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FRAMEWORK FOR INVESTIGATING POSSIBLE AREAS TO APPLY PRODUCT CONFIGURATION SYSTEMS FOR ENGINEER-TO-ORDER PRODUCTS

Qingsong Zhao [ORCID 0009-0001-4725-5460], **Lars Hvam** [ORCID 0000-0002-7617-2971]
Technical University of Denmark, Department of Civil and Mechanical Engineering, Kongens Lyngby, Denmark

Abstract: *This article suggests a framework for investigating possible areas to apply Product Configuration Systems (PCS) in Engineer-to-Order(ETO) companies to support the engineering processes of ETO products. The framework includes the following steps: identifying which parts of the product to focus on (e.g., types of equipment, level of detail), analyzing the corresponding current engineering processes, and establishing critical future goals for these processes, such as lead time, performance, costs, quality, and hours. Based on this analysis, a rough scope and business case are developed for each potential area of application. The next step includes modeling and creating prototypes of configurators to further facilitate the discussions and decisions regarding the development and implementation of PCS. This framework was tested in an engineering company that designs production systems for the pharmaceutical industry. The case study demonstrated that it is feasible to utilize this framework for creating and comparing multiple PCS for different applications, thereby supporting the company's investigation into where and how to apply configurators effectively.*

Key Words: ***Engineer-to-Order, Product Configuration System, Framework, Investigation***

1. INTRODUCTION

Many companies experience increasing demands for the delivery of customized products without compromising on delivery time, price, and quality. Mass customization has emerged as a key strategy to address this challenge (Hvam, Mortensen and Riis, 2008). To realize the benefits of mass customization, Product Configuration Systems (PCS) have been identified as essential enablers (Victor and Boynton, 1993). PCS are designed to combine predefined modules in a product according to a series of constraints, utilizing constraint-based programming (Hvam, Mortensen and Riis, 2008). The literature documents numerous PCS implementations in Engineer-to-Order (ETO) companies, highlighting the potential to streamline processes and achieve various benefits (Hvam, 2006; Hvam, Mortensen and Riis, 2008; Haug, Hvam and Mortensen, 2011; Wehlin *et al.*, 2021). However, the undefined solution space in ETO can result in an almost infinite number of configuration possibilities (Blecker *et al.*, 2004). To address this challenge, this study aims to develop and test a framework that assists ETO companies in effectively investigating where to use PCS in their products. By providing a structured framework, this research aims to facilitate more efficient PCS investigation phases for further development and implementation.

The paper is structured as follows: Section 2 reviews related literature within ETO and PCS, Section 3 outlines the research methodology, Section 4 describes the framework, Section 5 presents a case study and findings, and Section 6 discusses the implications and conclusions.

2. LITERATURE REVIEW

2.1 ETO

Companies have different strategies to achieve mass customization based on the position of the customer order decoupling point (CODP). The position of the CODP in the value-added material flow typically defines four types: Engineer-to-Order (ETO), Make-to-Order (MTO), Assemble-to-Order (ATO), and Make-to-Stock (MTS) (Rudberg and Wikner, 2004). Focusing on the specification process and the position of the CODP, four types of specification processes are defined: Select Variant (SV), Configure-to-Order (CTO), Modify-to-Order (MTO), and ETO (Hvam, Mortensen and Riis, 2008), as illustrated in Figure 1. The ETO process usually requires a considerable amount of work in design and specification to fulfill customer requirements. The MTO process is less complex and involves the creation of a product based on pre-defined modules and clear rules. The CTO process utilizes configuration systems to automate the specification process within a finite solution space. In the SV process, customers select variants of standard products based on their requirements (Hvam, Mortensen and Riis, 2008).

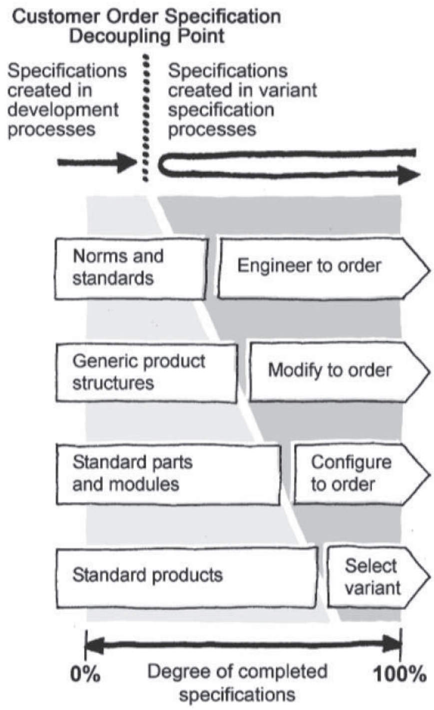

Fig. 1. *Different types of specification processes* (Hvam, Mortensen and Riis, 2008).

Based on degrees of engineering complexity and average annual units sold, Willner et al. (Willner *et al.*, 2016) identify four archetypes of ETO: complex, basic, repeatable, and non-competitive ETO. The study suggests standardization and automation strategies for each type and indicates that standardization can exist across all four types. Johnsen et al. (Johnsen and Hvam, 2019) also provide cases of ETO projects and products that can include a mix of standard modules or parts, modified components, and completely new modules or parts. Lu et al. (Lu *et al.*, 2009), considering the characteristics of parts in ETO products and the internal design processes of ETO companies, introduce the postponement design decoupling point (PDDP) to classify parts into various design types: ETO_{ETO}, MTO_{ETO}, ATO_{ETO}, and STO_{ETO}.

2.2 Application of PCS in ETO

PCS support the configuration process, which includes activities from collecting customer needs to releasing the product documentation necessary to produce the requested product variant (Forza and Salvador, 2002). PCS are widely developed and used in the manufacturing industry (Haug, Hvam and Mortensen, 2012; Shafiee, Hvam and Bonev, 2014). Haug et al. (Haug, Hvam and Mortensen, 2011) describe that PCS typically are used for high-level design in ETO companies because it would be extremely time-consuming to define the solution space at a detailed level. In contrast, PCS for detailed-level design during the sales phase are often used in ATO companies. Wehlin et al. (Wehlin *et al.*, 2021) explain that PCS can be employed for detailed-level design through two modules: The first is a sales configurator for generating accurate quotations based on customer requirements. The second is an enterprise-wide configurator for optimizing accepted orders for final design and production. These two types of configurators are also referred to as commercial configurators and technical configurators (Haug, Hvam and Mortensen, 2011).

2.3 Frameworks of developing PCS in ETO

Serval studies have proposed frameworks for developing PCS in ETO companies (Hvam, Mortensen and Riis, 2008; Shafiee, Hvam and Bonev, 2014; Kristjansdottir, Shafiee and Hvam, 2015, 2016, 2017). Hvam et al. (Hvam, Mortensen and Riis, 2008) provide a seven-phase framework that includes the analysis and redesign of business processes, product range modeling, software selection, and the modeling, implementation, and maintenance of the plan. Shafiee et al. (Shafiee, Hvam and Bonev, 2014) present a framework for scoping PCS in the initial phase, including identifying users and requirements, defining input and output, determining functionalities, and integrating product knowledge. Kristjansdottir et al. have presented three strategies: a framework for utilizing PCS for critical parts of engineering processes, which includes identifying operational objectives and critical processes, analyzing these processes to determine the most promising scenarios, and prioritizing future PCS projects (Kristjansdottir, Shafiee and Hvam, 2015); a framework for developing and implementing PCS, which involves setting objectives, choosing the right PCS for sales and engineering processes, ensuring uniform IT support, integrating PCS outputs across departments, and linking internal and external IT systems (Kristjansdottir, Shafiee and Hvam, 2016); and a framework for identifying potential applications of PCS, which consists of identifying potential PCS, aligning IT development, and establishing an overview of PCS applications (Kristjansdottir, Shafiee and Hvam, 2017).

Previous studies have provided several frameworks or guidelines for identifying different applications of PCS for the development and implementation of PCS in ETO companies. However, these studies often do not differentiate between various ETO products and their parts. There is also a need for a framework that assists ETO companies with limited experience in PCS in investigating where to apply PCS for complex ETO products.

3. RESEARCH METHOD

The research method is divided into two sections: the first section outlines the development of the framework, and the second section demonstrates a test of the framework through a case study.

3.1 Development of the Framework

The first phase of the research focused on developing the framework based on literature in the fields of PCS and ETO. The literature provided a deeper understanding of ETO processes and products, PCS applications in ETO companies, and various development strategies for PCS in these companies. Additionally, the authors utilized their experience with different PCS projects in ETO companies and their knowledge of the case company to develop a comprehensive framework.

3.2 Test of the Framework

The second phase of the research involves applying the proposed framework within a case company, an ETO company that designs complex production systems for the pharmaceutical industry but has limited experience with PCS and has not implemented PCS in the past ten years. Multiple stakeholders in the company have expressed interest in applying PCS but lack clear guidance on where to start and where PCS can be implemented in their ETO products. Therefore, this company was selected because it aligns with the study's focus: assisting ETO companies in investigating where to apply PCS for complex ETO products.

To validate the framework, a project team comprising both researchers and employees from the case company was formed. The framework was applied by this team, and data for the case study was collected through semi-structured interviews with various stakeholders over a six-month project phase. The framework and the results generated from each individual step were presented to the stakeholders, and their feedback was used to refine and improve the framework.

4. FRAMEWORK

This paper proposes a five-step framework to assist ETO companies in investigating possible areas to apply PCS to support the engineering processes of ETO products, as illustrated in Figure 2. The steps are as follows: (1) Focus Identification, (2) AS-IS and TO-BE, (3) Scope and Business Case, (4) Model and Prototype, and (5) Evaluation and Decision. The following subsections will provide a detailed description of each step.

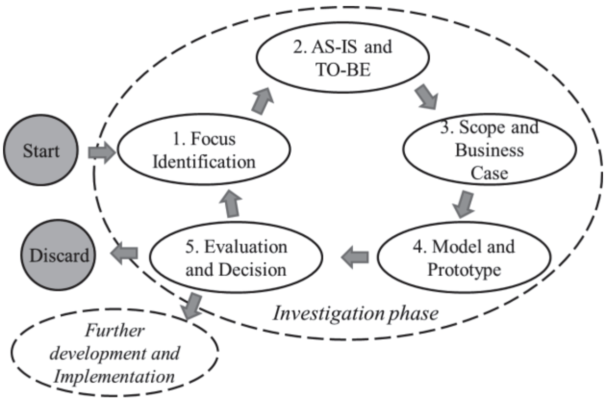

Fig. 2. *The proposed framework.*

4.1 Focus Identification

The first step aims to gain a clear understanding of the ETO product and its components and to identify which details and parts of the product to focus on. ETO products are inherently complex and consist of many detailed parts. To manage this complexity, dividing ETO products into various design types: ETO_{ETO}, MTO_{ETO}, ATO_{ETO}, and STO_{ETO} (Lu *et al.*, 2009) is recommended to support this step, as illustrated in Figure 3.

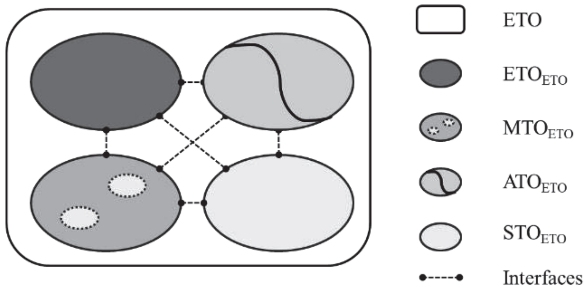

Fig. 3. *Design types in ETO products*

The following five aspects and questions can serve as guidelines for this step within the company:

1. Categorization
   - What design types do the parts in ETO products belong to?
   - What is the distribution of each design type?
   - What are common and uncommon?
   - What are critical for customers?
2. Variants and Complexity
   - How many variants exist within selected design types?
   - What are the most common and frequently used variants?
   - What key factors contribute to the complexity of variants?
3. Resources and Changes
   - How many resources are involved in engineering processes?
   - How often do design changes occur?
   - How many interfaces drive changes, and what are they?
4. Engineering Knowledge
   - How is engineering knowledge available and formalized?
   - How is engineering knowledge trained and shared across the company?
5. Strategic Alignment
   - Do selected variants/parts/products align with future demand?
   - What are the strategic priorities for the company?

These five aspects should be considered to identify which products, parts, or variants to focus on. The specific questions may be adjusted based on the particular context.

4.2 AS-IS and TO-BE

The second step involves analyzing the current engineering processes for the selected focus products, parts, or variants from the previous step, and setting future scenarios using PCS. To standardize the definition of current engineering processes, flow charts with Business Process Modelling Notation (BPMN) can be used to demonstrate communication between different actors and the tasks they perform (White and Derek Miers, 2008). This step provides companies with an overview of the current situation and the complication of the process, often referred to as the AS-IS process (Hvam, Mortensen and Riis, 2008).

Based on the analysis of current engineering processes, the benefits of using PCS can be formulated as targets for the TO-BE process. Hvam et al. (Hvam *et al.*, 2013) present observed benefits of using PCS in various companies, including lead time reduction, on-time delivery, resource consumption reduction, improved quality of specification, cost reduction, formalization of engineering knowledge, etc. These benefits can serve as the foundation for formulating the future TO-BE process, where PCS enhances specific processes to achieve the target benefits.

4.3 Scope and Business Case

The third step first involves setting rough scopes for the products. To limit the tasks of developing prototypes in the investigation phase, it is crucial to determine the appropriate level of detail and information to include in the prototype. This approach saves time and resources while demonstrating that most future targets can be achieved by PCS. Shafiee et al (Shafiee, Hvam and Bonev, 2014) present several questions to understand the level of detail in PCS, and these details and features are decided based on the necessary detail and accuracy of the PCS outputs.

Secondly, business cases are established by identifying key stakeholders and understanding costs and benefits. Shafiee et al (Shafiee, Kristjansdottir and Hvam, 2016) outline four steps for creating business cases for PCS projects. In this step, stakeholder analysis and cost-benefit analysis are emphasized due to their importance in the investigation phase. Based on the selected scopes, it is essential to first identify the actors involved and their requirements in the stakeholder analysis. MoSCoW rules are then used to prioritize the stakeholders' requirements based on: Must-have (Mo), Should-have (S), Could-have (Co), and Want-to-have (W) requirements (Bittner and Ian Spence, 2003). Cost-benefit analysis is used to compare the expected costs of PCS projects to the anticipated benefits for future scenarios outlined in the previous step. The costs of PCS projects include such as software licenses, as well as internal and external man-hours for modeling, programming, implementing, operation and maintenance of PCS projects (Shafiee *et al.*, 2023).

4.4 Model and Prototype

The fourth step includes modeling the selected scopes of focus products, parts, or variants and prototyping the PCS. A well-established modeling technique is the Product Variant Master (PVM) model. The PVM model normally contains three different views: the customer view, the engineering view, and the part view. The customer view describes the aspects of customers' interests, the engineering view provides the functional units and solution principles, and the part view presents all the physical objects that can integrate the final product (Hvam, Mortensen and Riis, 2008). However, engineering or design processes in ETO companies do not always include inputs from customers, and the engineering view often includes more than one discipline. To use the PVM model more inclusively, we suggest modifying the PVM model to include broader views: the input view, the knowledge view, and the parts view, as illustrated in Figure 4. The input view includes aspects of users' interests, the knowledge view presents solution principles and engineering knowledge used in PCS, and the part view presents all physical objects in the model. This modified PVM model accommodates various needs and ensures a more comprehensive representation.

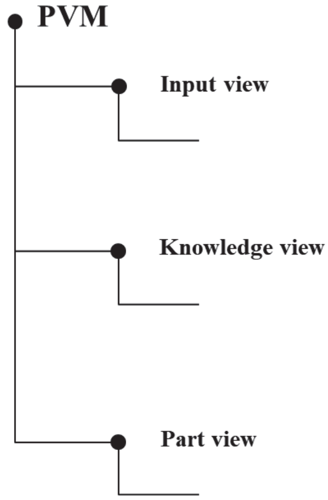

Fig. 4. *The modified PVM model*

The PCS prototype can be developed based on the PVM model, aligning with its input, knowledge, and part views. The output of the PCS is determined by the requirements identified in the stakeholder analysis conducted in the previous step, as shown in Figure 5.

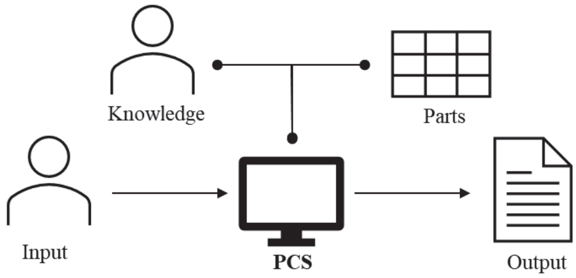

Fig. 5. *The concept of PCS*

The PCS prototype can be developed using various software options, including standard or non-standard software, depending on available resources. The PCS prototype can also be developed internally within the company or externally by vendors, based on specific circumstances.

4.5 Evaluation and Decision

The last step involves evaluating the prototype to ensure it meets predefined targets and stakeholder requirements. Feedback from all relevant stakeholders is crucial in this step for identifying any potential issues or improvements. Based on the comprehensive evaluation, incorporating results from all previous steps, a decision regarding the PCS prototype in the investigation phase is made. There are three potential decisions: further development and implementation of PCS, Reinvestigation with adjusted steps, and discarding the PCS prototype.

5. CASE STUDY

The framework was tested in a case company that offers complex ETO solutions for pharmaceutical machinery and facilities. Approximately ten years ago, the company attempted to implement PCS, but the effort was unsuccessful due to the extensive solution space that PCS could not effectively manage (Rohde, 2009). Since then, the company has not revisited PCS projects and has limited experience in this field. However, the company has expressed renewed interest in the application of PCS. To provide clear guidance on where to start and where PCS can be implemented, this framework was utilized to support the company in investigating possible areas for applying PCS to support their engineering processes. Data was collected from a case ETO product, a pharmaceutical production facility. The results of implementing the individual steps of the framework at the case company are presented in the following sections.

5.1 Focus Identification

To gain a comprehensive understanding of the ETO product, which is a pharmaceutical production plant consisting of various system levels, the levels of detail are categorized into process units, equipment modules, parts, and components, as illustrated in Figure 6.

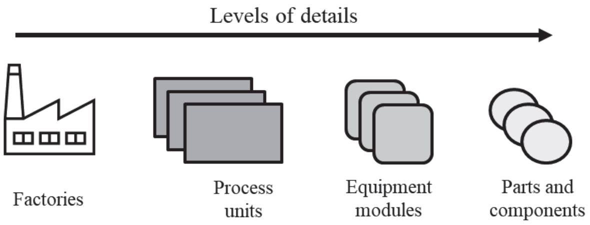

Fig. 6. *Levels of details*

The case company decided to initially start the investigation with parts and components, as this level of detail consumes a significant amount of engineering hours due to the numerous parts and components involved. Consequently, the contribution of parts and components to the ETO product was analyzed, categorizing them into different design types, as depicted in Figure 7.

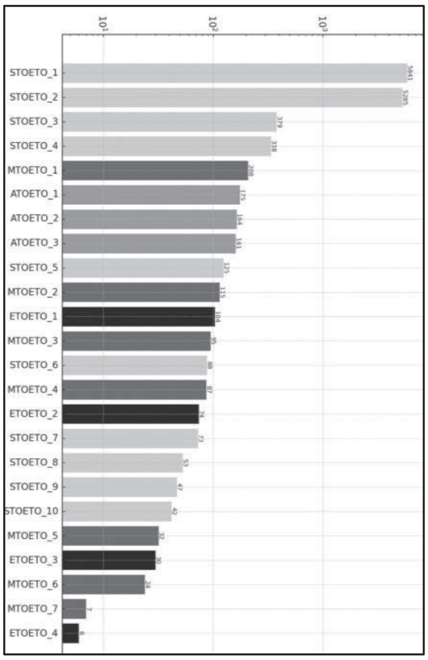

Fig. 7. *Counts of different design types*

Standard and uncomplicated parts that require minimal engineering efforts and are directly procured from vendors are categorized as STO_{ETO}. Parts that require some engineering hours for assembly into functional components are categorized as ATO_{ETO}. Parts that require significant engineering hours for adjustments and modifications during the design process are categorized as MTO_{ETO}. Lastly, parts that demand extensive engineering hours for in-house design and numerous alterations are categorized as ETO_{ETO}. These categorizations of design types may vary from case to case, and in some instances, more than one design type may coexist within one part. The case company has identified three interests that cover STO_{ETO} and ETO_{ETO}, and they are presented in Table 1.

Table 1. *Identified focuses*

	Focus 1	**Focus 2**
Design type	STO_{ETO}	ETO_{ETO}
Selected variant	STO_{ETO_1} and STO_{ETO_2}	ETO_{ETO_2}
Name	Valve and connection	Tank
Complexity	Low	High
Amounts	Around 10000	Around 70
Engineering Hours	0.5hr per piece	Many hours e.g. 50-500hr
Changes	Around 17.5%	Almost 100 % (Many iterations and changes)
Knowledge	Standard and Explicit	Tacit
Future Demands	High	High

Focus 1 involves standard components with accessible knowledge, and these components are numerous and repetitive, so they present significant potential for digitalization. Focus 2, on the other hand, involves highly customized parts that are crucial for the overall performance of completed ETO products. The knowledge required for designing these parts is tacit and varies between personnel. Implementing PCS for Focus 2 offers the potential to enable customization and standardize both the knowledge and processes involved. These two focuses both present potential high future demands as they have been used for a long time in the case company.

5.2 AS-IS and TO-BE

The current engineering processes for these two focuses were analyzed using BPMN diagrams. During the modeling process, several issues with the current processes were identified. For example, manual work on specification and documentation is common, leading to potential errors and long lead times, especially when more components or parts are involved. Modifications and changes are also frequently required due to customer demands or discovered errors. More effort is needed when these modifications or changes occur in the later stages of the process.

To address these challenges, two benefits of PCS were prioritized during the formulation of future scenarios: lead time and quality, as these factors are critical in the pharmaceutical engineering background of the case company. The main targets for future scenarios are improved lead time and high quality. The current processes versus future scenarios are presented in Table 2. This table highlights the expected improvements in lead time and quality with the implementation of PCS.

Table 2. *Current vs Future*

	Current	Future
Focus 1	Manual specification	Automation of specification
	0.5hr per piece	90% time saving
	Duplicate checks to ensure quality	Quality improved through digitalization
Focus 2	Manual design and documentation	Automation of design and documentation
	Tacit knowledge, different ways of working	Explicit knowledge and standard workflow with using one tool
	Repetitive and time-consuming work on updating the design	Less effort into updating the design

5.3 Scope and Business Case

To save time and resources in developing prototypes, while demonstrating most of the targets for future scenarios can be achieved by PCS in the investigation phase, the level of detail for the two focuses was narrowed down. Focus 1 was narrowed to a specific type of valve that is widely used and has well-structured information. Focus 2 was narrowed to a specific type of tank that is relatively easy to design and has minimal interactions with other systems.

Key stakeholders for each focus were identified, and their needs were analyzed during this step. For example, in Focus 1, mechanical component specification engineers were identified as the most important stakeholders since they contribute to the knowledge base and are potential users of PCS. Their Mo requirements include that the output of PCS must include the catalog ID of components, and their So and Co requirements include chemical classification properties and minimal input buttons, respectively. Another example in Focus 2, is that tank process engineers were identified as key stakeholders as they provide most of the requirements for tank design. Their Mo requirements include standardized predefined ranges that cannot be modified, while their So requirements include the ability to generate different types of documents. The cost-benefit analysis for the two focuses was conducted. The expected benefits include improvements in lead time and quality. The main costs are the man-hours spent by internal employees and external researchers and developers, as well as the license fees for the software.

5.4 Model and Prototype

Based on discussions and knowledge sharing with key stakeholders, the PVM model was modified to include Process Engineering as the input view (reflecting requirements from process design), Mechanical Engineering as the knowledge view (capturing expertise from mechanical engineers on valve and tank specifications), and the Part View to present information related to physical objects. These modified PVM modes are illustrated in Figure 8 and Figure 9.

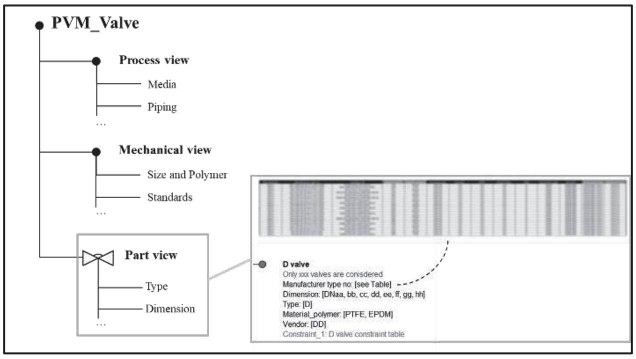

Fig. 8. *The Modified PVM of Focus 1*

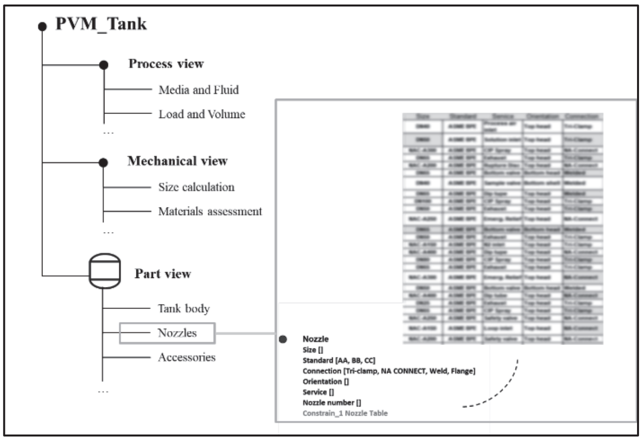

Fig. 2. *The Modified PVM of Focus 2*

The prototypes of PCS were developed based on the two modified PVM models. The prototype of PCS for Focus 1 was developed using Excel, as it meets most of the requirements of key stakeholders. This Excel-based prototype allows for mass specification of valves, configuring input data extracted from drawing software into detailed specifications for procurement. The prototype of PCS for Focus 2 was developed using commercial software with a research license, offering a more structured approach to document generation than Excel. This prototype provides a standardized method for the mechanical design of tanks based on predefined standard ranges defined by process specialists. Additionally, it serves as a checklist to ensure no essential information is missing before generating and sending documents.

5.5 Evaluation and Decision

The last step involves evaluating the PCS prototypes with key stakeholders to receive feedback on the performance of the prototypes based on defined targets and requirements. The summary of evaluations is presented in Table 3.

Table 3. Summary of *Evaluations*

Aspect	Focus 1	Focus 2
Software	Excel	Professional software
Improving manual works	Improved to some degree, but data input and extraction are still manual.	Improved with standard range selections and helpful documentation generation.
Timesaving	Time saved significantly; specifying one valve's previous time is now used for 100 valves.	Time is saved, and less effort is needed for changes and updates.
Quality	Almost 100% correct if input data is correct; errors in special cases or incorrect data.	Improved quality through standardized specifications.
Explicit knowledge	Prototype helps little with explicit knowledge; PVM helps a lot.	Introduces a standardized working method; makes knowledge more explicit, though may only work for a specific tank.
Suggestions	Investigate input data quality as crucial for configuration results; develop a standard, configurable drawing method.	Manage multiple configurations simultaneously; integrate into a collaborative platform; consider more tank types and their components.
Overall evaluation	Good idea	Good idea

Based on the evaluation, incorporating results from all previous steps, decisions regarding the two PCS prototypes in the investigation phase were discussed within the case company. It was decided that Focus 1 would undergo a reinvestigation phase to improve input data quality and explore the possibility of using better software that can automatically extract input data and feed configuration data. Focus 2 was approved to proceed to the development and implementation phase, utilizing a further structured approach.

6. DISCUSSION AND CONCLUSION

In ETO companies, there are many opportunities for digitalization and improvements through the use of PCS. The proposed five-step framework provides a structured approach for ETO companies to investigate potential areas for applying PCS.

The framework was applied in a case pharmaceutical engineering company. The results not only indicate that PCS can significantly improve engineering processes in ETO companies, but also show that it is still feasible to focus on different detailed levels of ETO to develop various prototypes of PCS, despite the complexity and broad solution space of ETO products. This approach helps build an understanding of PCS, showcases the benefits of using PCS, and generates interest for further development or investigation.

These findings align with previous research on PCS in ETO companies but extend the knowledge by providing a detailed framework for those with limited resources and experience in PCS. However, the framework was tested in a single case company and focused only on the mechanical parts of ETO products, which may limit the generalizability of the findings.

Based on the findings, ETO companies should engage key stakeholders early to ensure their requirements and targets are achievable using PCS. Future research should test the framework in different ETO contexts and disciplines to validate its generalizability. Additionally, prioritizing questions and providing detailed guidelines in the initial step will enhance the framework's applicability.

In conclusion, this study presents a comprehensive framework for investigating possible areas to apply PCS in ETO companies. It offers a valuable tool for ETO companies aiming to investigate PCS applications, facilitating more efficient and effective PCS investigation phases and paving the way for successful development and implementation.

7. REFERENCES

Bittner, K. and Ian Spence (2003) *Use Case Modeling*. Addison-Wesley Professional.[vi]

Blecker, T. *et al.* (2004) 'Product Configuration Systems - State of the Art - Conceptualization and Extensions', in *Eighth Maghrebian Conference on Software Engineering and Artificial Intelligence*, pp. 25–36. Available at: https://www.researchgate.net/publication/24114368.[viii]

Forza, C. and Salvador, F. (2002) *Managing for variety in the order acquisition and fulfilment process: The contribution of product configuration systems*, *Int. J. Production Economics*.[ii]

Haug, A., Hvam, L. and Mortensen, N.H. (2011) 'The impact of product configurators on lead times in engineering-oriented companies', in *Artificial Intelligence for Engineering Design, Analysis and Manufacturing: AIEDAM*, pp. 197–206. Available at: https://doi.org/10.1017/S0890060410000636.[ii]

Haug, A., Hvam, L. and Mortensen, N.H. (2012) 'Definition and evaluation of product configurator development strategies', *Computers in Industry*, 63(5), pp. 471–481. Available at: https://doi.org/10.1016/j.compind.2012.02.001.[ii]

Hvam, L. (2006) 'Mass customisation in the electronics industry: based on modular products and product configuration', *International Journal of Mass Customisation*, 1(4), p. 410. Available at: https://doi.org/10.1504/ijmassc.2006.010442.[ii]

Hvam, L. *et al.* (2013) 'Observed benefits from product configuration systems', *International Journal of Industrial Engineering*, 20(5–6), pp. 329–338.[ii]

Hvam, L., Mortensen, N.H. and Riis, J. (2008) *Product Customization*. 1st edn. Springer Publishing Company. Available at: https://doi.org/10.1007/978-3-540-71449-1.[vi]

Johnsen, S.M. and Hvam, L. (2019) 'Understanding the impact of non-standard customisations in an engineer-to-order context: A case study', *International Journal of Production Research*, 57(21), pp. 6780–6794. Available at: https://doi.org/10.1080/00207543.2018.1471239.[ii]

Kristjansdottir, K., Shafiee, S. and Hvam, L. (2015) 'Utilizing product configuration systems for supporting the critical parts of the engineering processes', in *IEEE International Conference on Industrial Engineering and Engineering Management*. IEEE Computer Society, pp. 1777–1781. Available at: https://doi.org/10.1109/IEEM.2015.7385953.[viii]

Kristjansdottir, K., Shafiee, S. and Hvam, L. (2016) 'Development and implementation strategy for the of product configuration systems in engineer-to-order companies', in *IEEE International Conference on Industrial Engineering and Engineering Management*. IEEE Computer Society, pp. 1809–1813. Available at: https://doi.org/10.1109/IEEM.2016.7798190.[viii]

Kristjansdottir, K., Shafiee, S. and Hvam, L. (2017) 'How to Identify Possible Applications of Product Configuration Systems in Engineer-to-Order Companies', *International Journal of Industrial Engineering and Management (IJIEM)*, 8(3), pp. 157–165.[ii]

Lu, Y.-J. *et al.* (2009) 'Configuration design of engineering-to-order product based on postponement design decoupling point', *Zhejiang University (Engineering Science)*, 43(12), pp. 2231–2236.[ii]

Rohde, K. (2009) *Applying Product Configuration Systems in Engineering Companies: Motivations and Barriers for Configuration Projects*.[iv]

Rudberg, M. and Wikner, J. (2004) 'Mass customization in terms of the customer order decoupling point', *Production Planning and Control*, 15(4), pp. 445–458. Available at: https://doi.org/10.1080/0953728042000238764.[ii]

Shafiee, S. *et al.* (2023) 'Framing business cases for the success of product configuration system projects', *Computers in Industry*, 146. Available at: https://doi.org/10.1016/j.compind.2022.103839.[ii]

Shafiee, S., Hvam, L. and Bonev, M. (2014) 'Scoping a Product Configuration Project for Engineer-to-Order Companies', *International Journal of Industrial Engineering and Management (IJIEM)*, 5(4), pp. 207–220. Available at: www.ftn.uns.ac.rs/ijiem.[ii]

Shafiee, S., Kristjansdottir, K. and Hvam, L. (2016) 'Business cases for product configuration systems', in *7th international conference on mass customization and personalization in Central Europe - Novi Sad, Serbia*.[viii]

Victor, B.I. and Boynton, A.C. (1993) 'Making Mass Customization Work', *Harvard Business Review*, 71(5), pp. 108–119. Available at: https://www.researchgate.net/publication/240104695.[ii]

Wehlin, C. *et al.* (2021) 'Integrating sales, design and production: A configuration system for automation in mass customization', in *ASME Design Engineering Technical Conference*.[viii]

White, S.A. and Derek Miers (2008) *BPMN modeling and reference guide: understanding and using BPMN*. Future Strategies Inc.[vi]

Willner, O. *et al.* (2016) 'Exploring the archetypes of engineer-to-order: an empirical analysis', *International Journal of Operations and Production Management*, 36(3), pp. 242–264. Available at: https://doi.org/10.1108/IJOPM-07-2014-0339.[ii]

CORRESPONDENCE

Qingsong Zhao, PhD student
Technical University of Denmark
DTU Construct
Nils Koppels Allé, Building 404
2800 Kgs. Lyngby, Denmark
qzha@dtu.dk

Dr. Lars Hvam, Prof.
Technical University of Denmark
DTU Construct,
Nils Koppels Allé, Building 404
2800 Kgs. Lyngby, Denmark
lavh@dtu.dk