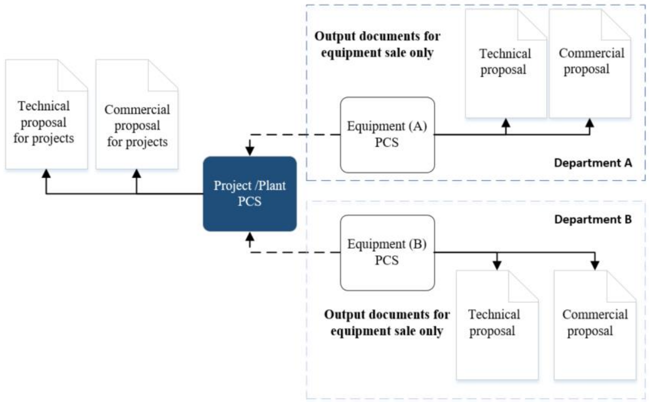

Figure 4. Generating output documents using information from PCS across departments.

5.2.3 *Step 2.3: Identifying required IT integrations (internal and external)*

This step lists the different IT systems used in the BU and includes descriptions of how those IT systems are used.

The company has already established some essential integrations for the commercial PCS already in use. These include integrations to databases storing information related to previously sold equipment and software performing both complex calculations and simulations. Other minor integrations are also established (e.g., to retrieve an updated currency rate). The analysis in this step reveals the following IT system requirements for interacting with the PCS:

- Integrating the commercial PCS to an ERP system to retrieve information related to customers and cost
- Integrating the technical PCS to a CAD system to generate 3D models
- Integrating the commercial PCS in the company with the *suppliers' systems* to ensure that information is up-to-date and to eliminate the need for manual adjustments

5.3 **Establishing an overview of PCS applications**

The overview was generated in a workshop where the results of the previous steps were presented to the managers of the BU. The results provided a guideline to draw up a figure that the managers could agree on. Figure 5 shows a simplified version of the overview. Additionally, based on how the PCS contributed to the overall objectives, the BU managers could make the initial prioritisation of the different PCS.

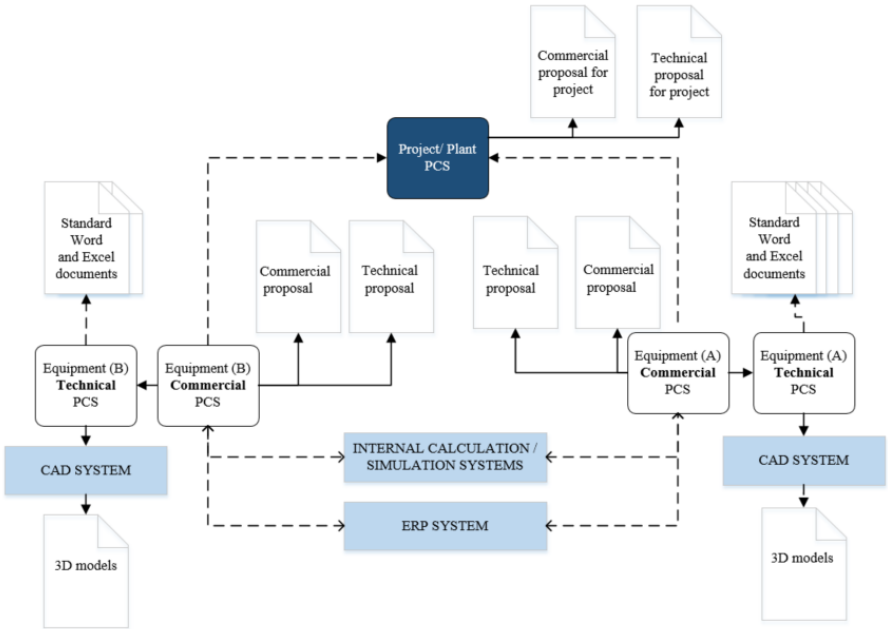

Figure 5. Simplified overview of how the sales and engineering processes can be supported by PCS and other IT systems.

By involving BU managers in the process of creating this overview, a common understanding and ownership were established regarding the application of PCS. Having managers within the BUs on board is defined as a key success factor in achieving the objectives of the PCS.

The results of applying our framework to the company and establishing an overview of different PCS applications led to additional work to support expansion of the PCS. This included defining how testing, maintenance, and user support should be designed. Furthermore, recourse was considered for the configuration team to ensure they would have the capacity to implement the potential PCS identified. A governance structure and a commitment of business resources were also defined. Finally, collaborations with external actors were discussed to share knowledge across ETO companies and to stay up-to-date on the newest developments in the area.

6. DISCUSSION AND CONCLUSION

In many cases, ETO companies are characterised by high product and process complexity. PCS used in ETO companies are often designed with a high level of abstraction due to a large solution space [16]. The configuration process can be divided into sales and technical processes, and corresponding commercial and technical PCS can be used to support those processes.

While the literature describes different development strategies [1,5,8,18,19], these frameworks do not provide guidelines for identifying different applications of PCS. This type of framework is especially important in ETO companies because projects with high complexity require gradual implementation of PCS [10]. The complexity in ETO companies results in multiple PCS. This paper contributes to the literature of PCS and managerial practice by proposing a framework to identify different applications of PCS in ETO companies to guide the implementation process.

Following a structured method of identifying different applications of PCS in ETO companies helps companies with strategic planning when justifying their investments in PCS projects, as they can demonstrate different PCS applications. This helps to align the main stakeholders, as they have a common understanding of different possibilities of using PCS. Furthermore, this method provides an overview of the complete product specification process that can be supported with multiple PCS and the required integrations with other IT systems. With a complete overview of the configuration process, optimised workflow can be established and different PCS projects can be prioritised.

The proposed framework to identify different applications of PCS is based on both literature and experience of the research team. The framework consists of three main steps: (1) identifying potential PCS, (2) aligning IT development, and (3) establishing an overview of PCS applications.

The framework is validated through a case study in an ETO company. The case company had already introduced commercial PCS with the aim of supporting the sales process. However, the company recognised that they needed an overview to further expand the application of PCS. The results of the case study show that the framework provided a structured approach for this purpose. The framework also gave the main stakeholders a common understanding of the overall objectives of PCS in terms of implementation and the initial prioritisation of projects. The process of creating this overview proved beneficial, as the stakeholders were able to express their opinions and take ownership of the projects. The involvement of relevant people thus led to strategic and smart decisions.

Even though the proposed framework is successfully validated in an ETO company, the authors of the paper recognise the limitations of having only one case study. Further studies should therefore include testing the proposed framework in other ETO companies. This should also include companies that have not introduced PCS. We decided to focus on ETO companies because they cover both process and product complexity. Future studies will also validate if the proposed framework can be used in companies with different manufacturing strategies and degrees of customisation.

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