Standardization in Engineer to Order Environments

Developing a Procedure to Establish a Suitable Standardization Strategy for Engineer to Order Product Families

Master of Science Thesis

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Delft University of Technology

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by

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Preface

This thesis is the final part of my Master's degree in Construction Management and Engineering (CME) at Delft University of Technology. I carried out this research during my graduation internship at Huisman Equipment in Schiedam. The topic of my study, standardization in Engineer-to-Order (ETO) environments, was both challenging and rewarding. By writing this thesis, I had the chance to learn how companies that make complex, highly customized products can still benefit from standardization to improve efficiency, quality, and overall performance.

Working on this thesis has been an important learning experience for me. During the project, I faced challenges in collecting, organizing, and analysing data. These challenges helped me improve my problem solving skills and grow both academically and professionally. It was especially satisfying to see that the results of my research could be useful in practice at the company.

I would like to sincerely thank everyone at Huisman Equipment for their warm welcome, support, and for sharing their knowledge so openly. The working environment was very positive, collaborative, and motivating. I really enjoyed going to the company about four times a week because of the friendly atmosphere and the feeling of really being part of the supply chain team. I am very grateful for the possibility and flexibility to do this during my internship, as it made the experience much more engaging and productive.

I am especially thankful to my company supervisor, Roy Melissant, for his guidance, helpful feedback, and ongoing support throughout the project. His insights into both the technical and organizational sides of the company were very valuable for my research.

I would also like to thank the many colleagues at Huisman who took the time to speak with me and participate in interviews. Their practical knowledge, honest feedback, and willingness to share their experiences were essential for this thesis and helped make the results useful and relevant.

I also want to thank my graduation committee at Delft University of Technology. I am especially grateful to my first university supervisor, Ir. M.W. Ludema, for his academic guidance, critical feedback, and ongoing support. Our meetings every two weeks were very helpful in keeping me focused, clarifying my ideas, and maintaining a high level of quality in my work. I am also thankful to my second supervisor, Dr.ir. J.S.J. Koolwijk, for his valuable suggestions and input throughout the process. A special word of thanks goes to the chair of my graduation committee, Prof.dr.ir. J.W.F. Wamelink, for his time and helpful feedback.

I also want to thank my fellow students and friends for their support during this final phase of my studies. I am especially grateful for their willingness to listen to my problems and frustrations. These conversations helped me stay motivated and put challenges in perspective. Their support made the process less stressful and easier to manage.

Finally, I want to thank my family for their constant encouragement, understanding, and patience. Their support has been essential throughout my studies, especially during this final stage. They have always helped me stay positive and remember the bigger picture.

I hope this thesis will be helpful to others working in, or studying standardization in ETO environments. I believe the findings and approach I developed can help companies improve their processes, make better decisions about standardization, and deliver more value to their customers and stakeholders.

Tim de Koning
Delft, September 2025

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Summary

In response to the increasing complexity of modern projects, particularly within Engineer-to-Order (ETO) environments, this thesis investigates how suitable standardization strategies can be effectively developed to enhance efficiency, reduce costs, and maintain flexibility. ETO projects, characterized by high levels of customization and client specific engineering, often suffer from inefficiencies due to the need to redesign components and processes for each new order. While standardization is a proven method for improving performance in mass production, its application in ETO settings remains challenging due to the variability and uniqueness of each project.

The research focuses on Huisman Equipment, a Dutch company specialized in the design and manufacturing of heavy construction equipment for offshore applications. Huisman operates in a highly customized ETO environment, producing a diverse range of products with varying degrees of uniqueness, from relatively common knuckle boom cranes (KBCs) to highly specialized motion compensated pile grippers (MCPGs). The main problem addressed is the difficulty in determining a suitable standardization strategy for every product family, in which trade-offs between customization and efficiency have to be made. It has been identified this problem does not only exist at Huisman Equipment but is present in other ETO organizations as well.

To address this problem the following main research objective (MRO) of this thesis has been formatted: *"To determine how a suitable standardization strategy can be established for product families in an Engineer-to-Order environment".* Achieving this objective addresses the identified problem by providing organizations with the insight needed to establish appropriate standardization strategies.

To help find a solution for this MRO, four research questions (RQ) and one design objective have been formulated. The first RQ is *Which internal and external factors influence the possible degree of standardization in ETO projects?*. This question has been developed to find out what factors need to be taken into consideration when developing a suitable standardization strategy. RQ2 sounds: *How can the current degree of standardization in ETO projects be measured?* and is used to find a way to quantitively indicate the standardization in projects. This is followed by RQ3 which is *What criteria can be used to assess whether the current degree of standardization aligns with project requirements and goals?*. Finding an answer to this question will help to find out if a higher degree of standardization is actually viable or if it should be avoided. RQ4, which is the last RQ set up, is *What project elements should be adapted to achieve a more suitable degree of standardization in ETO projects?*. Finding the answer to this question reveals what can actually be influenced to raise the degree of standardization to the desired level. By using the answers to these research questions, the design objective can be achieved which is *Establish a structured procedure to asses a suitable standardization strategy for product families in an ETO environment.*. By applying this structured procedure to a product family, a suitable standardization strategy should be found. Having found this standardization strategy will achieve the MRO.

To be able to answer all questions, achieve the DO, and achieve the MRO, the study makes use of the Design Science Research (DSR) methodology. This methodology is structured around six key activities and developed to create an artifact that is able to solve real-world problems. For this methodology, first the problem was identified, followed by a definition of the objective. Having achieved this, the artifact was designed which resulted in a procedure to develop a standardization strategy. When this had been designed, it was demonstrated on a real-world case: Huisman Equipment. Having demonstrated it, an evaluation was made on the functioning of the procedure. Lastly, by writing this thesis, the results are communicated which is the last key activity of the DSR.

In order to answer the research questions, identify the problem, develop the objective of the procedure, and really design the procedure, knowledge had to be obtained about ETO and standardization. To acquire this knowledge, a background literature study has been conducted. In here, first customer order decoupling points (CODPs) have been investigated of which ETO is one. CODPs are the points

in the production cycle where the process shifts from being driven by forecasts to being driven by actual customer requirements. Having developed this knowledge, ETO could be further evaluated. Where first is defined there can be full new designs made for ETO projects or they can be based on previous similar designs resulting in no universally accepted definition of ETO. To tackle this problem, ETO can be divided into an engineering and a production dimension. Moreover, it has been identified ETO companies can have different types. For this thesis the most important type is 'Type I' ETO which indicates the ETO is a vertically integrated company and thus producing practically everything in house. This is deemed the most important type of ETO for this thesis since Huisman is this type of ETO company.

As mentioned, this was followed by a literature research into standardization. In here, standardization has been defined as *constantly applying established processes, procedures and products in which regularity, repetition, and a proven track record of success are present*. Furthermore, it has been identified standardization can be divided into product standardization and process standardization. As applying standardization to ETO projects, defining advantages and limitations was also deemed relevant. Advantages defined are, among others: a decrease in costs and lead times, and improved efficiency and predictability. On the other hand, examples of limitations are the risk of losing innovation, a simplification of the end products and organizational resistance.

To further dive into the topic of standardization, key factors influencing standardization have been defined. These consist out of 14 factors that have been categorized into market, product and process related factors. The market related factors that have been identified are: delivery lead time requirements, volatility, customization requirements, order size and frequency, type of customer, and variations in regulations and standards. The product related factors are: maturity of the end product, customization opportunities, structure (modularity), and variance of integrated components. Lastly, the process related factors are: freedom of the sales process, freedom of the engineering process, freedom of the supply chain process, and degree of vertical integration in the supply chain. The market related factors in addition with the maturity of the end product are defined as external factors meaning organizations have no influence on them. The other product related and process related factors are internal factors indication influence can be exerted on these factors. Furthermore, a way to measure standardization has been found in literature for which the engineering complexity should be calculated. The engineering complexity is defined as the average engineering hours spent per product and is thus product family specific. It has been identified the lower the engineering complexity is, the more suitable the product family is for standardization. Besides this, a maturity model is analysed which can help to identify the current degree of standardization and the adaptations to do apply to standardize to a higher degree. Lastly, the market strategy applied by companies to their product families is also deemed relevant as it impacts standardization possibilities. For this it is important to identify the order winners and the strategic priorities of the product family.

As part of the DSR methodology, an artifact has to be set up. This artifact has been established making use of the insights gained during the literature study and applying the models reviewed during this study. The artifact that has been established is called the Standardization Strategy Development Procedure (SSDP) and is a structured tool designed to guide companies in developing a suitable standardization strategy for a given project. This procedure has been designed especially for vertically integrated ETO companies basing their products on previously designed projects. The SSDP consists of the following six sequential activities:

- A1: Determine the market strategy: Here the strategic priorities and the order winning criteria are defined.
- A2: Define product specific external factors: Here the external factors influencing standardization that have been identified during the literature study are determined.
- A3: Analyse current and previous projects: Here the data from previous projects is consulted to measure standardization. For this, engineering complexity (total engineering hours / total amount of projects) is deemed most relevant.
- A4: Analyse current internal factors: Here the internal factors influencing standardization that have been identified during the literature study are determined.

A5: Analyse potential improvements of internal factors: Here the maturity model in combination with the knowledge of experts is used to define potential improvements in the internal factors.

A6: Generate the applicable improvements into a new standardization strategy: Here the potential improvements are related to the boundaries set by the market strategy and external factors, resulting in a suitable standardization strategy.

In order to demonstrate the SSDP, it has been applied in a single embedded case study involving three product families produced by Huisman: knuckle boom cranes (KBCs), leg encircling cranes (LECs), and motion compensated pile grippers (MCPGs). Each product represents a different level of uniqueness and market conditions. In the case study, the first three activities of the SSDP are worked out for all three products. This has been done by looking into existing data and conducting interviews with experts. The findings of these activities demonstrate the suitability of the product families for standardization. The elements of the market strategy, the product specific external factors, and the engineering complexity of all three products are compared. All these elements indicated KBCs were as suitable or more suitable for standardization than LECs and MCPGs. This means KBCs are the most suitable for standardization and will thus be further analysed to develop a suitable standardization strategy for this product family.

To develop this suitable standardization strategy, the last three activities of the SSDP have been executed. To do so, additional information was collected by conducting interviews with various experts of varying departments to use their knowledge of the product family. By executing the three activities, first the current internal factors were identified. After these were defined, potential improvements were set up making use of the maturity model that was found during the literature study. The knowledge obtained from this model was supplemented with expert knowledge to discover what is actually possible. In the last activity of the SSDP the market strategy, external factors, and engineering hours found in the first three activities have been looked at again to define which potential improvements are really feasible. This resulted in the suitable standardization strategy which consists of overall changes, and changes specifically for the sales, engineering, and supply chain processes. The activities and adaptations required by this suitable standardization strategy are:

Overall:
Overall, it has been identified the customization opportunities that are offered need to be reduced to only offering a select amount of standard types of KBC. Besides these types, configurations should be developed that can be chosen by the customer to add to the design to make the product fit to their requirements. Furthermore, these standard types and configurations should be revised every two years to keep them up to date. This should be done making use of a session with at least the sales, engineering, and supply chain department since they are most affected by changes.

Sales:
In the sales process, the freedom of offers should be reduced to the standard product range combined with the standardized configurations. To do so, tenders should only be replied to when they are close to these standards. Some freedom should however be granted. When the customer demands small customization (e.g. an additional camera or additional lighting) that do not impact the main components the sales department should be free to offer it. On the other hand, bigger customizations should only be granted in consult with the engineering department. When bigger customizations are accepted the customer should accept a longer lead time and will have to pay the additional costs made. When multiple KBCs are sold at once, there should be more room for customizations as these can directly be applied to multiple products.

Engineering:
The engineering department should first of all work out the standard product range and standardized configurations. Furthermore, they should look at standardized interfaces between main components to assist modularization. To make standardization possible, the team should be divided into two teams, one dedicated to standardized components and one dedicated to customized components. In this way, expertise in standards and custom items is developed. Besides this, a database should be set up where all standards can be easily found. Making use of this database should be made mandatory.

Supply Chain:
Regarding the supply chain process, the process should be divided into two processes: one dedicated for standardized components and the other one dedicated for configurable and custom components.

For the new process designated for standardized components, arrangements with single source suppliers have to be set up. These arrangements should define a fixed price for the components for the coming year and let the suppliers produce the component on stock based on the forecasted sales of KBCs. The process dedicated for configurable and custom components should follow the current process applied. Furthermore, it is recommended to do additional research to develop own factories to enhance the vertical integration. Lastly, investigations should be done to arrange agreements between suppliers, ensuring that assemblies are delivered instead of separate components.

Activity 5 of the DSR methodology involves evaluating the artifact that is produced. This was first off all done by the researcher himself identifying problems ran into whilst executing the procedure. Overall, the procedure functioned effectively when applied in the case study at Huisman. During this evaluation it was identified the factor 'type of customer' was found to be more of an influencing variable than a separate factor. Although the SSDP was deemed a well functioning structured approach, it was noted that internal processes may need to be redesigned instead of only limiting freedom. This is the case as processes need to change when moving from ETO towards make to order (MTO). An example can be seen in both the engineering and supply chain process where the process is divided in two processes, one dedicated for standard and one for custom components. The evaluation further confirmed the SSDP as a practical tool, capable of guiding in developing tailored standardization strategies. Besides this evaluation the procedure was also presented to experts. The procedure and its results were first proposed to sales, engineering, and supply chain experts separately. After this, a session was organized with the same experts as well as additional experts from different departments. During these presentations of the procedure and its results it became clear the procedure is functioning well. However, there are some points the procedure could be improved on. These points were mostly concerning what exact customizations should be allowed and how this can be measured; what the exact difference is between smaller and bigger customizations; to what degree more customization should be possible when orders are bigger; and lastly there was, according to the experts, a lack of financial insights. To overcome these points, additional research should be done to identify how this can be defined and integrated.

By developing and evaluating the SSDP based on the literature review, the study provides theoretical implications, including the extension of standardization theory in the ETO environment. This has been achieved by integrating the factors influencing standardization with various models into one framework. Practically, the SSDP offers ETO companies a structured method which can be applied to develop a suitable standardization strategy that will help reduce costs and lead times whilst improving efficiency. On the other hand, limitations include the single case scope in the case study, embeddedness of the researcher in an ETO company, uncertainty of the long term impact, and the limited use of quantitative data. Future research should apply the SSDP across multiple organizations, explore the long term impacts, and investigate how processes should actually be redesigned when moving away from ETO.

Applying the SSDP in the case study resulted in a suitable standardization strategy for KBCs, it is recommended for Huisman to implement this strategy. Furthermore, it is recommended to apply the SSDP to the other product families as well. For implementing the SSDP in the organization it is recommended for each product family to make the product owner responsible for conducting the procedure. For other ETO companies it is also highly recommended to start applying the SSDP, especially for vertically integrated ETO organizations that base their products on previously designed products. For other types of organizations adaptions might be needed in the activities as the procedure was not specifically designed for these type of organizations.

To conclude, by integrating theoretical insights with a real world application, this study not only contributes academically but also provides practical value to the ETO industry. By designing, demonstrating and evaluating the SSDP, this thesis provides a structured, practical, and repeatable procedure that enables these organizations to develop their own suitable standardization strategy for the product families they produce. This indicates the development of the SSDP successfully addressed the research objective of determining how a suitable standardization strategy can be developed for ETO product families.

Contents

List of Figures

List of Tables

Glossary

This glossary defines key terms and phrases used throughout the thesis. Terms are listed in alphabetical order.

Term	Abbreviation	Definition
Activity System Map	-	Visualization of higher order strategic themes and linking them to each other as well as to key activities performed to achieve these strategic themes.
Assemble to Order	ATO	A customer order decoupling point where components are assembled only after receiving a customer order.
Closed Market	-	A market that can not be entered due to for example regulations, requirements, high entry barriers, or limited suppliers.
Configure to Order	CTO	A customer order decoupling point where standard components are configured to meet individual customer requirements after an order is received.
Customer Order Decoupling Point	COPD	The point in the production process where the product is customized to the specific customer order instead of forecasted.
Design Objective	DO	A specific goal guiding the development of the procedure in this study.
Design Science Research	DSR	A research methodology focused on creating and evaluating an artifact to solve an identified real world problem.
Design to Order	DTO	A customer order decoupling point where products are specifically designed and engineered after an order is received.
Engineer to Order	ETO	A customer order decoupling point where products are specifically engineered after an order is received.
Engineer to Stock	ETS	A customer order decoupling point where engineering work is completed before an order is received.
Engineering Complexity	-	The average engineering hours that need to be spent per product of a product family (Total engineering hours / total amount of products).
Engineering Dimension	ED	The dimension of a CODP that focusses on engineering.
ETO ”Type 1”	-	Vertically integrated companies which have their core competencies in design, manufacturing, assembly, and project management.

Term	Abbreviation	Definition
External Factors	-	Factors that can not be directly influenced by the organization.
Hydraulic Power Unit	HPU	A system that generates, controls, and transmits hydraulic power.
Installation, Commissioning and Testing	IC&T	The process of installing equipment, verifying its functionality, and ensuring it meets specifications before use.
Internal Factors	-	Factors that can be directly influenced by the organization.
Jack-up Vessel	-	A type of vessel that has legs that can be jacked down to the seafloor to push the hull of the vessel above the surface of the water.
Kaizen	-	'Continues improvement' in Japanese. Stressing the essence of continuous improvement of standards to ensure they remain up to date and effective.
Knuckle Boom Crane	KBC	A type of offshore crane with a jointed boom that can be used for a wide variety of purposes.
Leg Encircling Crane	LEC	A crane designed to encircle along the legs of a jack-up vessel used to install offshore wind turbines.
Main Research Objective	MRO	The primary goal the research aims to achieve.
Make to Order	MTO	A customer order decoupling point where manufacturing begins only after a customer order is received.
Make to Stock	MTS	A customer order decoupling point where products are manufactured before an order is received.
Market Strategy	-	A strategy for reaching target customers and achieving competitive advantage in a specific market.
Metric ton	mt	A unit of mass equal to 1000 kilograms.
Modular	-	Designed with standardized units or sections that can be easily assembled, replaced, or configured.
Monopile	-	A large, single steel cylindrical foundation driven into the seabed to support offshore wind turbines or other marine structures.
Motion Compensated Pile Gripper	MCPG	A piece of heavy construction equipment that is used to drive monopiles into the seabed whilst compensating for vessel movement.
Order Configuration Uncertainty	-	Uncertainty that arises as no accurate forecasts can be made about what configurations are required by the customers.
Order Winner	-	A characteristic of a product or service that directly contributes to winning customer orders.
Product Family	-	A group of the same type of products sharing common features, components, or design elements.
Production Dimension	PD	The dimension of a CODP that focusses on production.

Term	Abbreviation	Definition
Request for Quotation	RFQ	A formal document inviting suppliers to submit price bids for specific products or services.
Research & Design	R&D	Activities focused on investigating new ideas and developing new products or processes.
Research Question	RQ	A clear, focused question that guides the investigation in a research project.
Ship Classification Societies	-	Organizations that establish and maintain technical standards for the construction and operation of ships.
Single Embedded Case Study	-	A qualitative research method focusing on a single case with embedded sub-units for in depth analysis.
Standardization	-	Consistently applying established processes, procedures and products in which regularity, repetition, and a proven track record of success are present.
Standardization Strategy Development Procedure	SSDP	The procedure developed in this thesis which can be used to formulate strategies to standardize product families to a higher degree.
Toyota Production System	TPS	A production methodology based on lean manufacturing, waste reduction, and continuous improvement.
Vertical Integration	-	A strategy where a company controls multiple stages of its production or supply chain.

1 Introduction

This chapter covers the introduction of the thesis. First of all, background information is given on project complexity, standardization, and engineer to orders which are the main subjects of this thesis. After this, the problem is defined which concludes companies conducting highly customizable projects have difficulties defining a suitable standardization strategy. This problem is transformed into a main research objective and the scope of the research in Section 1.3. Finally, the structure of the thesis is introduced in the last section of this chapter.

1.1. Background

Over time, projects have become increasingly complex making it more and more challenging to maintain their objectives within the constraints of time, cost, quality, and safety (Cristóbal, 2017). This complexity is caused by the more complicated products, supply chains and sales channels needed in projects nowadays (Hansen et al., 2021). Various studies have been conducted on project complexity and how to manage this, indicating it is a key component in the success of projects (Luo et al., 2017). In their paper, Kermanshachi et al. (2021) highlight that multiple studies indicate project complexity negatively impacts projects. They emphasize that complexity negatively influences costs, project scope, objectives, and outcomes. Furthermore, the complexity in projects also results in conflicts within the organization and inefficiencies. Being able to partly tackle or manage this complexity will thus positively impact projects.

A way identified to tackle complexity is making use of standardization. This technique became known in the mass production industry, especially the case of Toyota Motor Corporation is well known. At Toyota, the most critical parts are identified and the standardized to the maximum. It should be noticed however, that not all work is standardized to the same degree. Making sure the critical parts are executed well, other parts can be more relaxed about making sure top notch results can be achieved (Tregear, 2014).

Although standardization has its origin in the mass production industry, other industries also try to benefit from its positive influences by adopting it. Industries can be characterized by the Customer Order Decoupling Point (CODP). The CODP indicates from which step in the design process the customer has ordered the product and what activities have already been forecasted before that point (Hoekstra et al., 1992). The later in the process the customer gets involved the more standardization can be applied. In an ETO environment the CODP is at the moment in the process where the engineering of the end product starts, from this moment on the customer is thus able to influence and customize the process. When the CODP is postponed, the process will be more forecast driven resulting in more standardization. Other approaches having a more postponed CODP are assemble to order (ATO), configure to order (CTO), make to order (MTO), and make to stock (MTS) (Olhager, 2010).

As there are little to no forecast driven activities, the ETO environment is characterised by projects that are executed specifically to the requirements given by every individual customer. Often times this is done by reusing or modifying designs from already executed projects, fully customized to the wishes of the customer (Bertram et al., 2020). In this study for example, Huisman Equipment will be investigated as the main case of interest. Huisman Equipment is a company designing and manufacturing heavy construction equipment, mostly for the offshore sector (Huisman Equipment, n.d.). Huisman is characterised as an ETO company that engineer solutions to the requirements of the customer. The solutions are however mostly based on previous designs made for products that are produced for other clients. Although parts are copied, still major product specific changes are made causing high product variety and complex projects. This results in difficulties implementing standardization (Särkisilta, 2021).

Despite the challenges posed, standardization can still be of great value in the ETO industry. As noted by Vollmar and Gepp (2015) project execution can be improved by implementing standardization as projects are engineered again every time resulting in inefficiencies and loss of knowledge. Moreover, Haug et al. (2009) mention standardization will result in shorter lead-times, reduced costs and less errors in manufacturing.

1.2. The Problem

As mentioned before, projects are getting more and more complex resulting into inefficiencies (Cristóbal, 2017). This complexity intensifies in the Engineer to Order (ETO) environment, where each project is treated as a custom order, requiring specific components and equipment to be designed and built for individual customers. These projects face constant unpredictable events like new orders, breakdowns or rush orders impacting all the previously mentioned constraints (Micale et al., 2021).

Moreover, the current way of executing projects in these highly customizable projects can be seen as inefficient. Although projects can be quite alike, they are every time engineered again. This benefits customer demands, fosters innovation and in that way provides a competitive advantage. However, this is not necessarily required for each single project executed. The complexity that being highly customizable brings results in higher costs, longer lead times and other inefficiencies (Bertram et al., 2020).

Ideally, complexity in ETO projects would be reduced making projects more efficient. A solution to manage complexity, enhance efficiency, and improve project outcomes is standardization. This involves standardizing specific critical components across multiple projects as well as standardizing the design process of the projects. By doing so, engineers can avoid repetitive research on these components, besides that, bulk purchasing becomes possible. This approach leads to reduced costs, shorter lead times, and increased overall project efficiency (Mehta, 2024).

There are however limitations to standardization in ETO projects that should be taken into account. These limitations include: a limit to the ability to address customer demands; loss of competitive advantage through reduced innovation; higher risk of product imitation and organizational resistance due to a threat of craftsmanship (Haug et al., 2009), (Thomassen & Alfnes, 2017).

In order to apply standardization these limitations should be identified for every specific product family. This is important as the possibilities of implementing standardization in the ETO environment are product family specific. The possibilities range from the potential of being fully standardized to no standardization possible at all. Ideally, for every product family the best useful standardization strategy should be identified where a balance between standardization and customization fitting to the project specific customer requirements can be achieved.

Being able to identify what standardization strategy should be applied is valuable for companies operating in the ETO environment like Huisman Equipment is. Huisman has end products in its portfolio with different levels of uniqueness. For example, the design and construction of knuckle boom cranes (KBC) is done by various other companies as well, however, far more unique products are also manufactured. An example of such a product is a motion compensated pile gripper (MCPG), used to install monopiles for offshore wind turbines. Huisman is the only company capable of constructing a working piece of such equipment. Providing products varying in uniqueness makes it difficult for Huisman to define what standardization strategy they have to apply for each project.

Overall, the value of standardization is well understood, however, identifying the most suitable standardization strategy for each product family remains unclear. To illustrate the problem, Huisman is taken as an example. Currently for each project, a project team is assigned to design the specific equipment to the requirements of the client. Although most projects are based on previously performed products, to comply to customer requirements, every product has to be adapted including adaptations of critical components like motors, gearboxes, and electronic modules. Moreover, fundamental changes are made to the design in order to make the equipment fit on the vessel it will be installed on. This often leads to engineers reinventing the wheel as they repeatedly spend significant time identifying suitable components and ways for these components to work together. This results in high costs and long lead times which might be possible to avoid making use of standardization.

The application of product specific standardization strategies could benefit Huisman as inefficiencies will be reduced during the project both in terms of the product and the process. There however is uncertainty on how to determine to what degree to standardize product families and their project, and what to base this on. To conclude, there is a problem defining the right standardization strategy to apply for the varying product families in the portfolio.

Having difficulties determining what standardization strategy to use for each product family is not unique to Huisman but is widespread in industries that require high levels of customization, such as construction, manufacturing, and shipbuilding (Mehta, 2024), (Willner, Powell, et al., 2016). Developing solutions for this problem would have significant implications beyond Huisman Equipment.

1.3. Main Research Objective and Scope

As identified, companies operating in an Engineer-to-Order (ETO) environment face challenges in identifying and implementing a suitable standardization strategy. The high degree of product customization and project-specific design makes it difficult to define standard approaches that still meet customer requirements. Consequently, the objective of this thesis is:

To determine how a suitable standardization strategy can be established for product families in an Engineer-to-Order environment

By achieving this objective, any confusion in determining the standardization strategy for organizations operating in the ETO will be reduced. By working out the objective, insights will be gained on what activities to perform to determine the most suitable standardization strategy. These insights will be worked out into a procedure which can be used to determine a suitable standardization strategy for product families in an ETO environment.. The strategy developed through this procedure will identify the areas to focus on. How these areas should be worked out in detail will be beyond the scope of this research. Following the procedure will therefore indicate whether standardization is possible and which departments should be prioritized when implementing a higher level of standardization. During the set up of this procedure, focus will be particularly placed on ETO companies designing and producing products based on previous projects or designs, however, fully adapted to the customizations of the customer. These companies are chosen as this research will be conducted at Huisman Equipment, an ETO company operating in a similar manner. During the case study executed, three different product families will be analysed to indicate the differences within these products to identify why products should be standardized in different ways.

1.4. Structure of the Thesis

The thesis will consist out of seven main chapters setting the main structure of this thesis. These seven chapters all have relevant subsections in order to establish a well organized structure. The seven main chapters in this thesis are: Introduction, Thesis Project Methodology, Background Literature Study, Developing a Standardization Strategy Development Procedure, Case Study at Huisman Equipment, Discussion, and Conclusion and Recommendations.

in the first chapter, *Introduction*, an introduction to the subject is given. First a background of the subject is presented after which the problem has been formulated. Furthermore, this problem is translated into the main research objective (MRQ) that will help to find a solution to the presented problem.

The second chapter, *Thesis Project Methodology*, gives an outline of the methodology including the research design and method. Here, first the design science research methodology is introduced, clarifying how it will be applied to this thesis. Moreover, the research questions that help find a solution to the MRO are presented. Furthermore, the data collection methods that will be used in the thesis are further elaborated on.

Chapter 3, *Background Literature Study*, presents the literary basis the thesis will be based on. The study executed in this chapter will serve as basis for the framework that will be developed in Chapter 4. First the customer order decoupling point will be explained followed by a section introducing engineer to order in further detail. This is followed by a section further elaborating on standardization. Moreover, key factors influencing the degree of standardization are introduced which are split up into market, product, and process related factors. The next section (Section 3.5) presents a way to measure standardization in projects after which a maturity model that can be applied to standardization is presented in Section 3.6. The last section of Chapter 3 explains market strategy and how this has influence on standardization in projects. At the end of this chapter, a conclusion of the literature study is presented.

In Chapter four, *Developing a Standardization Strategy Development Procedure*, a procedure is designed that can be applied to solve the main research objective . In order to do this, the knowledge acquired during the literature study performed in Section 3 will be integrated. The procedure is called the "Standardization Strategy Development Procedure" or SSDP for short, consisting of six activities. These six steps are explained more in depth in Section 4.2. Executing the six activities will result in a suitable standardization strategy for the product family assessed whilst using the procedure. This chapter will end with a chapter conclusion, concluding the development of the SSDP.

This will be followed by the *Case Study at Huisman Equipment* in chapter 5. In this chapter, the main case and the sub-units of the case study are first introduced. After the introduction, the SSDP established in Chapter four will be applied to the sub-units to demonstrate the applicability in a real life situation. First, the first three activities are applied to all three products after the results are compared concluding in the most suitable product for standardization. The SSDP will be further worked out for this specific sub-unit resulting in a suitable standardization strategy for this particular product family. As the SSDP has now been demonstrated, an evaluation of the procedure is conducted in Section 5.7. To finalize this chapter a conclusion is drawn from the case study conducted during this chapter.

After the case study has been executed the results of the thesis will be discussed in Chapter 6, *Discussion*. In this chapter, the findings will first be discussed, including the answers to the research questions and an explanation of how the design objective has been achieved. Furthermore, the chapter will address the theoretical and practical implications. After this, the research limitations will be presented, along with recommendations for future studies to address them.

Lastly, a conclusion can be drawn and recommendations are defined in Chapter 7, *Conclusion and Recommendations*. First the conclusion will be drawn in Section 7.1. Combining the conclusion together with the discussion and results of the case study, recommendations for Huisman Equipment and for the ETO industry in general are established. The chapter is finalized by a final remark which concludes the full thesis.

2
Thesis Project Methodology

This chapter elaborates on the chosen approach to write this thesis. First, the research design and methodology are outlined, introducing the 'Design Science Research' methodology and explaining how it will be applied to the subject. In Section 2.2 four research questions and one additional design objective have been formulated to help find a solution to the main research objective stated in Chapter 1. Furthermore, it is explained how the literature study will be applied and how the case study is employed in order to find a solution to the MRO. Besides this, it is explained how the procedure will be evaluated. Lastly, an overview of the thesis project methodology is given in Section 2.5.

2.1. Research Design and Method

The objective defined in Section 1.3 is *"To determine how a suitable standardization strategy can be established for product families in an Engineer-to-Order environment"*. To achieve this objective, a structured research will have to be conducted. This will be achieved following the design science research (DSR) methodology. DSR is a problem solving research methodology used in fields like information systems, engineering, and technology development. The goal of this methodology is to create and evaluate an artifact like a model, method, or system that is established to solve real-world problems. This aligns closely with the focus of this research, which aims to address a real-world problem by developing some kind of model or method. Peffers et al. (2007) set up six activities that need to be executed when using this methodology.

1. *Problem Identification & Motivation*: In this activity, the specific problem that requires a solution, and the importance and relevance of solving this problem, is determined. For this research, this has been formulated in Section 1.2 where the problem is elaborated on.
2. *Define the Objectives of a Solution*: Here, the objective of the solution should be investigated by looking into how a proposed solution is better than the current way of working. For this, the state of the problem and the current solution should be investigated.
3. *Design and Development*: This activity is used to set up the artifact. The design and development will be done on theoretical foundations which have been constructed in the last two activities. The artifact for this research will be a procedure for determining the most suitable standardization strategy for ETO projects.
4. *Demonstration*: In this activity, the procedure will be applied in order to demonstrate the usefulness. In this research this will be done during an embedded single case study.
5. *Evaluation*: Activity four is followed by an evaluation activity which indicates if the procedure is able to solve the problem set up in activity one.
6. *Communication*: After the evaluation has proven the procedure is working, it should be communicated so others can use it as well. In this case, this will be done by writing this thesis.

During the first phase of the research, a literature study will be conducted in order to gather knowledge about the main subjects needed to achieve the main objective of the research. In this phase of the research, the first three activities of the DSR are executed. The problem will be identified and the objective of the solution will be discovered. Furthermore, literature will be consulted to base the design and development of the procedure on. To do so, first a background study will be conducted including gathering information concerning customer order decoupling points, engineer to order, standardization, and the market strategy. Furthermore, determinants and measurements of standardization in ETO projects are researched. Here, factors influencing standardization in projects are derived from existing literature. Besides this, a model to measure standardization in projects and a maturity model of standardization will be analysed in order to explore their usability when setting up the procedure.

After this has been done, the artifact, which will be a procedure, can be established. To do so, the knowledge gained during the literature study will be incorporated in the activities that need to be executed during this procedure.

The next phase consists of an embedded single case study at Huisman Equipment, a heavy equipment manufacturing company operating in an ETO environment. In this phase, the procedure that has been developed will be applied in real life applications to demonstrate its functioning. By applying the procedure in a case study, an evaluation of this procedure can be made as well. Three different products and their projects will be analysed, this will offer the possibility to make a comparison giving insights into the functioning of the procedure. Moreover, possible additions or adaptations can be obtained from the case study.

After these activities have been executed, recommendations can be given to Huisman on what should be changed in order to apply a more suitable standardization strategy. Furthermore, the research objective will be achieved as a more suitable standardization strategy will have been developed by applying the procedure. The activities taken and insights gained during the process of setting up this more suitable standardization strategy will fulfil the objective of this research.

2.2. Research Questions and Objective

The main research objective posed in Section 1.3 is:

To determine how a suitable standardization strategy can be established for product families in an Engineer-to-Order environment

To achieve this MRO, the research will be structured around four research questions (RQ) and one design objective (DO). These questions have been established taking the DSR methodology into consideration. Each question addresses a different dimension of the standardization challenge in ETO projects and builds upon the previous one to develop a comprehensive understanding.

First, it is important to investigate what impacts the suitable degree of standardization that should be applied to the product family and its projects. To do this, distinguishing factors and decisions influencing standardization in ETO projects should be identified to better understand the objective of standardization. Furthermore, these factors can be integrated during the design and development of the artifact when considering what needs to be adapted in the current strategy. This may include internal factors like the processes of the project as well as external factors like market related factors. In order to do this, the first research question has been set up:

RQ1: *Which internal and external factors influence the possible degree of standardization in ETO projects?*

Second, in order to assess or improve standardization, it is necessary to understand the current situation, as explained in the DSR. Since this study focuses on existing products and projects, the degree of standardization can be estimated using documented variables. This leads to the second research question:

RQ2: *How can the current degree of standardization in ETO projects be measured?*

Moreover, it is important to identify if the current degree of standardization applied is a suitable degree for the project. To find this out, the third research question has been formulated:

RQ3: *What criteria can be used to assess whether the current degree of standardization aligns with project requirements and goals?*

If the analysis reveals that the current level of standardization is inappropriate, research should be conducted to identify what should be adapted in order to increase the level of standardization to a more suitable level. Therefore, the fourth research question is:

RQ4: *What project elements should be adapted to achieve a more suitable degree of standardization in ETO projects?*

Finally, an artifact in the form of a structured procedure should be established. This procedure can be used to establish a suitable standardization strategy for product families in an ETO environment. In order to accomplish this, the following design objective has been established:

DO1: *Establish a structured procedure to asses a suitable standardization strategy for product families in an ETO environment.*

Answering these research questions and achieving the design objective will guide the research to accomplish the main objective of this research. Doing this will help to reduce the confusion present in determining a suitable standardization strategy for the highly customizable products in the ETO environment.

2.3. Literature Study

As mentioned before, A literature study is essential for establishing a theoretical foundation to understand what is exactly needed to achieve the objective of the research. In general, a literature study ensures that the research builds on existing knowledge. Specific angles can be analysed shaping the way of thinking resulting in useful new insights. By conducting a literature study, the risk of reinventing the wheel is also reduced as literature produced on the theme is investigated. Moreover, relevant terminology and key terms are identified which can be implemented in the research using the right definitions of these terms. Furthermore, useful models developed by other researchers can be identified, which may either be applied directly in the study or provide insights to support the research. Lastly, a literature study gives the ability to relate findings to findings others have done (Sekaran & Bougie, 2016).

In order to find relevant scholarly articles, multiple academic databases have been conducted. Online libraries used are Google Scholar, Web of Science, and Scopus. These sources provided journal articles and conference papers that cover topics related to the research.

To conduct the literature review, the following keywords, among others, were used in the search: standardization, project, strategy, method, complexity, ETO, engineer-to-order, customizable, efficiency, component, benefits, limitations, equipment and barriers. Variations, synonyms or combinations making use of boolean operators are used to achieve more accurate results.

From these results, titles were scanned as a first selection to find articles that are potentially relevant. After this, the abstracts of the potential relevant articles were read. The abstracts provided an overview of the document showing the study purpose, research method, findings, and the conclusion of the document. When this did not give enough information, the introduction, problem statement, research questions and table of content were conducted. By analysing these, there could be confirmed if the document was really relevant for the study conducted (Sekaran & Bougie, 2016). When relevant articles were found, notes were made including the topic and vision of the author on the topic. Besides this, the relevant articles were downloaded and stored in well structured folders categorised on the topic the articles were relevant for. In this way, the articles could easily be accessed when information was needed during the research.

The literature has further been analysed by identifying common themes, contrasting viewpoints, and knowledge gaps related to standardization strategies in the ETO environment and its subtopics. First of all, an overview of relevant topics was gathered by analysing varying articles making up the sections of this thesis. Having produced an overview of the relevant topics provided the ability to compare these findings and viewpoints, resulting in the information of the sections.

Using this method, the literature study has been used to answer all RQs posed in Section 2.2. Having found these answers gave the ability to design a procedure that can be used to develop a standardization strategy.

2.4. Case Study

In order to collect real life insights into the research objective and to demonstrate and evaluate the procedure, a case study has been conducted. By doing so, the DO stated in Section 2.2 will be achieved. In the case study three different product families designed, engineered and constructed by one company have been analysed. This type of case study is called an embedded single case study. In this kind of case study, multiplicity of evidence is researched in multiple sub-units within one main case (Scholz & Tietje, 2002).

2.4.1. Case selection

As mentioned before, Huisman Equipment has been selected as the main case for this study. Huisman has corresponding characteristics for this case study as they produce their products beginning with the idea and ending with turnkey equipment for their customer. Because they produce their products in this way, they work according to an engineer to order approach which is relevant for this research. The company produces different types of equipments which are mostly designated for the offshore construction industry. These types of equipment range from cranes, offshore wind tools, pipelay and drilling equipment as well as any special equipment related to this.

Due to time reasons, a selection of product families had to be selected to base this research on. These products have been selected based on two main requirements. First off all, the three sub-units are currently produced and will most likely be produced the coming years by Huisman as there is a ongoing demand. Secondly, a difference in the market conditions is deemed relevant. The market will make a genuine influence on standardization, looking into different market conditions will gain insights in what is relevant whilst determining the suitable standardization strategy. These differences will give indications what is, and what is not influencing standardization.

The project families chosen as sub-units in this single embedded case study are:

1. **Knuckle boom crane (KBC):** This is a relative common crane in the offshore sector, various types of KBCs have been designed by Huisman ranging from 80mt up to 550mt. These cranes are used in the offshore wind industry, and the oil and gas industry. For these cranes there is a highly competitive market as a lot of companies can manufacture these type of cranes. Different suppliers offer these cranes with different customer customization options, ranging from ETO to make to stock (MTS).
2. **Leg encircling crane (LEC):** This type of crane is constructed around the jack-up of a jack-up-vessel and is primarily used in the offshore wind industry to install wind turbines at sea. These type of cranes are bigger and more specialistic, resulting in less companies being able to produce these type of cranes. The competitive market is thus smaller than the one for KBCs but still present.
3. **Motion compensated pile gripper (MCPG):** This piece of equipment is used to install monopiles in the seabed for wind turbines. Vessel motion and wind cause the monopile to move and should thus be countered, this is done by the MCPG. This type of working equipment is currently only produced by Huisman who thus have a monopoly in this type of equipment. Although the market is really niche, there is a future outlook as wind turbines will be installed in deeper waters more in the future (Yuan et al., 2023).

A further explanation of Huisman and these products can be found in Chapter 5.

2.4.2. Data Collection

According to Yin (2017), six sources of evidence are often integrated in case studies. In order to strengthen the case study multiple of these sources should be investigated as in this way a wide variety of data is collected. This results in triangulation, which enhances the validity of the study by using multiple sources of evidence to confirm the same finding and reduce the risk of bias or error. The six sources of evidence presented by Yin (2017) are:

1. **Documentation**: Includes written reports, administrative documents, letters, news articles, and other relevant documents. Documentation is particularly deemed useful for supporting evidence obtained from other sources.

2. **Archival records**: Includes service records, organizational records, maps, charts, and survey data. These can be used to study historical trends or events.
3. **Interviews**: Often the most important source in case studies. Interviews can be conducted in a structured, semi-structured, or unstructured way, providing direct insights from participants.
4. **Direct observations**: Involve observing events as they happen in real time. These can range from formal to informal observations.
5. **Participant observations**: The researcher takes part in the events being studied, gaining insider access but also risking bias.
6. **Physical artifacts**: Tangible items such as tools, instruments, or other objects that may reveal insights into the studied phenomenon.

For this research, the first four of these sources of evidence are available and will be used to study the research objective. The following subsections will elaborate on how they will be used. As mentioned, triangulation can be achieved using this approach. Using these various sources ensures the data collected from one source can be checked by the data collected from another source.

2.4.3. Use of Documentation

During the study, several types of documentation have been investigated in order to check on other data found and to get insights into the main case and sub-units. These documents primarily existed out of documentation that can be found online about the main case, the sub-units, and the markets that are operated in. Examples of these are brochures of the sub-units that can been obtained from the main case as well as from competitors. Furthermore, online news articles were investigated that hold valuable information on contracts of the sub-units that are awarded to Huisman or developments in the markets the sub-units are in. Lastly, documentation regarding market strategies have been investigated.

When using documentation it is important to be aware that the information provided is not always fully accurate as the author may be bias when writing the document. It thus is important to always look in detail to where the documentation was published, what author wrote the document, and with what purpose the document was written (Yin, 2017).

2.4.4. Use of Archival Records

The next source of evidence that was consulted were archival records. Archival records were made available by Huisman as this thesis is written in collaboration with the company. The availability of these records is an advantage of a single embedded case study in contrast to a multi-case studies as when applying a multi-case study companies tend to be more secretive to protect their commercial advantage (Bass et al., 2018).

Archival records that were used mainly consist of records on previous projects documented by Huisman. The archival records being most useful and influential for this study were spreadsheets containing engineering hours of previously conducted projects as well as forecasts set up for projects that were executed during the research. These documents consist out of the engineering hours spent per engineering discipline and provide the total amount of engineering hours spent or forecasted to be spent on the project. Furthermore, charts showing the tenders received were useful during the investigation to the external factors influencing standardization. Besides this, the portfolio including all previously conducted projects was relevant when determining the sub-units of the case study.

Just as with using documentation, it is of importance to check the accuracy of the archival records as the author might have been bias whilst making them. Moreover, mistakes can be made in the production of these records. It is again important to always investigate who wrote the article and with what purpose the records were made Yin (2017).

2.4.5. Use of Interviews

According to Yin (2017), interviews are one of the most important sources of evidence in case studies. Interviews offer first hand knowledge from experts working with the product families on a day to day basis providing a more nuanced perspective on the real world challenges in those projects. During these interviews the viewpoints from various experts are important as they might have varying opinions and knowledge on certain topics. This difference will be apparent between different disciplines within Huisman. These interviews will help to find out what, according to the experts, can and can not be done in the field of standardization and what strategies are implemented already. Additionally, by conducting interviews a better understanding of the projects and the market they are in will be established.

The interviews were conducted in a semi-structured way. Semi-structured interviews are chosen over other interview formats because they provide a balance between structure and flexibility (Mueller & Segal, 2014). Unlike structured interviews, which follow a strict questionnaire, semi-structured interviews allow for deeper exploration of topics based on the responses of the interviewees. This is particularly important during the research as different interviewees will have unique challenges or approaches that have not been identified before and need follow up questions to better understand them.

Compared to unstructured interviews, semi-structured interviews ensure that key topics are consistently covered while still allowing interviewees to elaborate on aspects that may not have been anticipated. This format helps uncover unexpected insights while maintaining comparability between different interviews.

In order to conduct the interviews the following steps based on the article written by Adams (2015) were taken:

1. First of all, the interviewees were selected after which interviews were arranged. This was done well in advance and included a short introduction and an estimated duration of the interview
2. Secondly, the interview protocol was set up. This was done as an interview guide rather than a fixed questionnaire. In this guide, open ended questions that facilitate follow-up questions were formulated in an understandable manner. For some questions, predefined follow up questions were already stated to go more in depth on certain topics. One of the interview guides can be found in Appendix 7.4 as an example.
3. When the interview guide was designed, interviews could be conducted. At the start of the interview, confidentiality was explicitly explained to the interviewee. During the interview, the flow was flexible basing the order of questions and topics on the conversation. In the end, all key questions set up were covered during the interview. Moreover, comments were directly made during the interview which resulted sometimes in additional follow up questions or clarifications as the interviewer repeated the questions which resulted in extra clarity and depth of the interview.
4. Lastly, the responses obtained were analysed. This was done directly after the interview to make sure all comments were still well understood. The comments made were organised based on the topics dealt with during the interview and stored securely on the company owned and secured database. During the analysis of the obtained data, first themes and patterns from the single interview were sought after. Key insights and takeaways were noted down which were later compared with the key insights and takeaways from other interviews conducted. In a few instances this raised additional questions, since the researcher was embedded in the company, it was easily accessible to ask for clarification.

During the research multiple interviews have been conducted looking for answers concerning questions about various topics. First of all, an interview has been held with a project supply chain lead engineer. During this interview the main focus was on the setup of the organization and how projects are actually executed. Next, three engineers have been interviewed, all expertised in one of the products researched during the case study. During these interviews, the main focus was on how the product worked, how the product was structured and how, in general, standardization has been applied to the product at this moment. These interviews were conducted to establish a better understanding of the products and the way of working at Huisman. Furthermore, an interview has been conducted with an employee of the research and development discipline. This employee focusses, among other things, on the potential standardization of the drivetrain in various projects. Using his expertise, the factors influencing standardization have been reviewed and adapted where needed. After these interviews had been conducted, the SSDP was finished and could be demonstrated for which six more interviews were conducted to gather additional information. For the first two activities of the SSDP three interviews had to be conducted. These interviews were held with a tender and concepts engineer, a sales manager, and a technical project manager. These interviews resulted in the knowledge and data needed to determine the market strategy and the external factors of all three products. This was possible since Huisman is set up as a project organization where everyone gets assigned to various projects obtaining knowledge about various products. For activity four and five of the SSDP three more interviews were conducted. The interviewees in this case were a technical project manager who is engaged closely in the design of KBCs, a sales manager who sold multiple KBCs and a supply chain manager. During these interviews, first of all the current status of the internal factors was discussed after which questions were asked regarding potential ways to further standardize concerning the internal factors. The interview protocol designed for the technical project manager is placed in Appendix 7.4 as an example. Besides these interviews, the results of these interviews were later discussed with the same interviewees to determine the impact and possibility of potential changes the other interviewees suggested to define the standardization strategy in activity six of the SSDP.

An overview of all interviews conducted can be found in Table 2.1.

Table 2.1: Overview of the conducted interviews

Function Interviewee	Topic(s) Discussed	Duration (min)
Supply Chain Coordinator	Overall order fulfilment process at Huisman	60
Electrical Engineer	General information about MCPGs	60
Technical Project Manager	General information about LECs	60
Technical Project Manager	General information about KBCs	60
Principal Engineer R&D	Factors influencing standardization	60
Tender and Concepts Engineer	Market strategies, predominantly focussed on KBCs	60
Sales Manager	Market strategies and market related factors of KBCs, LECs, and MCPGs	60
Technical Project Manager	Variations in regulations and standards	30
Technical Project Manager	Product related factors, the engineering process of KBCs and standardization potential	60
Sales Manager	Sales process of KBCs and standardization potential	30
Supply Chain Manager	Variance of integrated products, vertical integration, the supply chain process of KBCs, and standardization potential	60

2.4.6. Use of Direct Observations

According to Yin (2017), observations will provide additional information about the topic as well as new dimensions for understanding context or the phenomenon that is studied. During the research done for this thesis, the main researcher was working on the thesis at the office of Huisman Equipment for on average four days a week. During the time at the office, direct observations have been obtained from employees working on the projects. By being part of the company, feeling for the company and products was created resulting in a better understanding of the case company itself, as well as the sub-units of the research. There was thus no specific focus on observing a specific element but the brought picture provided useful insights. Being able to have short conversations and discussions with employees and listening to conversations and discussions between employees gave the best observations and insights. This was caused by the informal settings and spontaneous dialogues. Besides working on the thesis in the office, meetings about the sub-units have been attended in which additional data is gathered.

The insights gathered by these direct observations will help to better understand the context of the research. The observations were especially valuable when investigating other sources of evidence like conducting interviews or investigating archival records as more knowledge and understanding of the problems and current status had been obtained.

2.4.7. Evaluation

To evaluate the SSDP overall as well as the outcome of the SSDP, 2 steps have been taken. The first step was to evaluate the result of the SSDP individually with experts in the field of sales, engineering and supply chain. To do so, a meeting was planned with managers from these departments where the results were presented and explained. During these meetings, not only the results of the specific department were treated but the results of the other departments as well. This was deemed relevant as the strategy applied for different departments will also affect the specific department of the manager the results were presented to. During these meetings, valuable feedback was gained which could be worked out in the standardization strategy that was developed during the case study.

Besides these individual meetings, a session has also been organized where managers from different departments were present. Among others, the sales manger, the engineering manager, multiple supply chain managers and a manager of operations were present. In total, the session was attended by 12 employees besides the researcher. During the evaluation, first a 20 minute presentation was given by the researcher in which the methodology of developing the SSDP was shown, the SSDP was further explained, and the results were presented to the attendees. During and after the presentation there was room for questions, discussions and feedback. This helped discover potential improvements regarding weak points of the SSDP overall, as well as the developed standardization strategy. In total, the session took one hour in which 20 minutes were filled by the presentation and 40 minutes of discussion. The result of the session can be found in Section 5.7.

2.5. Thesis Project Methodology Overview

Figure 2.1 depicts the thesis project methodology overview. In this overview can be seen what activities of the DSR are performed during the literature study, design phase, and case study. Furthermore, the accompanying research questions and design objectives are depicted. As can be seen in the overview, conducting the literature study will have to result in answers to all research questions that have been posed. Making use of these research questions will provide the ability to set up the procedure in the design phase. Designing the procedure followed by a demonstrating and evaluation during the case study phase of this research will achieve the DO that has been set up. Using this and the answers to all research questions will help achieve the MRO.

Lastly, in the most right column of Figure 2.1, an overview of the chapters and their sections is provided. From this overview can be seen what chapters hold the information to the steps of the DSR, the RQs and the DO.

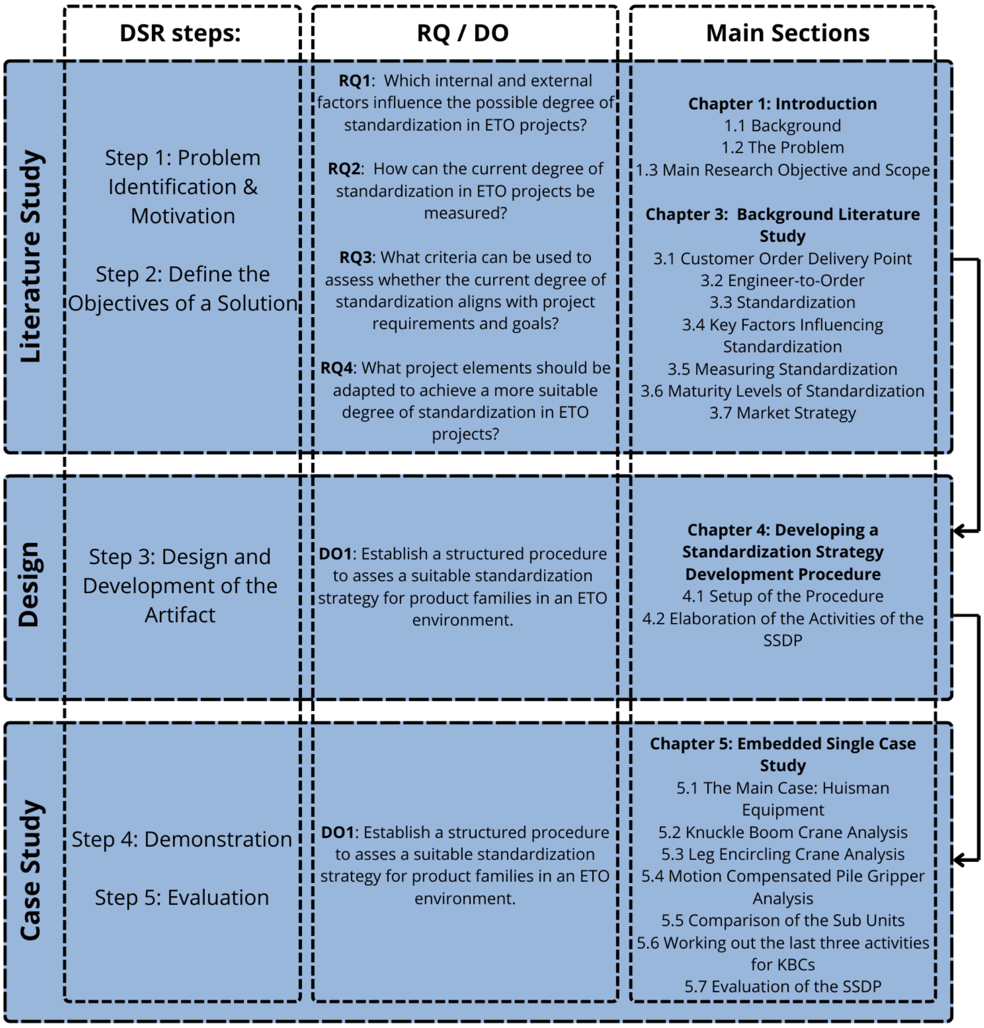

Figure 2.1: Thesis Project Methodology Overview

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3
Background Literature Study

This chapter comprises the literature study that has been conducted. The purpose of conducting the literature study and writing this chapter is to develop background information and answer the research questions. The knowledge collected during this research is needed to construct the procedure in Chapter 4. In order to establish the required knowledge, first definitions and background information have been defined in the first three sections of this chapter. First of all, customer order decoupling points (CODP) are explained, defining what a CODP is and how it influences standardization. This is followed on a section devoted to engineer to order (ETO), which is a CODP. In this section, ETO is defined after which the processes are split up into engineering and construction. Additionally, different types of ETO are explained as well as the characteristics of an ETO environment. Section 3.3 is focussing on standardization, after a short history of standardization, a definition is given to the term. After this, it has been identified standardization can be split into product and process standardization which are both elaborated on.

Now the needed background is gathered, the next sections can go more in depth to be integrated in the procedure which will be set up in Chapter 4. Section 3.4 treats the key factors influencing the degree of standardization. The factors are divided into market, product and process related factors. These factors are of importance for the procedure as external factors will set the boundaries of standardization where the internal factors can be influenced to adapt standardization. By setting up these factors an answer to RQ1 can be obtained. Besides the key factors, a method that can be used to measure standardization is given in Section 3.5, this method will be the answer to RQ2. Applying this method in the procedure will give insights in the potential of standardization of the product. This is then followed by Section 3.6 where a maturity model that can be employed to indicate the maturity of standardization in products is introduced. This maturity model can be applied in the procedure to indicate how mature the current product is regarding standardization and how it can possibly be improved. Combining this maturity model with the factors set up will result in an answer to both RQ3 and RQ4. During the investigation to standardization it became clear the market strategy is of high importance as well. Because of this, Section 3.7 has been dedicated to market strategy to make sure this can be integrated in the procedure as well. This chapter is closed with a conclusion based on the content of the chapter.

3.1. Customer Order Decoupling Point

To be able to understand what engineer to order exactly is. it is first important to understand what a customer order decoupling point (CODP) is. The CODP can be indicated as the moment in the supply chain where the product can be linked to the customer order (Olhager, 2010). According to several articles (eg. Wikner (2014), Gosling et al. (2017), Cannas et al. (2019), and Harfeldt-Berg and Olhager (2024)) the first introduction of this point was done by Sharman (1984), he however called it the Order Penetration Point and identified it as the last stock point in the supply chain where inventory is held before it is customized to the requirements of the customer. At this moment the product thus becomes associated with the customer who made the order as they start influencing the product that is ordered (Harfeldt-Berg & Olhager, 2024).

Traditionally, the CODP separates the supply chain into two phases, on the one hand the process before the order and on the other hand the process after the order is received. Wikner and Rudberg (2005b) argue there is not just one single point but more a zone, the customer order decoupling zone (CODZ). As, according to the authors, there are three degrees of uncertainty in which activities are performed: uncertainty, some uncertainty and certainty. During the 'some uncertainty' phase the certainty gradually increases due to more information becoming known about the actual order that will be placed, this phase is the CODZ.

Olhager (2010) indicate that before the order is received the process is forecast-driven, the more forecast driven the more downstream the CODP is positioned. In contrast, after the customer order is placed the process is customer order driven, the more customer order driven the supply chain is, the more upstream the CODP is positioned. Moreover, the further upstream the CODP is positioned the more customizable the end product will be. However, this will result in increasing lead times and costs. On the other hand, if the CODP is moved downstream the customization will reduce, as well as lead times and costs (Schoenwitz et al., 2017).

Four main CODPs are identified making a differentiation between engineering, fabrication, assembly and delivery. These are: make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO), and engineer-to-order (ETO). This is better visualized by Olhager (2010) as illustrated in Figure 3.1

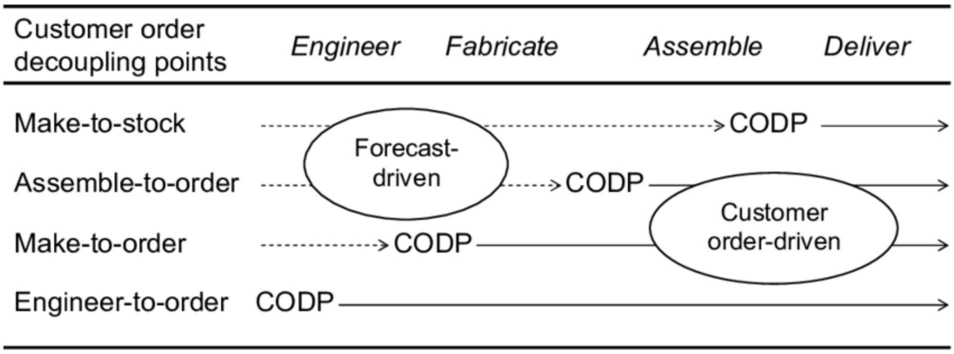

Figure 3.1: Customer order decoupling points (Olhager, 2010)

As described by Willner et al. (2014), MTS is fully forecast driven, most of the activities are performed before the order is placed. The product will be designed, produced and placed into stock without any interference of the customer. After the product is ordered it will be directly shipped to the customer without the customer having any customization options. ATO is mostly forecast driven where assemblies are made to order, built up from pre-manufactured parts and components. Here the customer thus has some influence, however, it is still mostly forecast driven. MTO is the process where the end product is partly forecast driven, however, the biggest part is customer order driven including all manufacturing and assembly operations with influences from the customers requirements which are processed using configurators the customer has to choose from. ETO works just like MTO, however, without an predefined solution space with configurators. In this production strategy the customer also has influence on the engineering and design of the end product (Harfeldt-Berg & Olhager, 2024). The degree of customization can range from small extensions that are specially engineered for the customer to the full design to the full development of a new product Willner et al. (2014). ETO will be further explained in Section 3.2.

3.2. Engineer-to-Order

3.2.1. Definition of ETO

In today's competitive manufacturing landscape, customization has become a key differentiator, leading to the widespread adoption of the ETO approach. Despite the growing relevance of ETO, there is no universally accepted definition of ETO in literature as explained by, among others, Willner, Powell, et al. (2016) and Gosling et al. (2009). The biggest difference is that some researchers indicate a product has been designed before and is fully adopted to the requirements of the customer. However, other researchers see ETO as a complete new design of a product that has never been made before. This will then too be designed fully to the requirements of the customer (Willner, Powell, et al., 2016).

K. Porter et al. (1999) make a distinction between these two interpretations by introducing ”Design to Order” (DTO). In a DTO approach, the end product is designed specifically for the customer, fully tailored to their requirements. On the other hand, in the ETO class the end product is already defined. However, there is the full availability to change it in any way needed specifically to meet the demand of the customer. The provided end product is thus fully customizable allowing for any modification that are required by the customer.

Wikner and Rudberg (2005a) reduce confusion among these different definitions and interpretations by adding an extra dimension to ETO. They identified the CODP should be split up into a production dimension ($CODP_{PD}$) and an engineering dimension ($CODP_{ED}$). In this way of approaching the CODP the production dimension for ETO will always be MTO_{PD} as Wikner and Rudberg (2005a) indicate the full flow of production in ETO is the same as in MTO as both are driven by customer orders. The engineering dimension is a bit more complex. Here ETO_{ED} indicates the situation where a new product should be designed and engineered to order. However, when the product is based on an existing design it will be changed to adapt to order (ATO_{ED}). In this situation an existing product is thus adapted to the specific requirements of the customer. Furthermore, in the engineering dimension engineer to stock (ETS_{ED}) is the last option, in this case the engineering is done before the order and is thus ’in stock’. Table 3.1 gives an overview of the traditional CODPs are related to the two dimensions.

Table 3.1: Traditional CODPs in terms of production and engineering CODPs Wikner and Rudberg (2005a)

Traditional CODPs	Traditional CODPs in terms of	
	Engineering	**Production**
ETO	ETO_{ED}	MTO_{PD}
-	ATO_{ED}	MTO_{PD}
MTO	ETS_{ED}	MTO_{PD}
-	ATO_{ED}	ATO_{PD}
ATO	ETS_{ED}	ATO_{PD}
MTS	ETS_{ED}	MTS_{PD}

3.2.2. Engineering and Construction Process in ETO

Just like Wikner and Rudberg (2005a) split up the term ETO into the engineering and production dimension, Cannas et al. (2019) split up the process of ETO into two processes: the engineering and the production process. The authors based their processes on 16 articles concerning ETO which resulted in six sub-flows in the engineering process and four sub-flows in the production process. The customer order decoupling point can be placed on any of these sub-flows.

The first sub-flow of the engineering process the customer can penetrate is at the moment research is still conducted, here the product concept is defined. This will be followed by the development sub-flow where codes, standard and principles are established consisting of for example materials that will be used and what performance is expected from the product in various conditions. Next, the point when the design is made, where detailed product specifications are set up, is a penetration point. The following two sub-flows concern changes to the existing design. First major changes indicating changes to the technical and/or functional characteristics of the product. The next sub-flow in which the customer can become involved in the engineering process occurs when only minor modifications are made to the existing design. These changes are only superficial and do not affect the technical or functional characteristics of the product. The last sub-flow is combining pre-defined design options making it a configuration.

As mentioned before, the production process is split up into four sub-flows where the customer can penetrate. First of all the purchase of raw material followed by making parts and/or sub assemblies from these raw materials. Next, the assembly of the parts and/or sub-assemblies and lastly the delivering of the finished product.

The engineering and construction process and their sub-flows are depicted in Figure 3.2 in order to give a better overview.

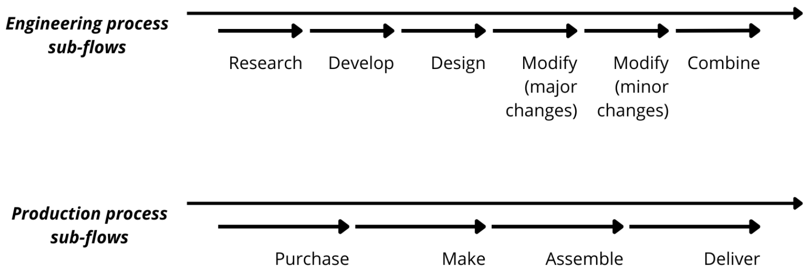

Figure 3.2: Engineering and production process sub-flows adapted from Cannas et al. (2019)

Depending on which point the customer enters in both the engineering and the production process indicate the level of customisation that is applied based on the customer specific requirements. The further down in the process the more is standardized as the previous performed steps will be executed in a forecast driven way where standards will be applied (Olhager & Wikner, 2000).

3.2.3. Types of ETO

Bertrand and Muntslag (1993) indicate that ETO can vary among different firms working in the ETO environment. They identified four differences among different ETO firms:

- The complexity of the products
- The degree of customer specificity of the product
- the lay-out and complexity of the production process
- the characteristics of the market and the competitors

Although the term ETO can thus be applied to various firms, there are still differences in the way work is executed depending on the overall complexity. This has also been noticed by Amaro et al. (1999) and Hicks et al. (2001), these researchers have split up ETO in different classification categories or types of ETO. Amaro et al. (1999) categorises non make to stock companies into categories based on the degree of customization; the responsibility for design, specifications and purchasing; and the activities that take place after the customer order has been placed. This results in four categories of ETO, five categories of MTO and two of ATO. The degree of customization is divided into four categories:

1. Pure: Produce new design
2. Tailored: Modification to an existing design
3. Standardised: Pick from set or design options
4. None-standard product: Take existing design as is

Amaro et al. (1999) do see ETO as a pure degree of standardisation where a whole new design is made. The first category of MTO could also be considered as ETO as here modifications are made to an existing design where every activity is conducted after the receipt of order except the design. The different types of non to make stock companies are displayed in Table 3.2. In the table the term design refers to the basic idea of the product, often a rough set of drawings. Specification means the set of detailed drawings to support production as well as the list of both technical requirements and of materials to use. Routing refers to the definition of the actual path the product will follow in the shop floor indicating which machines to use in which sequence.

Table 3.2: 11 types of non make to stock companies (Amaro et al., 1999)

The classification categories	ETO				MTO					ATO	
	1	2	3	4	1	2	3	4	5	1	2
Degree of customisation											
Pure	X	X	X	X							
Tailored					X						
Standardised						X	X			X	
None								X	X		X
Company responsibility for:											
Design	X				X	X	X	X	X	X	X
Specification	X	X			X	X	X				
Purchasing	X	X	X		X	X	X	X	X	X	X
Activities after receipt of order:											
Delivery	X	X	X	X	X	X	X	X	X	X	X
Assembly	X	X	X	X	X	X	X	X	X	X	X
Processing	X	X	X	X	X	X	X	X	X		
Purchasing	X	X	X		X	X		X			
Routing	X	X	X	X	X						
Specification	X	X			X						
Design	X										

Hicks et al. (2001) take another approach to categorize ETO companies and divide them into four ideal types of ETO companies. These four types are based on core competencies, the competitive advantage achieved with those core competencies, the vertical integration, supplier relationships, the stability of the environment they operate in, and the type of risk induced.

Type I companies are the *Vertically Integrated Companies* which have their core competencies in design, manufacturing, assembly, and project management. The knowledge these companies have about the product and process, and the ability to integrate internal processes can be seen as their competitive advantages. Most of the activities are conducted in house, indicating a high level of vertical integration. In order to reduce uncertainty in the supply chain these type of companies have an adversarial supplier relationship purchasing from several different suppliers. Furthermore, these type of ETO companies operate in a traditional market with predictable demand. Risks that are faced are under-utilization of the capacity, poor return on capital and under-recovery of overhead costs.

Type II companies are the *Design and Assembly Companies* which have their core competencies in design, assembly, and project management. Their competitive advantage lies in their ability to integrate systems and coordinate both internal and external processes. These companies maintain a medium level of vertical integration, often outsourcing component manufacturing while retaining high value-adding assembly activities in-house. Supplier relationships are based on partnerships that involve sharing product and process knowledge enabling more flexibility. Type II companies operate in uncertain environments and face risks such as losing manufacturing related design competencies and the possibility of suppliers becoming future competitors due to shared knowledge.

Type III companies are the *Design and Contract Companies* that primarily focus on design, project management, and logistics. They achieve a competitive advantage through systems integration and effective coordination of internal and external processes. All physical production activities, including manufacturing and assembly, are outsourced, resulting in a low level of vertical integration. Supplier relationships are built on partnerships. These companies operate in dynamic environments and face overall contractual risks related to supplier performance and capabilities.

Type IV companies are the *Project Management Companies*, functioning primarily as consultancies with core competencies in project management, engineering expertise, and logistics. Their competitive advantage is build up from their reputation, engineering knowledge, and flexibility. These companies have a very low level of vertical integration, outsourcing both design and all physical processes. Relationships with suppliers and subcontractors are managed through clearly defined contractual agreements rather than close partnerships. As these companies operate in dynamic, project-based environments, very little operational or financial risks are faced. A risk faced however, is a loss of reputation.

3.2.4. Characteristics of ETO

Although there are differences between types of ETO some characteristics can be identified in all of them. First of all, customer requirements are received and should be transformed into the end product which are highly complex and produced in small batches or as one-of-a-kind products (Fortes et al., 2023). More customization in projects results in higher risks, longer lead times and higher costs (Hicks et al., 2000). However, the better an ETO company is able to understand and translate customer requirements into the end products the more value is created by ETO companies (Konijnendijk, 1994), (Mello et al., 2016). Furthermore, the projects are time limited and deliver complex equipment to third parties, to do so ETO companies are constantly working on research, development, engineering, procurement, and manufacturing (Caron & Fiore, 1995). Moreover, Powell et al. (2014) indicate the difficulty or even impossibility of forecasting demand, ordering and producing in advance or setting up batch production methods due to the low volumes ordered by customers. This causes uncertainty resulting in complex planning and control of projects. At last, where in most industries the price is the most important factor, in ETO the lead time, designs and flexibility are generally more important (Thomassen & Alfnes, 2017). However, as indicated by Birkie and Trucco (2016) price is becoming more important nowadays.

When comparing the ETO industry to the production industry the biggest differences that can be identified are first of all the penetration point of the customer into the process. In an ETO industry the CODP is far upstream the supply chain where in the production industry the CODP is far further downstream. Furthermore, the complexity lead times and volumes of this end product produced differ heavily between the two industries (Gepp et al., 2016).

3.3. Standardization

3.3.1. Definition of Standardization

The first to mention standardization in literature was the car engineer Henry Ford. Henry Ford implemented standardization in the production of his cars in the production industry (Jose & Tollenaere, 2005). Later in the early 1970s, another company in the automobile industry further explored standardization. Toyota Motor Company developed the Toyota Production System (TPS) which has the aim to eliminate waste and optimize the workers capabilities in the production of their cars. By doing this cost reduction is achieved as processes and products are standardized to make sure waste is eliminated and workers capabilities optimized (Lander & Liker, 2007). In 1990, Womack et al. published a book based on the TPS, here the term lean was first introduced to the world for this way of working (Womack et al., 2007).

Aapaoja and Haapasalo (2014) indicate standardization is the basis if lean culture is aimed for, standardizing results in continues improvements, involvement of employees, and identification of problems. This corresponds to Ohno (1988) who investigated the TPS and concluded that without standards there can be no improvement. As shown by Kumar et al. (2022) there are a lot of techniques to achieve the purpose of lean manufacturing. Several of these techniques are related to standardization, such as work standardization and the 5S method, which stands for Sort, Set in Order, Shine, Standardize, and Sustain. Furthermore, the Kaizen technique is also related to standardization. Kaizen means 'Continues improvement' in Japanese. It stresses the essence of continuous improvement of standards to ensure they remain up to date and effective. Särkisilta (2021) visualized how standardization and Kaizen improve the process and keep it at a high level, this is illustrated in Figure 3.3. This method complements a quote by Henry Ford in 1926: "Today's standardization is the necessary foundation on which tomorrow's improvement will be based. If you think of standardization as the best you know today, but which is to be improved tomorrow, you get somewhere. But if you think of standards as confining, then progress stops." (Paulsen, 2013).

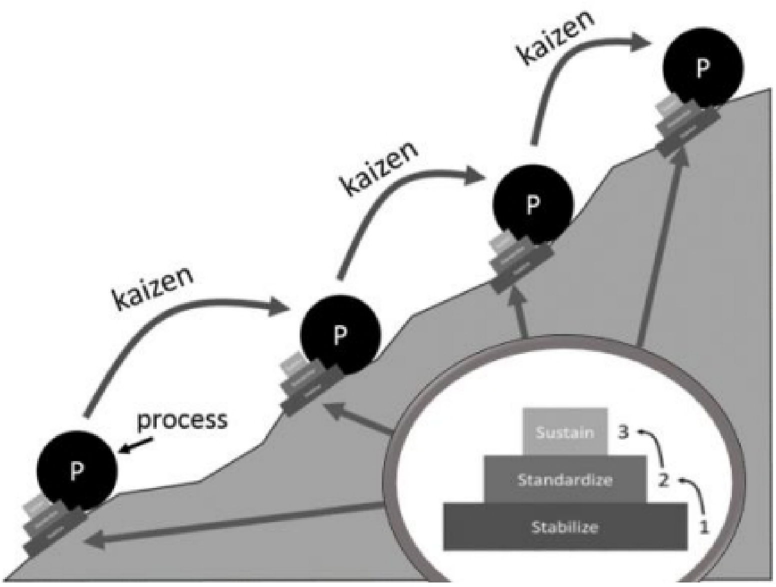

Figure 3.3: The purpose of standardization and Kaizen (Särkisilta, 2021)

Many different industries have tried implementing lean into their production process which should be possible according to Womack et al. (2007). However, implementing it in other industries than the production industries is difficult as characteristics of these environments differ from the production industry (Lander & Liker, 2007). As explained in Section 3.2 the ETO environment is characterized with high levels of customization and this thus makes implementing the lean principles and in particularly standardization difficult to achieve. Before finding out how standardization should be applied and identifying the benefits and limitations of standardization in the ETO environment first a definition of standardization should be formulated.

The definition given to standardization by Gibb (2001) summarizes and combines best how other researchers define standardization. Applying their interpretation, standardization can be defined as: *Consistently applying established processes, procedures and products in which regularity, repetition, and a proven track record of success are present.*

The main goal of standardization within projects is to get more control over the final output of activities in the project reducing waste. Waste can be described as anything other than the minimum amount of time of employees, equipment, shop floor space and materials (Mor et al., 2019) needed to produce an end product. In this way risks can be predicted and minimized and reliability in end products free of defects can be maintained (G. Wang et al., 2010), (Kasiri et al., 2017). More benefits will later be explained in Section 3.3.4.

Despite the advantages projects should most of the times not be fully standardized as there are limitations as well which will be further explained in Section 3.3.5. The degree projects are standardized to can thus vary heavily ranging from just one small component of the project to the whole project itself (Choi et al., 2022).

Lampel and Mintzberg (1996) set up five degrees of standardization which are in decreasing level of standardization: pure standardization, segmented standardization, customized standardization, tailored customization and pure customization. These five degrees indicate if the design, fabrication, assembly and distribution of the project are standard or custom and in that way define the degree of standardization. These levels of standardization are quite similar to the CODP discussed in Section 3.2 as normally from the moment the order is placed a project becomes customized to the requirements of the client.

Standardization can be split up into two main domains: product standardization and process standardization. As indicated by Aapaoja and Haapasalo (2014) there is an interconnected nature between the two as they support and complement each other. Processes should be set up in such a way they facilitate the use of standardized products or components. On the other hand, the standardized products or components should be determined in such way they supports and enhance the processes set up. The processes and products should thus be implemented in parallel in order to achieve the best benefits of standardization. This can also be seen in the paper written by Lampel and Mintzberg (1996) who show the process and product strategies for different industries. The strategies indicate the degree of standardization applied to the end products. As can be seen in Table 3.3 for each separate industry the same strategy is applied for the process and the product of that particular industry. This does only not hold true for the routing industry which concerns delivery services and data transmission.

Table 3.3: Industry Strategies Mapping adapted from Lampel and Mintzberg (1996)

Industry	**Process Strategies**	**Product Strategies**
Mass	Standardization	Standardization
Thin	Customization	Customization
Catalog	(Segmented) Standardization	Segmented Standardization
Menu	Customized Standardization	Customized Standardization
Tailoring	Tailored Customization	Tailored Customization
Routing	Customized Standardization	Customization
Agent	Tailored Customization	Tailored Customization
Bulk	Standardization	Standardization

3.3.2. Product Standardization

In order to adapt product standardization in projects the complex end product of the project should be able to be decomposed into submodules and components. These submodules or parts should be standardized where possible making them able to be shared, swapped and used in multiple projects. In product standardization, the focus is laid upon the use of these common parts, components, modules and platforms in various sectors of the project like research and development (R&D), production, and purchasing (Z. Wang et al., 2016).

As explained by Gepp, Gölzer, and Grobholz (2015) standardization is often preceded by modularization. Modularization is the decomposition of the project into different modules which can vary in size due to their complexity. Modules could in theory be the whole project but can also be assemblies or just a bundle of components. Modularity and standardization will result in the ability to design a variety of products integrating the same components or modules. When the same modules are integrated over different projects these projects can be called platforms (Jose & Tollenaere, 2005). Integrating platforms among the variety of projects in a company will result in family design savings as the design of the module has already been designed before.

According to Johnsen and Hvam (2019), the level of standard configurations reduces complexity by increasing standardization. When more standard components and modules are set up they can thus be introduced in standard configurators which can be used to configure the end product.

Gibb (2001) emphasizes product standardizing is not as simple as just integrating standard parts. He indicates the importance of interchangeability of components in projects making the interfaces between components more important then the components themselves.

In order to achieve product standardization relations should be set up with vendors willing to standardize as well. These suppliers of the materials should be able to always deliver the standardized component or modules whenever and where ever they are needed and for that healthy relationships are important

(Choi et al., 2020).

An example of an industry where product standardization has a big impact is the shipbuilding industry. This industry transformed itself from an industry where end products were one-off to an industry where standardization an modularization is utilized widely (O'Connor et al., 2015).

3.3.3. Process Standardization

As emphasized by Aapaoja and Haapasalo (2014) process standardization is the basis for continues improvement where employees get involved, problems will be revealed and only reliable technology is implemented. By implementing standardized processes and procedures project teams will work more efficiently and waste will be reduced, this will be further explained in Section 3.3.4. Advancements in technology like modern business systems, IT and management techniques allow standardized processes to be more advanced and flexible (Gibb, 2001).

Just like product standardization, there is also a difference in degree of process standardization. It can vary from absolute standards where no one can deviate from like standard documentation or procedures worked out at a very detailed level. On the other hand, it can also be more strategic integrating a standard framework or approach (Gibb & Isack, 2001). The first is a more coercive approach where is specifically defined what should and what should not be done. The latter leaves more room for deviations, it are more standard directions being more proactive. The second approach is seen as the approach producing better results (Aapaoja & Haapasalo, 2014).

A way of standardizing is by integrating a higher level of standard configurators as mentioned in Section 3.3.2 (Johnsen & Hvam, 2019). In the process these configurators should then be implemented when for example designing the product or in the process of setting up the product with the client.

Examples of process standardization are standardizations in contractual relationships and partnerships where in the documentation identical clauses are set up which can possibly be supplemented with the needed variable clauses. Furthermore, procedures for meetings, financial appraisals, procurement, quality plans and standard approaches for changes in the project can be set up. Moreover, the procedure of project management can be standardized as well (Gibb, 2001). Besides this, the production process can also be standardized where the requirements of the customer are postponed as far as possible in the production process. In this way the the production process can be the same for the projects before the specific requirements are adapted allowing the production facility to be set up for these standard operating procedures (Swaminathan, 2001).

As described by Mor et al. (2019) standardization of work can be a way to standardize the process as well. This way of standardizing consists out of standard working routines that are established to be the currently best known methods and sequences to conduct each process for each worker. To make this approach succeed the operations should be conducted exactly like stated in the standard. In this way, random operations will not be performed reducing variations in cycle times. It should be noted that standard work is not the best working routine that will ever exist. It is the best routing that is known when used, however, improving it is a continues process just like the improvement of the other process standardizations.

3.3.4. Advantages of Standardization

The advantages of standardization have been researched by many scholars identifying why organizations could benefit from standardization. As described in Section 3.3.1 the main goal of standardization is to get more control over the final output of activities with the project reducing waste.

By gaining control over the final output and in that way reducing waste several benefits can be recognized. Choi et al. (2022) set up six areas concerning the benefits of standardization. These are:

1. Cost savings
2. Improvement of schedule
3. Improvement of efficiency, predictability and flexibility
4. Better value for money
5. Improvement of reliability and accuracy

6. Added control of projects

The advantages of cost savings are further elaborated on by O'Connor et al. (2015) who identified economic advantages of standardizing whilst reviewing modular plants. Most of these cost related advantages can be recognized in other industries as well. First of all, they indicate a design should only be made once and can than be used multiple times. This will result in less engineering hours what leads to lower costs, this advantage has been identified by Gepp et al. (2016) as well.

Furthermore, there will be a learning curve in the use of standardized components and processes. This is further elaborated on by Gibb (2001) showing that the familiarization of personnel working with these components and processes ensures productivity and thus less working hours spent. They also indicate there is a continual improvement in safety and control of risks due to this familiarization.

Moreover, increased reliability will be obtained as the standardized components are thoroughly tested and used more often. By taking away the variability in these projects and by stakeholders getting more familiar the quality of the end product will also be enhanced Mehta (2024).

Next, O'Connor et al. (2015) also point out the advantage of discounts in procurement when components are bought in bigger volumes as purchasing leverage will be achieved via multi purchase agreements. Standardization will also decrease the amount of claims, conflicts, and change orders in the projects which in their place will lead to less unplanned costs (Aapaoja & Haapasalo, 2014).

Besides this, another advantages obtained by standardization can be recognized in the research by MacCarthy et al. (2003). In their paper, the researchers look into different modes of mass customization. When looking at the information streams there can be recognized that when standardizing more, less information streams are needed between departments. This will save valuable time and reduce possible mistakes made when handing over information.

Lastly, Birkie and Trucco (2016) emphasized short lead times in projects are becoming an important competitive advantage these days. By implementing standardization within projects, lead times will reduce caused by the reduced engineering hours that need to be spent on the project and the increased productivity in realizing the project.

The potential of standardization is present on single projects however, it will be leveraged more when they are repeated in more orders developing economies of scale (Dea & Gans, 1986). This will be caused by the reduction of variety which can be applied both physically and non-physically. However, Tassey (2000) mention the positive impact is difficult to analyse as it enables economies of scale which results in only bigger suppliers that can produce the demand excluding small innovative firms and thus their potential competitive innovation.

3.3.5. Limitations and Challenges of Standardization

As can be seen from the last positive influence highlighted, standardization has not only positive influences on projects but will also introduce its limitations and challenges when applying it to projects.

In their study Haug et al. (2009) look into the transition from ETO to mass customization where standardization is a main topic. They emphasize the importance lies in finding the right balance between flexibility and standardization. This is of importance as not all projects can be standardized to the same degree as some projects have high customer specific requirements. When these can not be delivered due to standardization a possible loss of market opportunities will be induced (Semini et al., 2014), highlighting the importance of understanding the market.

Standardization is also susceptible to changes in the markets environment, when changes in the market happen the standards set up could be useless requiring changes in the standards (O'Connor et al., 2015). Implementing standardization in an ETO environments will result in a simplification of the end products the organization is able to produce which can be fine for some products, however, other products should not be simplified. Simplifying by means of standardization will result in a loss of innovative capability as standards are applied and less new designs are created.

Having a standard design could also cause competitors to imitate that standard easier and organizational resistance could arise as employees get less freedom in designing the end product (Haug et al., 2009). Moreover, setting up a knowledge-base needed for standardization is a challenge as well as knowledge needed is often spread over the whole organization.

Choi et al. (2022) explain the importance of standardization management needed to facilitate a good execution of standardization in projects. An important challenge to take into account is making sure data is stored and managed correctly, when standards are introduced they should be able to be found and documented correctly. Karandikar and Nidamarthi (2007) see this as a complexity factor as engineers rather use their own personal design or develop a design from scratch when the standard design can not easily be found. It is thus of importance to make employees aware of the standards and to insist them on using the standards (Choi et al., 2023). Moreover, lack of appropriate managed data will result in a lot of time to be spent when changes have to be made to the standards.

Lastly, a challenge identified is the need for suppliers cooperating in setting up standards to the specifications needed. Without the suppliers cooperating in setting standards and being able to deliver the needed amounts of these standards there is no point of standardizing (Choi et al., 2023).

3.4. Key Factors influencing the Degree of Standardization

As described before in Section 3.1 the more downstream the CODP is located the more standardized the end product and the project of that specific product will be. In their article, Olhager (2003) defined factors affecting the positioning of the CODP (they refer to it as order penetration point). They combined 20 articles concerning factors affecting this point which made them conclude there are three main categories: market related, product related, and production related factors. Later, Cannas et al. (2020) focussed more on ETO companies in their case study reviewing 11 ETO companies with in total 24 ETO end products. They as well identified key factors influencing standardization for which they first conducted a literature study and later a case study. In their study they however defined, market, product and process related factors.

To set up the factors that influence the degree of standardization the same main categories are used as Cannas et al. (2020) set up in their research. These categories are considered because, as outlined in the previous section, standardization can be applied at both the product and process levels. It is thus interesting to determine factors in these domains to identify how standardization could be employed in a more suitable way. Furthermore, external factors are also of importance since they have a genuine influence on the potential of standardization. Because of this, the market related factors will also be determined. Section 3.7 will further elaborate on the market strategy as this heavily influences the market related factors. External factors indicate the organization has no direct control over these factors. Besides the market factors, the maturity of the end-product can also be classified as an external factor. On the other hand, the product related factors are factors the organization has direct control over and are thus internal factors. These factors will result in the characteristics of the end product produced. Finally, the process related factors can also be directly influenced by the organization. These factors represent the internal processes that can be influenced to enhance standardization.

3.4.1. Market Related Factors

In order to win tenders an organization should have a competitive market advantage which can be achieved by adhering to the market needs. Standardization can be a tool to accomplish this. The degree of standardization will make impact in the following cases.

First of all, *the delivery lead time requirements* are important. As indicated by Naylor et al. (1999) specific markets require shorter lead times than other markets. As mentioned in Section 3.3.4 one of the advantages of standardization is the reduction in lead time when introduced to the product and project. The degree of standardization should thus be increased if possible when low delivery lead times are required by the customer.

The volatility in the market is another factor that influences the degree of standardization. Volatility can be a differentiation in the market due to seasonal demand but can also be a variation in the market due to varying customer needs and requirements over time. There is a possibility that in a certain year no customers require a certain feature where the next year this feature is demanded by all customers causing a volatility in the end product. Mason-Jones et al. (2000) indicate agility is needed in a volatile market place as changes often occur, this indicates standardization should be limited. When there is a low volatility in the market, standardization becomes more useful as there is less uncertainty. An addition to this can be found in the article by Semini et al. (2014), the authors stress that when there is a high demand for a product, customers often accept a higher degree of standardization. On the other hand, when bad market times arise customers demand more customization.

The customization requirements wished for by the client is another factor influencing standardization. When there are a lot of differences in requirements between different orders standardization becomes less applicable. Moreover, the amount of changes of requirements after the order has been placed plays a role in standardization as well. When customers require and get the flexibility to make many changes after the order has been placed, standardization becomes difficult to implement as the standards will have to be changed to the new requirements posed by the customer. This was also noted in Section 3.1, where it was observed that postponing the CODP reduces customization, as the process becomes forecast-driven, allowing standards to be applied.

The size and frequency of orders makes impact on the possibility of standardization as well. Big sized orders and high frequencies make that the product should be produced regularly making standardization a suitable strategy to reduce, for example, cost and lead times. However, there should be the right demand as customer independent costs will be made for standardizing that have to be earned back (Semini et al., 2014). When these demands are seasonal this becomes more difficult as a high volatility is introduced in that case. This however does provide the opportunity to produce standard parts and components during the low demand periods (Olhager, 2003). When integrating standards and thus reducing variety in these frequent orders or larger sized orders, economies of scale can be attained as supplier specialization becomes possible increasing efficiency and lowering the price and lead times (Tassey, 2000).

In their case study, Cannas et al. (2020) identified two insights regarding the *type of customer* ordering the product. First of all, The technical knowledge of customers will play a role in the standardization of the end products. When the customer has low technical knowledge more freedom will be available in the development of the end product as the customer will not have any technical additions or input that should be introduced to the end product. This results in the possibility to implement existing standard technical specifications in the end product. Furthermore, the size of the customer will also make impact as smaller companies will most often ask for minimum prices and fast deliveries. As explained in section 3.3.4 this can be achieved by implementing standards into the end product. As Cannas et al. (2020) identified in their case study, smaller cost-conscious companies will accept the reduction of customization if the product is cheaper. On the other hand, bigger companies prefer customized solutions for there equipment needed, they care less about the price that has to be paid and can often accept longer delivery lead times. Moreover, the degree of standardization will also be impacted regarding if the customer will be the end user of the product or if they will sell or rent it out to one of their own customers. End users usually require more customized features resulting in a lower degree of standardization possible.

Besides these studies, Brabrand et al. (2021) identified another factor as a complexity driver for standardization. From their article can be concluded *variations in regulations and standards* hamper the level of standardization that can be applied to an end product. Varying regulations and standards in for example different geographic areas can influence if a product is standardisable or not. When the regulations and standards are variable, standardization becomes less useful as changes need to be made according to the appropriate regulations and standards the end product is designed and manufactured for.

An overview of the market related factors is depicted in Table 3.4

Table 3.4: Overview of Market Related Factors

Category	Factors	Key References
Market Related Factors	Delivery lead time requirements Volatility Customization requirements Order size and frequency Type of customer Variations in regulations and standards	Olhager (2003); Cannas et al. (2020); Naylor et al. (1999); Mason-Jones et al. (2000); Semini et al. (2014); Tassey (2000); Brabrand et al. (2021)

3.4.2. Product Related Factors

Besides the market related factors there are also product related factors that will influence the degree of standardization possible in projects.

First of all, *the maturity of the end product* that is manufactured during the project. Iakymenko et al. (2022) identified two types of maturity. At first, the maturity of the product design, which implies how the product design is developed over time. This is especially important for standardization as changes result in extra hours that need to be made to the design new products are based on. Secondly, the maturity of the technology used and implemented. When the technology used is evolving over time the changes in technology need to be implemented in new products as well to stay competitive with competitors. When the technology used in an end product is rather new, many changes need to be made to update the design to the newest technologies as it is not as stable yet as mature technologies that have been implemented often times before. When a new technology arises, geometries, materials, and components used will keep changing during the innovation of the technology decreasing the degree of standardization possible.

Next, *the customization opportunities* available have an impact on standardization as well. This has been pointed out by both Olhager (2003) and Cannas et al. (2020) as there are big differences between having no catalogue at al; a catalogue used as guideline or a catalogue with standards a client has to choose from. When the end product offers a lot of customizable features it will naturally have a negative impact on the degree of standardization. When the customization opportunities are reduced a decrease in variety will be obtained resulting in a higher degree of standardization.

Furthermore, *the structure of the end product* will have impact on the standardization possibilities. If an end product has a modular structure a higher degree of standardization is often able to be achieved. Products can have different levels of modularity varying in non-existent, partial or complete. When a modular design is established the customer normally gets the possibility to choose between predefined modules that are proven solutions. When the customer requires a customized solution this can be applied to only one module instead of the complete system (Semini et al., 2014). Moreover, Cannas et al. (2020) notes that when an end-product is pure standardised configurations have been identified as non-modular as no variation is needed in the modules due to the pure standard end product.

The *variance of integrated components* will also have impact on the degree of standardization. When varying components are integrated for the same purpose the degree of standardization decreases. Differentiation can be made between standard components which are always used, configurable components which are a selection of components from which the most useful are chosen per project and, special components which are integrated project specifically (Willner, Gosling, & Schönsleben, 2016). Moreover, having a variety of components limits economies of scale or network externalities as no standards are integrated (Tassey, 2000). The more special components are integrated the lower the degree of standardization will be.

An overview of the market related factors is depicted in Table 3.5

Table 3.5: Overview of Product Related Factors

Category	Factors	Key References
Product Related Factors	Maturity of the end-product The customization opportunities Structure (modularity) Variance of integrated components	Olhager and Wikner (2000); Cannas et al. (2020); Iakymenko et al. (2022); Semini et al. (2014); Willner, Powell, et al. (2016); Tassey (2000)

3.4.3. Process Related Factors

In the process of executing a project there are also factors that influence the degree of standardization possible. Cannas et al. (2020) identified the freedom given in processes impact the degree of standardization.

First of all, *the freedom of the sales process*. As mentioned before, the degree of standardization is impacted by the allowed degree of customization in the project. When a high degree of freedom is given to the sales team there will be a high variety in orders as customers will customize the product by the options given by sales. To reduce this variety the sales team could start working with standard configurators or full standards that should not be deviated from (Haug et al., 2009). When freedom of sales is limited more standards can be introduced as orders will be less or not customized increasing the degree of standardization.

Secondly, *the freedom of the engineering process* will also limit standardization. If engineers are given a lot of freedom to design the end product they will produce variants every time. In order to move towards standardization, engineering work should be standardized Haug et al. (2009). Moreover, when setting up standards it is of importance to integrate the various engineering disciplines to ensure the intended function of standardization. When one discipline deviates from the standards this impacts other disciplines (Gepp, Foehr, Vollmar, et al., 2015).

A third factor in line with these two factors is *the freedom of the supply chain process*. If there is a lot of freedom when ordering components different components are ordered for the same purpose. All these components will have different measurements and interfaces and are different to possible standards set up. When the supply chain is more lean more standard products will be ordered. On the other hand, agility and thus more freedom in the supply chain causes variety in the products (Naylor et al., 1999), (Mason-Jones et al., 2000).

At last, another process related factor can be identified in the article by Iakymenko et al. (2022). The authors indicate *the degree of vertical integration in the supply chain* to be of importance as well. When the production of components is performed by the same company that is executing the project the degree of standardization can be higher as the company is not dependent on a supplier. In this way, the company obtain more control over the process and make itself more resistant to changes from outside. Because of this, the company can also implement needed changes to standards more easily when those have to be implemented. Having the production of components in own hands reduce risks like suppliers that stop producing a certain product and knowledge about the standards is better protected as there are no third parties the knowledge is shared with (Monsur & Yoshi, 2012).

An overview of the market related factors is depicted in Table 3.6

Table 3.6: Overview of Process Related Factors

Category	Factors	Key References
Process Related Factors	Freedom of the sales process Freedom of the engineering process Freedom of the supply chain process Degree of vertical integration in the supply chain	Olhager (2003); Cannas et al. (2020); Haug et al. (2009); Gepp, Foehr, Vollmar, et al. (2015); Naylor et al. (1999); Mason-Jones et al. (2000); Iakymenko et al. (2022); Monsur and Yoshi (2012)

3.5. Measuring Standardization

In order to get an indication about the degree of standardization a measurement can be made based on previously executed projects and expected values. To do so, variables should be used which are well documented or can be well forecasted.

Willner, Powell, et al. (2016) set up a matrix to analyse the archetypes of ETO organizations. This is a 2x2 matrix where each quadrants presents one of the four archetypes that can be given to ETO products, this matrix is depicted in Figure 3.4.

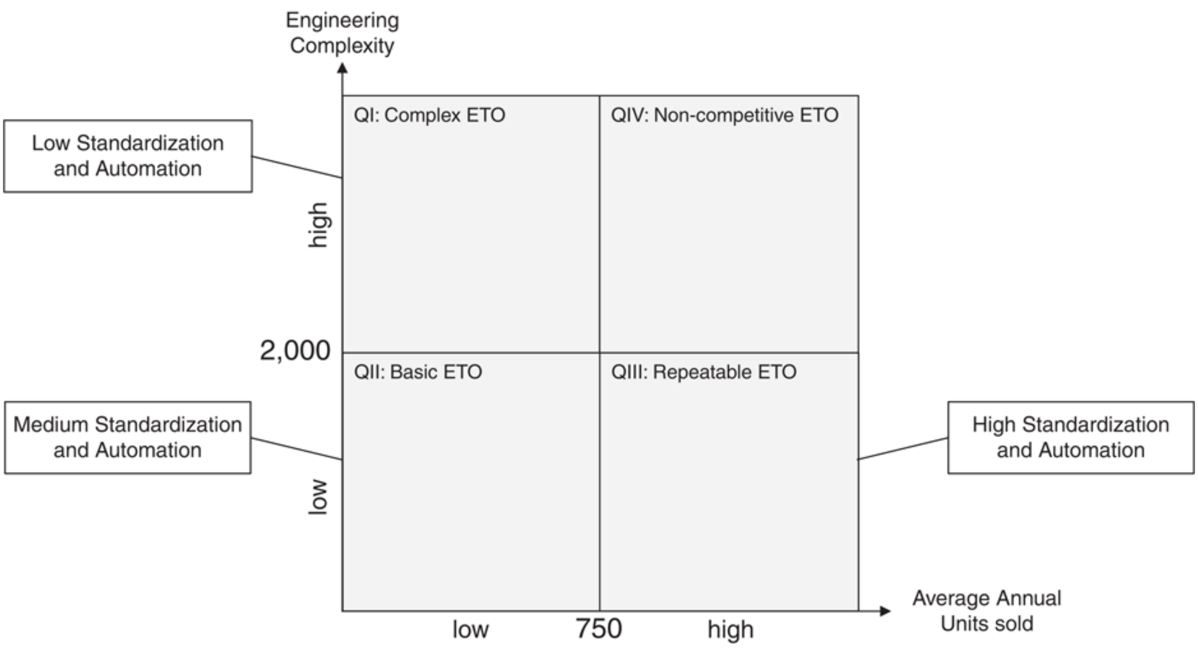

Figure 3.4: 2x2 ETO archetype matrix (Willner, Powell, et al., 2016)

The archetypes are based on two quantitative factors: Average annual units sold and engineering complexity. The average annual units sold are defined by the total amount of units sold in n years divided by the amount of years n (Equation 3.1).

$$\text{Average annual units sold} = \frac{\sum_{y=1}^{n} \text{Units sold}_y}{n} \tag{3.1}$$

This variable is also applicable for this study as there is a correlation between standardization and the amount of units sold as a higher degree of standardization will result in the possibility to produce more products. This will be the consequence of the increased efficiency and productivity standardization will induce as explained in Section 3.3.4. Furthermore, Willner, Powell, et al. (2016) explain this variable is generally well documented giving organizations the capability to measure it for finished projects.

Additionally, the engineering complexity is defined as the amount of engineering hours divided by the average annual units sold (Equation 3.2).

$$\text{Engineering Complexity} = \frac{\text{Engineering hours}}{\text{Average annual units sold}} \tag{3.2}$$

As indicated by Willner, Powell, et al. (2016) engineering complexity is chosen over product complexity as the product structure can be really complex, however, the engineering can be relatively simple as little order specific engineering is required. The complexity in the ETO environment can thus better be depicted by the engineering complexity as this influences the lead times and costs more. This is also what is required to indicate the degree of standardization as every order specific engineering hour spent on a project indicates customizations are done to the base product.

To find the order specific engineering hours per product the amount of engineering hours should be divided by the average annual units sold, engineering complexity can thus be expressed as engineering hours per unit. Just like the average annual units sold, engineering hours are also generally well documented making it an applicable variable to implement.

In the matrix (Figure 3.4) these two variables are plotted. When for a certain project the variables are defined, this particular project can be plotted in the matrix. As mentioned before, this will indicate what archetype of ETO defined by Willner, Powell, et al. (2016) the project will be in. Besides identifying the archetype a project is in, the matrix also gives an indication of the degree of standardization in projects. The authors illustrate this by indicating for each archetype if there is high, medium or low potential for standardization and automation.

This is first of all caused by the average annual units sold as standardization will cause an ETO organization to be able to produce more products as efficiency is increased decreasing lead times. This ensures there is more time to sell, design, manufacture and produce extra items increasing the average annual units sold.

Furthermore, engineering complexity is a variable that can be linked directly to the degree of standardization. This especially holds true for ETO organizations basing their products on previous products produced. When this is the case the engineering hours spent on the product will all be put into the customizations and other changes needed which relate to the degree of standardization in the project. When no customizations or changes have to be done this means the project is identical to the previous project indicating no engineering hours are spent on the project, this initiates the full project is standardized.

In the process related factors influencing standardization identified in Section 3.4, other departments are also mentioned besides engineering to have influence on standardization. These factors however, should not be included in the matrix when identifying an indication of the degree of standardization. This is the case as the amount of engineering hours is only impacted by changes and other customizations made. On the other hand, for example the supply chain team is also impacted by the amount of different components and materials they have to order which can differ greatly between different products. In the following section will be indicated how each factor is exactly related to either or both engineering complexity and annual units sold.

3.5.1. Linking Engineering Complexity and Average Annual Units Sold to the Standardization Factors

As explained, the factors influencing standardization identified in Section 3.4 can be linked to the two variables set up by Willner, Powell, et al. (2016). Nearly all factors mentioned have a significant impact on engineering hours.

Shorter *delivery lead time requirements* will decrease the engineering hours as more predefined standards have to be used which are worked out already. On the other hand, more *customization re-*

quirements will result in more engineering hours that need to be spent in order to implement all customizations. As more custom requirements are implemented less standards can be used resulting in engineers having to redesign the standard and implement the custom requirements in the final design other processes will also be influenced as they have to implement the customizations. This will take time resulting in the extra hours spent on the project. This will be influenced by the *freedom in the sales process* as well. When during the sales process a lot of customizations are granted engineering hours will increase as the customizations will have to be implemented. When there is a strict sales process only offering standard configurations, engineering hours will decrease as these configurations will have been established before and can be integrated in various projects.

Furthermore, the *size and frequency of orders* will also have impact on the hours spent on the project. When the size of orders increases multiple of the same end product can be produced whilst only engineering that solution once, decreasing the average engineering hours spent per end product. Frequent orders will also reduce the hours that need to be spent as the new orders will be based or copied from the previous orders placed. This is possible as in this short time no new innovations will have taken place that will cause changes in the design. This can be linked to *the maturity of the end product* as well. If there is a lot of innovation possible for the end product or components used in the end product the engineering hours will increase as engineers will have to implement these innovations in the product these changes will also result in more hours spent in other departments as they will also need to do extra work to implement these innovations.

The *type of customer* placing the order will also have impact on the amount of engineering hours spent. As indicated in Section 3.4 bigger customers generally require more customizations increasing the engineering hours spent. Moreover, when the technical knowledge of the customer is high, they will most likely require special customizations increasing the amount of engineering hours as well as hours spent on other processes. The application of the end product by the customer has an impact as well as this will result in *variations in regulations and standards*. When regulations and standards differ per specific product these should be adapted. These adaptions will result in extra engineering hours that need to be spent.

Factors related to the *structure of the product* will also influence the used engineering hours. When a product is set up in a modular way customizations will only impact the module they relate to instead of the whole system. However, if there are multiple sub-systems in a module or end-product multiple or even all of these sub-systems will be impacted by customizations, asking for extra hours to implement this. Additionally, a higher degree of *variance of integrated components* in the end products result in an increase in hours in multiple processes of the project. When varying components are used these should be incorporated in the design all having different measurements and interfaces.

Just like the freedom of the sales process mentioned before, the *freedom in the engineering process* negatively impacts the engineering hours spent as well. If engineers get freedom to make their own new designs they will take this chance resulting in more hours spent than when they use pre defined standards. This also accounts for the *freedom in the supply chain process*, when supply chain orders items that have been ordered before the interfaces the components have are known or the same component has been used in the same type of product before minimizing the engineering hours needed to spent to integrate a new component.

At last, The *degree of vertical integration* in the supply chain. When there is a high degree of vertical integration components will be constructed by the company executing the project. When the components are self produced there will be less problems with new versions or availability of the component at the supplier. Moreover, the component can also be designed especially for the projects they will be used in, which results in less time that needs to be spent integrating them into the project. This will result in no need to adapt the design to differences in this component making sure no extra engineering hours need to be spent. It is important to note that the engineering hours spent on the design of the specific component are not included in the engineering hours spent on the project as for the project the component is seen as any other component obtained from a supplier.

All these factors will not only influence the engineering hours but will also impact the possibility of average annual units sold as an increase in degree of standardization offers the chance to shorten the complete project. This does not directly imply a big increase in annual units sold is achieved. There are some factors though that can have a significant impact on the average units sold.

First of all, the *delivery lead time requirements*. When customers require a short delivery lead time for their ordered products more products can be produced annually as the whole process will take a far shorter time.

The *volatility in the market* will also have an influence on the annual units sold as a low volatility in the market will provide the opportunity to produce in advance resulting in the possibility to produce more annual products.

Order size and frequency of orders will impact the annual units sold as well. When orders of multiple products are placed these only have to be designed once and can be manufactured at the same time resulting in an increase is potential annual units sold. The same holds for a higher frequency of orders.

At last, the *freedom of the sales process* will also have a genuine impact. When the sales process fits to the customers requirements, a market advantage can be obtained resulting in more products sold. Furthermore, when the sales team sells large orders, or more frequent orders naturally more annual orders will be obtained.

An important note to make is the fact that a change in these factors does not directly influence the annual units sold. Before more units are sold there should be a market demand by customers to sell the products to.

A full overview of the factors and there influence on engineering hours and annual units sold is depicted in Table 3.7.

Table 3.7: Overview of Market, Product, and Process Related Factors

Category	Factors	Engineering Hours	Annual Units Sold
Market Related Factors	Delivery lead time requirements	↓	↑
	Volatility		↓
	Customization requirements	↑	
	Order size and frequency	↓	↑
	Type of customer*	↑	
	Variations in regulations and standards	↑	
Product Related Factors	Maturity of the end product	↓	
	Customization opportunities	↑	
	Structure (modularity)	↓	
	Variance of integrated components	↑	
Process Related Factors	Freedom of the sales process	↑	↓
	Freedom of the engineering process	↑	
	Freedom of the supply chain process	↑	
	Degree of vertical integration in the supply chain	↓	

In the columns representing the engineering hours and annual units sold an upward arrow (↑) represents an increase when the factor increases, a downward arrow (↓) represents a decrease when the factor increases.
*An increase in 'Type of customer' indicates the customer requires more customization

As shown, all factors identified in Section 3.4 can be related to one or both variables used by Willner, Powell, et al. (2016). It can be concluded the matrix they set up can be used to determine the degree of standardization that is applied in the end products. Placing multiple products in the matrix can give a more detailed view on the degree of standardization achieved relative to other projects placed in the matrix.

3.6. Maturity Levels of Standardization

In order to standardize more in an ETO environment and thus move more towards MTO, different product and process stages have to be taken as a direct transition is not feasible. A representative framework that can be used as a guideline when moving towards ETO is the maturity model set up by Willner, Gosling, and Schönsleben (2016). However, it is important to recognize that the same objective can be achieved through different means. The maturity model set up by Willner, Gosling, and Schönsleben (2016) consists out of five levels of design automation in the sales-delivery processes of ETO products. Design automation is closely related to standardization as standardization is needed for the movement towards more design automated procedures (Wacker & Treleven, 1986). The authors describe design automation as *"an approach for minimizing the effort required for repetitive design tasks"*, standardization can be seen as a way to do this and is thus related to design automation. Moreover, the authors often refer *"standardization and automation"* when referring to design automation, indicating there is an interconnected relation between the two phrases. In the paper both product and process standardization are highlighted which have also been identified in Section 3.3.1. The five levels of design automation the authors identified are:

- Level 1: Ultimate Freedom
- Level 2: Product Standardization
- Level 3: Automation of Tendering
- Level 4: Automation of Order Execution
- Level 5: Full Automation

From these five levels can be seen that moving from level one to level two requires product standardization after which process standardization follows in the further levels, first in tendering followed by standardization of the rest of the order execution process. Relating this to the factors, first elements related to the product related factors should be standardized to a higher degree after which the freedom in sales should be constrained followed by the rest of the processes in the order execution.

However, as indicated in Section 3.3.1 Aapaoja and Haapasalo (2014), identified there is an interconnected nature between product and process standardization. First adapting the product to a more standardized form will thus already influence some processes as well. This can better be seen from Figure 3.5 where the 'Strategies' and 'Processes' dimensions are depicted that belong to each level. When product standardization is implemented, the process shifts from ad-hoc to nascent, indicating that processes are becoming more standardized in line with the product standardization.

Moreover, the content provided in the 'Strategies' dimension about the solution space and the distinction between standard, configurable and special components can be linked to the product related factors. This is the case as this impacts the customization opportunities, structure and variance of integrated components. The 'Processes' dimension can be linked to the process related factors, especially the reduction in freedom can be recognized in the increase in levels as the processes become more defined as the maturity level increases.

Besides 'Strategies' and 'Processes' Willner, Gosling, and Schönsleben (2016) give two more dimensions: 'Systems' and 'People', although these are valuable for the maturity model they are kept out of scope for this research as there is no direct link to the key factors influencing standardization (Section 3.4).

	Level 1 – *Ultimate Freedom* –	**Level 2** – *Product Standardization* –	**Level 3** – *Automation of Tendering* –	**Level 4** – *Automation of Order Execution* –	**Level 5** – *Full Automation* –
Strategies	• Open solution space; customer is free in defining order specifications • No performance management: budget and schedule are not tracked and often exceeded	• Definition of product lines; creation of product structures; product modularization • Distinction between standard, configurable and special components • Basic performance management: budget and schedule are manually tracked	• Implementation of commercial product structures in sales configurators → formalization of solution space • Advanced performance management: budget and schedule are tracked; deviations are monitored	• Implementation of technical product structures in engineering configurators → formalization of solution space • Superior performance management: Budget and schedule are tracked; deviations are monitored and used to define improvement measures	• Fixed solution space that is regularly adjusted to customer needs • Performance measurement used for continuous improvements
Processes	• Ad-hoc processes, occasionally chaotic	• Nascent processes; no clear distinction between processes for standard, configurable and special components • Replication of processes across locations	• Process 1 (standard & configurable components): Tendering guided by sales configurators; automated generation of tender documents (semi-automation) • Process 2 (special components): roughly defined process	• Process 1: Order execution process guided by engineering configurators; automated generation of purchase orders & drawings • Process 2: meta-process for special components	• Fully defined and coordinated processes
					MTO

Figure 3.5: Maturity Model adapted from Willner, Gosling, and Schönsleben (2016)

3.7. Market Strategy

After their study to decoupling configurations, Cannas et al. (2019) conclude the driving factor of engineering and production decoupling points are strategic objectives set up by the organization. As explained in Section 3.1, the customer order decoupling point is directly related to the degree of standardization, since standards are applied before the decoupling point in both engineering and production. This is caused by the fact activities are performed in a forecast driven way, introducing less customization as the customer penetration point is at a later stage in the process (Duray et al., 2000).

By using strategic objectives the market strategy is defined. In this way, the organization sets the target customers and the way they intend to approach and sell to these customers. As can be seen in Section 3.4.1, the market related factors have a close relation to the customer, which is indirectly chosen by the organization itself by means of the market strategy.

Cannas et al. (2019) indicate the first step to define the most suitable decoupling point is therefore to analyse the strategic objectives that make up the market strategy the organization has set up for the particular product family analysed. This will depend on how the organization is planning to obtain a competitive advantage over their competitors. Various authors define different order winners as can be seen from Table 3.8. Comparing the order winners set up by these authors they come down to the six order winners: price, time, flexibility, quality, customer service, and innovativeness.

Table 3.8: Order winners by authors

Author(s)	**Order Winners**
Naylor et al. (1999)	Service, quality, cost, and lead-time
Mason-Jones et al. (2000)	Quality, price, lead time, and service level
Christopher and Towill (2001)	Quality, cost, availability/lead time, and service level
Olhager (2003)	Price, design, flexibility, and delivery speed
Wikner and Rudberg (2005a)	Quality, cost, time, and customisation
Dekkers (2006)	Costs, lead times/productivity, and flexibility
Gosling et al. (2017)	Cost, lead time, customization, customer service, and innovative engineering work
Cannas et al. (2019)	Price, time, flexibility, reliability, and innovativeness

To win an order at least one of these order winners needs to be focussed on in order to obtain a competitive advantage. These market priorities should be aligned with the product and associated processes to keep focus to compete as effectively as possible (Sousa & da Silveira, 2019). To do so, trade offs need to be made as focussing on one criteria will most of the time be at the expense of another criteria. For example, Gosling et al. (2017) point out the flexibility affects the time and price. According to M. E. Porter et al. (1996), making trade-offs are essential as this will purposefully limit what the organization offers deterring straddling or repositioning from competitors as they will have to degrade the value of their current activities. Moreover, being 'stuck in the middle' is a strategically disadvantaged position as the organization will always lose to other organizations standing out in a certain order winning criteria (M. E. Porter, 1980).

Cooper (1984) states the strategy determined for new products consists out of four strategy blocks that form the components of the strategy a company sets up for a product.

First of all, the nature of the product is of importance, this has to do with the characteristics of the product that will be manufactured. There should be determined if the product is groundbreaking or relatively similar to already existing products.

Furthermore, the targeted markets are part of the product strategy. Investigation should be done to the market, finding out if it of high or low growth, what level of competitiveness is present, if it is a mass or a specialized market, and what the size of the market is.

The technology applied in terms of development and production is important to base the product strategy on. Here should be determined if a new product fits the company or if it is a different sector than is normally focussed on. Moreover, it should be looked at if it integrates with the production line of the company or if changes should be made.

At last, The direction, stance and commitment of the product will be part of the strategy as well and particularly of importance for standardization. For this building block, determining how the product will be placed in the market is of importance. Here defining if the product will be offensive or defensive, if it is market or technology driven, if it is pro or re-active and the risks taken in the process should be taken into account. Furthermore, it is of importance to identify how orders will be won. As mentioned before, this has to be done by making trade-offs between price, time, flexibility, reliability, or innovativeness to differentiate from competitors.

Combining these building blocks will result in a product strategy that can be implemented for the specific new product. It is important to set up a market strategy for all products as different products demand different strategies (Willner, Powell, et al., 2016). Setting a new product strategy is outside the scope of this research as already existing products are investigated. However, as mentioned before, the product strategy does have a genuine influence on the degree of standardization possible for the product.

In order to obtain a good overview of all this data, an activity system map can be drawn up. In these activity system maps the strategic position of the company is depicted by placing higher order strategic themes and linking them to each other as well as to activities performed to achieve these strategic themes. From these strategic themes and activities the order winners, nature of the product, targeted market, and direction, stance and commitment can be derived (M. E. Porter et al., 1996).

3.8. Chapter Conclusion

Chapter 3 provided a comprehensive theoretical foundation essential for understanding the complexities of standardization within ETO environments. First of all, CODP was defined as at what moment in the process the customer gets involved in the project, which plays a role in determining the degree of customization and standardization possible in a project. The chapter then looked into the characteristics of ETO, highlighting the complexity, high customization levels, and the challenges these pose for implementing standardization. Furthermore, standardization has been defined as *consistently applying established processes, procedures and products in which regularity, repetition, and a proven track record of success are present.*. Besides this, advantages like cost savings, reduced lead times, and overall gain of efficiency have been identified. On the other hand, limitations are loss of innovation, simplification of end products, and organizational resistance.

A key contribution of this chapter was the identification and categorization of 14 factors influencing the degree of standardization in an ETO environment. These were categorized into market related, product related, and process related factors, and further classified as internal or external depending on the ability of the organization to influence them. These factors are: volatility, customization requirements, order size and frequency, type of customer, variations in regulations and standards, the customization opportunities, structure (modularity), variance of integrated components, freedom of the sales process, freedom of the engineering process, freedom of the supply chain process, and degree of vertical integration in the supply chain.

Additionally, the chapter introduced a method for measuring standardization using engineering complexity and average annual units sold. The maturity model for standardization and automation further improved the analysis by providing a framework to evaluate and guide standardization practices.

Finally, the chapter emphasized the role of market strategy when determining a standardization strategy in an ETO environment. Especially the order winners and strategic priorities are deemed relevant. By integrating these theoretical insights, Chapter 3 provided the basis for a practical, structured approach to define a suitable standardization strategy, further developed in the following chapter.

4

Developing a Standardization Strategy Development Procedure

In this chapter, a procedure will be established that will be used to determine a suitable standardization strategy for ETO product families. By setting up this procedure DO1 will be achieved. First of all, the procedure is set up where the objective and requirements of the solution are defined and the procedure is established. In here, the six activities needed to define a suitable standardization strategy are defined. This is followed by Section 4.2, where the activities are further elaborated on. In this section, there will be explained what should exactly be examined in each activity and where the data needed for this can be gathered. The last section will wrap up this chapter, providing a chapter conclusion.

4.1. Setup of the Procedure

Having gathered the required knowledge during the literature review, the procedure can be set up. For this, first the objective of the solution has to be defined after which the procedure is designed and developed. In the procedure, the factors and models introduced in this chapter will be integrated to help reach the design objective.

4.1.1. Requirements of the Procedure

The main objective of the procedure is to provide organized steps that can be taken to determine a suitable standardization strategy for ETO projects. The procedure will especially be designed to find a solution for ETO products that are designed based on previous designs. This implies the CODP is actually ATO_{ED} and MTO_{PD} in terms of engineering and production domains respectively (Wikner & Rudberg, 2005a). Besides that, the type of ETO where the solution should be defined for is ETO 'Type 1' bein vertically integrated companies as defined by Hicks et al. (2001). This is both important as the case the procedure will be applied to has these characteristics. Although the procedure is produced for this case it should be able to be used for all ' Type 1' ETO companies basing their projects on previously conducted projects.

As identified in Section 3.3, standardization has advantages as well as limitations and challenges. The procedure should assess as many advantages as well whilst limiting the limitations and challenges of standardization. Examples of advantages the procedure should result in are cost savings, reduction in lead times, and an improvement of efficiency and predictability. Limitations like changing market environments, simplifications of the end product, loss of innovative capabilities, and organizational resistance should be taken into account. Besides this, the standardization section also indicated standards have to be revised as standards should continuously be improved. This indicates the framework should be developed in such way it can be used recurrently to develop new standardization strategies that are applicable for the market and organizational conditions at that specific time. Furthermore, it has been identified various departments will be influenced by standardization. For the development of the procedure it is important these departments are aligned with the developed standardization strategy.

As mentioned, standardization strategies in ETO product families are not one size fits all, which is one of the main reasons for setting up this procedure. In Section 3.4, key factors influencing standardization are established. The procedure should consider these factors in order to determine a product specific suitable standardization strategy. These factors will also integrate the influence standardization has on various departments. Within the procedure, distinction should be made between two types of factors which have been identified in Section 3.4:

- External factors: These are factors that can not be directly influenced by the organization.
- Internal factors: These are factors that can be directly influenced by the organization.

By making this distinction, it will be clear what factors are able to be influenced and what factors should be accepted and taken into account when influencing the other factors.

Besides this, the inclusion of engineering complexity and average annual units sold should be integrated. These measurements of standardization defined by Willner, Powell, et al. (2016) have been elaborated on in Section 3.5. Integrating this way of measuring standardization ensures that decisions are also data driven and not solely based on qualitative data.

Furthermore, it has also been discovered in Section 3.7 that the market strategy set for a product has a genuine impact on what standardization strategy to apply on the project. The final solution should thus also be based on the market strategy set for the product.

As mentioned in Section 1.3 (Main Research Objective and Scope), the procedure will be developed as a first observation if standardization is possible, and if so, what internal factors influencing standardization should be focussed on. After the standardization strategy has been developed, more research is thus needed into the identified internal factors to determine how these should exactly be influenced based on the directions given by the procedure.

4.1.2. Design of the Procedure

In order to reach the objective to determine a standardization strategy, several activities will need to be conducted. These activities will make up a procedure which will be the artifact to reach the objective. The procedure will be called the ***Standardization Strategy Development Procedure*** or ***SSDP*** for short. The activities have been designed and developed based on the literature study conducted in Chapter 3.

The SSDP consists out of six activities that will have to be taken to determine a suitable standardization strategy for product families in an ETO environment. The activities will be first introduced after which they will be further elaborated on in the next section (Section 4.2).

A1: **Determine the market strategy**: First of all, it is important to determine what market strategy is applied for the product. As indicated in Section 3.7, the market strategy will have a genuine impact on what standardization strategy is suitable for the project. When setting up the standardization strategy the market strategy should be taken into consideration as standardization could negatively influence the order winner(s) of product.

A2: **Define the product specific external factors**: The external factors consist out of factors the organization itself does not have direct influence on. These are the market related factors influencing standardization that have been set up in Section 3.4.1. Besides this, the maturity of the end product is seen as an external factor as well as this can not directly be influenced. By analysing these external factors, insights can be gained for which products standardization is potentially possible and where standardization should be avoided. This has been indicated in Table 3.7, where can be seen if the factors have a positive or negative influence on the possible degree of standardization.

A3: **Analyse current and previous projects**: Gathering insights into current and previous projects is of importance to determine the state of the problem and to identify how this could potentially be improved. In order to develop these insights, standardization should be measured, as explained in Section 3.5, this can be accomplished by determining the engineering complexity. This will especially help when comparing it to other projects as this will give insights into which product is most suitable for standardization. Moreover, data of engineering hours can give insights on various projects executed to design the same type of product. When the amount of engineering hours deviate heavily, this will indicate more standardization has previously been implemented in these types of projects.

A4: Analyse current internal factors: Besides analysing the state of current and previous projects it is also valuable to evaluate the internal factors in terms of product and process related factors. As mentioned in Section 3.4, these factors influence the possible degree of standardization. It is thus of importance to evaluate the current situation of these factors to identify if they can possibly be adapted to improve the degree of standardization.

A5: Analyse potential improvements of internal factors: As stated above, there should be investigated how the product and process related factors can be influenced in order to enhance the degree of standardization. In Section 3.6 the maturity model set up by Willner, Gosling, and Schönsleben (2016) is introduced. By implementing the insights obtained in the previous step the current maturity level can be exploited. This will then give first insights in potential adaptations that can be executed in order to move to the next maturity level. Furthermore, insights from experts can help to define how the transition to a next maturity level can be achieved.

A6: Generate the applicable improvements into a new standardization strategy: By comparing the potential improvements analysed in the previous step to the market strategy and the external factors, the applicable improvements can be identified. these applicable improvements together will be the building blocks of the new standardization strategy that will be suitable for the product it has been developed for.

Conducting these six activities will develop a suitable standardization strategy that can be applied to the specific type of product it has been designed for. These six activities keep the objective of the final solution of the procedure into consideration by making the right product specific trade offs in order to maximize the advantages and minimize the limitations and challenges of standardization.

In addition to the six activities, an extra activity should be carried out when it is unclear which product would benefit most from a new standardization strategy. This activity takes place between activity three and activity four, since at this stage the suitability of standardization for each product can be assessed. In the case study presented in Chapter 5, this activity is applied. In here, the first three activities are completed for all products. By comparing the outcomes of these activities, the product most suitable for standardization can be identified. For this product, the final three activities are conducted, as it will gain the greatest benefit from a well-aligned strategy.

4.2. Elaboration of the Activities of the SSDP

In this section the six main activities of the SSDP will be further elaborated on. There will be indicated what should be investigated and where the data could be gathered from. Furthermore, links to the literature in Chapter 3 are made to give insights in the development of the activities. Each of the following sections focuses on a distinct activity.

4.2.1. Activity 1: Determine the Market Strategy

Section 3.7 explains how a market strategy is set up and what order winners should be focussed on for which, as defined by M. E. Porter et al. (1996), trade offs should be made. It is thus first of all of importance to identify what trade offs are made, indicating what order winner or winners is/are focussed on. The six order winners that have been defined are price, time, flexibility, quality, customer service, and innovativeness. Defining the order winner(s) focussed on is of importance as some of the order winners encourage standardization where others discourage the implementation of standardization.

In some cases, the market strategy has been documented indicating how orders will be won, when assessing these type of documents the order winners focussed on can be identified. When it is not documented other sources should be consulted. One of those sources to consult are employees working in, for example, the sales department. These people often know more about the market and how is competed in this specific market, which indicates what order winners are focussed on.

As mentioned in Section 3.3.4, standardization has as advantage that it decreases price and lead time and improves quality and customer service. When focussing on these activities, it is thus recommended to standardize to a higher degree as this will positively influence these order winners.

On the other hand, in Section 3.3.5 the limitations and challenges of standardization are elaborated on. In this section has been identified standardization negatively influences flexibility and innovativeness. When these are thus focussed on as order winners, standardization should be limited in order to keep a competitive advantage. Defining the order winners will thus later in the SSDP be of importance to identify the suitable degree of standardization.

Besides identifying what order winners are focussed on it is of importance as well to analyse the building blocks of the market strategy (Cooper, 1984). As explained in Section 3.7 analysing these building blocks determines the market strategy. Identifying what decisions have been made and what characteristics the product and market have can be used in the consecutive activities too, for example, to determine the product specific market factors.

First of all, there should be identified if the product is groundbreaking or similar to other products. This should be accomplished by comparing the product to products of competitors that are used for the same purpose. When there are big differences between the product produced and the product produced by competitors or competitors are not able to produce the product at all, it is a groundbreaking product.

Next, the targeted market is deemed relevant. There should be identified if the market is growing or stable. This can be achieved by looking at data gathered by third parties like consultancy firms. From these firms, data can be obtained containing expected values of the coming years for the market. The level of competitiveness in the market should be considered as well. This can be determined by looking at the amount of competitors in the market, each occupying a market share. Additionally, it should be investigated if the market is a mass market indicating a lot of the same products are sold or a niche market where only little but very special products are sold. Besides the market it should also be defined which customers are targeted within this market. This can for example be end users, resellers, or organization that will rent out the product bought. This can be determined by looking at what kind of customers ordered the product previously and what they did or will be doing with the product.

The third building block is left out of scope for this thesis as this focusses on how the new product integrates with existing products produced. However, in this thesis the scope is on products that are already produced for a longer time.

In the last building block the direction, stance, and commitment should be defined for the product as well. For this building block it is important to identify the main goal of producing the product which can be to obtain a financial benefit, developing brand awareness, keeping a continual basis of work, etcetera. This main goal will affect the direction stance and commitment taken for the product. The goal should be indicated as focus should be kept on this goal. When in a later activity of the SSDP the standardization strategy will be adapted the main goal should still be focused on and thus be identified. Furthermore, it is valuable to indicate if this goal is reached in an offensive or defensive way and if the product is market or technology driven.

As explained in Section 3.7, an activity system map can be established in order to obtain an overview of the collected data resulting in new insights and a better understanding of the product, the strategic themes, and the activities that are related to these themes.

4.2.2. Activity 2: Define the Product Specific External Factors

As mentioned by Cooper (1984), one of the building blocks when setting up the market strategy is investigating the market. During the first activity, there has been investigated what type of market the product is in and what competition is faced. This analysis should be applied to determine the product specific external factors set up in Section 3.4. These factors have been defined as factors the organization does not have influence on. The product specific results of these factors will be kept in consideration during activity six when developing the standardization strategy. The market related factors will first be elaborated on focussing on what exactly should be looked for.

High **delivery lead time requirements** result in a higher suitable degree of standardization. The lead time requirements should be identified relative to other products produced to identify what product would suit standardization the best. High delivery lead time requirements indicate the customers demand their product in a very short time. On the other hand, low delivery lead time requirement indicates the customer can accept longer lead times. To define the delivery lead time requirements, tenders can be analysed to see within what time customers demand their product. These tenders should be obtained from the sales department and can best be assessed by one of those experienced employees. The delivery lead time requirements are depending on the customer targeted which has been analysed in activity one as specific customers demand shorter lead times.

High **volatility** lowers the suitable degree of suitable standardization. To assess the volatility, major changes of the product over time should be investigated considering demand and requirements. When many changes are visible the volatility is high, whereas when less changes are present the volatility is low. Moreover, previous conducted projects should be investigated to identify if changes can be recognized in the amount of projects and recurring requirements within different periods of time. Besides this, research by third parties on the overall size, growth, and demand of the targeted market can be investigated to get insights into the volatility, when this is differing over time the market is volatile.

Customization requirements negatively influence the suitable degree of standardization. Just like delivery lead time requirements, these should be identified relative to other products produced by the company to identify if the product is suitable to standardize compared to the other products. When customers demand little customization requirements it indicates this factor is relatively low, in contrast to a lot of customization requirements where the factor is thus high. In order to find this out, tenders can be reviewed to indicate how many special requirements customers have. This assessment can best be done by someone experienced working with the tenders like an employee working in the sales department. Moreover, final designs of executed projects can be reviewed to see what customization requirements have been actually implemented which can best be assessed by an engineer that has experience with these projects.

Increasing **order size and frequency** will raise the suitable degree of standardization. The order size can be identified by looking at the order size received by customers as well as looking at returning customers placing returning orders for the same product. The frequency of orders can be identified by looking at the average annual units sold (Equation 3.1 (Willner, Powell, et al., 2016)). This data can be obtained at the sales department that will most likely have documented this data.

The **type of customer** will influence the suitable degree of standardization in multiple ways. The customer is mostly dependent on the market strategy as this defines the targeted customer. The final use of the product by the customer should be identified. When the customer is the end user, this typically leads to more customization requirements compared to situations where the product is intended for rental or resale. Furthermore, the technical knowledge and size of the customer increase the demand for customizations and thus decreases the suitable degree of standardization. To investigate the type of customer, tenders and previous products sold can be investigated to determine the type of customer ordering the product as previously mentioned, sales employees will have experience with this documentation. Furthermore, the market strategy defined in activity one can be looked at to find out what the targeted customers are.

Variations in regulations and standards decrease the suitable degree of standardization of the product. The variations in regulations and standards can be assessed looking at differences in these regulations and standards present in products sold under varying conditions. This can be investigated by looking at the varying regulations and standards required for previous projects. When there are large differences, this factor is thus high whereas when there are little to no differences it is low. This information can best be obtained from the engineering department as employees working here have experience implementing these variations in the final design of the product.

Besides the market related factors a product related factor is also considered as an external factor. This factor is the maturity of the end product. This is an external factor as no direct influence can be exerted by the organization on this factor.

Maturity of the end product positively influences the suitable degree of standardization. As mentioned by Aapaoja and Haapasalo (2014), there are two types of maturity: technological and design. For this factor it should thus be determined how many changes happen over time concerning the technology applied and the design made. In terms of design this should not be based on customer requirements but changes made due to optimizations of the design. To acquire this information, employees from the engineering department should be consulted. These people will have experience designing and innovating the product and will thus be able to tell what changes have happened and, if applicable, what improvements are expected for the future.

To summarize, the degree of the following factors should be determined during this activity: delivery lead time requirements, volatility, customization requirements, order size and frequency, type of customer, variations in regulations and standards, and the maturity of the end product.

4.2.3. Activity 3: Analyse Current and Previous Projects

In the previous activity, information has already been gathered from current and previous projects in order to assess the external factors. However, more insights can be gained regarding the suitable standardization degree when analysing these projects.

As elaborated on in Section 3.5, the engineering complexity can give valuable insights when assessing the suitable degree of standardization. As mentioned in Equation 3.2 the engineering complexity can be calculated by dividing the total amount of engineering hours spent by the total amount of projects. In this way the average engineering hours spent can thus be calculated per project. It is important to mention there are more accurate ways to define engineering complexity as indicated by Willner, Gosling, and Schönsleben (2016). This way of approaching is however chosen since the required data is generally available.

According to Willner, Powell, et al. (2016) and Haug et al. (2009) the lower the engineering complexity is, the more potential there is for standardization. The data needed to obtain this engineering complexity can best be obtained from project controllers. These project controllers will have made forecasts concerning engineering hours used for products that are still in production. Moreover, they will have received the actual spent hours to check on their forecasts which can be used to calculate the engineering complexity.

Additionally, the 2x2 matrix set up by Willner, Powell, et al. (2016) which is elaborated on in Section 3.5 can be filled in to assess which ETO archetype the project is in. This will give insights into the possibilities of standardization matching the archetype the product is in.

Besides calculating the engineering complexity of the product family, engineering hours can give more indications of the potential for standardizing. When comparing engineering hours for varying projects in the same product family insights can be gained on the possibility of standardizing. When the engineering hours spent differ a lot, this indicates standardization has been applied in the projects with a low amount of engineering hours illustrating standardization is possible but not applied for all specific products produced. Moreover, no engineering hours spent indicate the project was a full copy of a previous project. The more engineering hours spent the more customizations have thus been implemented in the end product. In contrast, the lower the engineering hours, the more standards have been applied to the product.

Furthermore, the data obtained from current and previous projects can also be used to get insights in order size and return of customers. This can be done to identify if orders containing multiple orders show decreases in engineering hours illustrating parts are standardized among the separate projects of the order.

4.2.4. Activity 4: Analyse Current Internal Factors

As mentioned in Section 3.4, the internal factors consist out of the product and process related factors influencing standardization, excluding the maturity. Internal factors have been defined as factors that can directly be influenced by the organization and are thus adaptable when the degree of standardization should be adapted. In order to achieve this, first the current status of these factors should be analysed.

Product Related Factors

The **customization opportunities** are the possibilities kept open in the design where customization can be applied to the product. To investigate the amount of customization opportunities the initial design of the product should be considered. When nearly a full new design is developed for each order, the customization opportunities are thus the highest possible. When the design is based on a previous design there are certain parts of the project fixed. It should be considered how many parts of the product are not fixed and can thus be customized to the requirements of the customer. The designs the product is based on should be acquired from the engineering department as these employees will built further on this design and determine what this design should be.

The **structure (modularity)** indicates if the product is divided into modules or not. To uncover to what extend modularity is applied engineers working on the product should be consulted. These engineers will be able to explain how the design of the product is made up and thus also know the modules integrated in this design.

The **variance of integrated components** can be uncovered utilising the knowledge of engineers or supply chain employees. These people will know which components are ordered and how they differentiate from each other impacting the suitable degree of standardization. The more integrated components vary for the same purpose in a product, the more differences there are between different products of the same product family resulting in a lower degree of standardization.

Process Related Factors

The current **freedom in the sales process** can be uncovered by consulting employees working in the sales department to find out to what extend they are able to offer customizations to customers or if they are restricted to certain standards set up. When standards are set up it is important to find out if these standards have to be implemented or if there is freedom to deviate from the introduced standards. When deviating from the standards is normal the freedom of the sales process is thus high, when deviation is hardly tolerated the freedom is low.

To assess **the freedom given to engineers**, the engineers themselves should be asked into their way of working. There should be investigated if standard procedures are set up when doing this and if in these procedures standards are applied. These standards can be databases that contain standards which have to be implemented or a standard way of designing a certain component. Moreover, standard components can be standardized which can not be deviated from or for every project different components can be integrated. When various components can be used, and no standards are set up for designing or using standard databases there is high freedom of the engineering process. In contrast, when there are clear prescriptions of how standards have to be implemented from which can not be deviated, the freedom in the engineering process is low.

To asses the **freedom of the supply chain**, there should be investigated if components used for the same purpose in different products within a product family are varying or similar. This can be done by looking into the bill of materials of the products as well as by questioning supply chain employees. By doing so the supply chain strategy can be identified which indicates from what companies the specific components can be ordered. Besides this, there should also be questioned if there can be deviated from this pre set list of suppliers. When there can be deviated from the list and there are many suppliers on the list, the freedom of the supply chain process can be considered high. When the list is limited to a couple of supplier which can not be deviated from, the freedom is very limited and thus low.

The **degree of vertical integration in the supply chain** is the last factor that has to be investigated. The degree of vertical integration in the supply chain indicates the number of components that are procured from other companies compared to the amount of components produced in house. This can be assessed again by looking at the bill of material to find out what specific components are bought from other companies. Furthermore, engineers designing the product will be able to explain what components are produced in house and what components are produced by other companies. When all components are produced in house the degree of vertical integration is at its maximum. On the other hand, when everything is purchased from other companies and only assembled the degree of vertical integration is at the lowest possible degree.

4.2.5. Activity 5: Analyse Potential Improvements of Internal Factors

The next activity is set up with the goal to analyse what potential improvements can be made in the internal factors. As explained in Section 3.4, the company has direct control over the internal factors influencing standardization and these can thus be adjusted to develop a better suitable standardization strategy.

A first indication of changes that can be applied can be found by applying the maturity model developed by Willner, Gosling, and Schönsleben (2016). This maturity model has further been elaborated on in Section 3.6. First the current position in this maturity model should be analysed, this can be accomplished by using the information gathered in the previous activity concerning the internal related factors. When the current level has been determined, the higher levels indicate what should be changed to move to a higher level of standardization. There is a possibility some aspects are already in a higher level then other aspects, when this occurs, it is first of all important to move the aspects that are still in the lower level into a higher level.

Furthermore, there should be investigated how all internal factors can further be adapted to increase the degree of standardization. This will dependent on the abilities of the company, the product, and the ability of suppliers and is thus very product specific. Insights obtained in activity three, where the engineering hours were investigated for various projects of the same product family, can be used to have first indications of the impact of potential standardizations. Table 3.4 indicate the change made in engineering hours and thus in standardization when the factors are increased.

The internal factors will now be discussed indicating how they can be changed to increase the degree of standardization. This is however very product specific as it is dependent on the limits of the product as well as the current status of the factors.

Product Related Factors

Increasing the amount of **customization opportunities** will decrease the degree of standardization. In order to increase the degree of standardization, the customization opportunities should thus be limited. The possibilities of doing this depend on the current customization opportunities available in the product which has been identified in the previous activity. Potential decreases of customization options can best be formulated together with experts designing the end product. Possible options are to change the current customization opportunities into configure to order options where preset options are derived which the customer has to choose from. Furthermore, the customization options can also be made fully standard where the customer will have no influence on it any more. By doing so, the product will move away from ETO and move more towards MTO and in particular ETS_{ED} for the engineering domain as defined by Wikner and Rudberg (2005a).

The **structure (modularity)** of the product will positively influence the suitable degree of standardization when more modularity is applied. However, Cannas et al. (2019) mentioned that when a product is fully standardized there will be no modules any more as everything is always the same. It will be assumed modularity will benefit the degree of standardization as in the high customizable environment this procedure is designed for, fully standardized solutions are typically not demanded. In order to increase the degree of standardization, the product should thus be derived into more modules which can be assembled together. To investigate the possibilities of modularity, the knowledge of engineering employees concerning the design should be consulted. Implementing modules to the design transforms the ETO product more towards a MTO product and particularly ATO especially when the modules are fully standardized. When certain modules are fully standardized these can even be produced to stock transforming the CODP in term of production towards ATO_{PD} (Wikner & Rudberg, 2005a).

Increasing the **variance of integrated components** will decrease the degree of standardization. In order to standardize to a higher degree the variance of integrated components should thus be kept as low as possible. In order to do this, components should be pre-defined from a select number of suppliers. The less suppliers, the less variance there will be in the product. In order to investigate the possibilities, both supply chain and the engineering department should be consulted. Furthermore, to do this, the varying products within a product family should be able to integrate the same kind of components. Just like the customization opportunities, the components could also be selected on a configure to order basis, where the configuration is made based on the specific product produced. However, the configurations available should be standardized to a select amount of components to keep the components standard. Making use of standardized components provides the opportunity to buy the component to stock making bulk orders possible. Moreover, ordering a component more often results in economies of scale. This will reduce the lead time and costs, two of the advantages of standardization.

Process Related Factors

The **freedom of the sales process** negatively influences the suitable degree of standardization when increased. To limit the customizations in projects the freedom of the sales process should be limited. This can be done by only allowing changes in certain components or modules of the design, or by moving from ETO to CTO making sure the configurations which are offered are pre-defined and thus need little to no engineering hours to assemble the full design. It is of importance that these configurations are clearly set up and easy to find and implement as these are challenges of standardization as discussed in Section 3.3.5.

The **freedom of the engineering process** has, just like the freedom of the sales process, a negative impact on the suitable degree of standardization when it is increased. In order to increase the degree of standardization this freedom should be decreased. This can be accomplished by setting up standard components and modules which have to be used when making a design for a new product. By doing so, at least these components and modules do not need to be designed and the interfaces are known, reducing the engineering hours having to be spent on the specific product. However, as mentioned in Section 3.3.5, this could cause organizational resistance as engineers rather make new designs than implement standards. It is thus of importance to motivate engineers to use the standards and make sure a well organized database is available which can be used to easily find the standard components or modules.

The **freedom of the supply chain process** should also be limited to enhance a higher suitable degree of standardization for the product. Limiting the freedom in the supply chain process can be accomplished primarily by limiting the number of suppliers where specific components can be ordered from. Components should thus only be ordered from a select number of suppliers making sure interfaces and dimensions are known and CTO becomes possible in terms of components. When certain components are regularly used these can even be bought to stock making bulk purchases possible which reduces the price and lead time as discussed in Section 3.3.4.

Besides limiting the freedom within these departments, the literature study also shows that standardization creates opportunities to improve communication (MacCarthy et al., 2003). To achieve this, however, communication channels and documentation must also be standardized, which likewise requires limiting freedom. As discussed in Section 3.3, this can be accomplished by introducing standardized documents that must be prepared for every specific product produced, establishing a standard procedure for meetings, and defining standard information flows between departments through the use of these documents and meetings.

A high **degree of vertical integration in the supply chain** improves the degree of standardization of the product. By producing more components in house and thus increasing the degree of vertical integration the product becomes less dependent on suppliers. This enhances standardization as components produced in house are far less susceptible to external factors like suppliers making changes to their products or suppliers not being able to deliver the components needed. To improve the degree of vertical integration, research and development should be conducted to determine how certain components can be produced in house. The benefit of in house production is that it can be designed to perfectly fit the designs it needs to be integrated into. However, it should be noted that research and development to start developing new components will normally take a long time as knowledge should be gained and a lot of tests should be performed before the components works like required.

4.2.6. Activity 6: Generate the Applicable Improvements into a New Standardization Strategy

During this activity, the information required in the previous five activities needs to be combined to develop a new suitable standardization strategy. The potential improvements defined in activity five should be balanced with the market strategy investigated in activity one; the corresponding external factors investigated in activity two, and the insights gained on the current standardization applied in activity three. When identifying the right standardization strategy, it is important to ensure that the new approach does not negatively affect the market strategy or external factors. In the design of the SSDP there has been assumed these are developed to the full potential and causing the best business potential possible. Negatively influencing these will thus cause a decrease in the organizations business potential.

Market Strategy

Regarding the market strategy defined in the first activity, first of all the order winners give clear insights into the potential of standardization. As defined in Section 3.3.4, price, time, and quality will be improved when standardizing. When focus is on these order winners, improving the degree of standardization is thus recommended. On the other hand, as identified in Section 3.3.5, flexibility and innovativeness will reduce when standardization is implemented. When these factors are focussed on as order winners, the impact the potential changes make on these order winners should thus closely be investigated. Moreover, when these are not the main focus, they should still be considered as customers will always demand some flexibility in highly custom environments. Besides this, the company should move with innovations in the market even though innovation is not the main priority. Customer service is an unique case since standardization can both support and limit its role as an order winner. After the product is delivered, standardization helps by ensuring spare parts are possibly held in stock and the components are familiar to service teams, leading to quicker and more efficient support. However, during the ordering process, standardization limits the options of the customer as the ability to tailor products to specific customer needs is limited.

As determined by Cooper (1984) the strategy is defined by four building blocks, these are mostly making impact on the market related factors influencing standardization. However, the main goal of the product influences standardization by itself. It is recommended to investigate the advantages and disadvantages of standardization (Sections 3.3.4 and 3.3.5) and define how this will possibly impacts the main goal of the product to define a suitable standardization strategy that suits the goal.

External Factors

During the second activity of the SSDP the external factors have been defined. These factors will indicate if standardization is recommend or should be avoided on some or all aspects of standardization. A first indication can be found in Table 3.7, where is indicated what happens to the engineering hours and thus to standardization when the certain factor is increased. This will give a first indication if the factors increase or decrease the suitable degree of standardization.

When **delivery lead time requirements** are high, the degree of standardization should be high as well. As identified in Section 3.3.4 standardization reduces lead time and should thus be implemented in all forms when short lead times are required.

In a volatile environment standardization should be decreased. **Volatility** results in changes over time making standardization less useful as the standards will have to change to the changes caused by the volatile environment. This mainly concerns product standardization, in terms of process standardization some adaptions can potentially be implemented depending on what is already implemented.

When **customization requirements** are high, standardization should be avoided. The customization requirements will result in deviations from the preset standards making the implemented standardizations less useful. This as well mainly concerns standardization in the product itself. Standardization in the process can potentially be implemented in terms of standardized documents or a standardized way to implement customizations.

Bigger **order sizes** or more **frequent** orders will strengthen standards introduced. In larger orders, the standards can directly be adopted in multiple products reducing the average engineering hours. The same holds for more frequent orders as the additional money spent on creating the standards will be spread over more products before the standards have to be changed due to new innovations or other shifts in the market.

When the **type of customer** targeted are the end users, standards should be limited as end users often tend to require customizations. The same holds for customers having a lot off technical knowledge about the product ordered or being large sized companies as indicated in Section 3.4. Standardization both in terms of product and process should be limited as clients will potentially interfere with both depending on how much influence they try to have on the product.

Variations in regulations and standards decrease the suitable degree of standardization of the product. Standardization can only be implemented when adhering to the highest requirements set by the authorities. This is only feasible to do when the variations in regulations and standards is minor as this will otherwise impact the costs to much. Moreover, standards could still be applied in elements of the product where no regulations or standards are set for or where these are similar for all authorities. Concerning the process, standards could be set up that define how to deal with certain regulations and standards that vary every time.

Lastly, the **maturity of the end product** impacts the suitable degree of standardization as in a mature product little changes happen concerning the design or technology employed. However, immature products that are often groundbreaking undergo many changes due to new optimized designs or new technologies. Standardization should be avoided as this will counter innovativeness needed to keep or obtain a market advantage.

Besides having impact on the degree of standardization itself, the external factors will also have influence on the degree to which the internal factors can be influenced. This relation is depicted in Table 4.1 which indicates if the possibility of change of the internal factors increases or decreases when the external factor is increasing. For clarity, the relation between standardization and the internal factors has also been depicted in the table. Making use of this, it can be seen if the relationship between the internal and external factor positively or negatively influences standardization.

For some instances, the relations '*depends*' is noted down. This indicates it depends on the situation if a higher external factor increases or decreases the internal factor. Delivery lead time depends on whether components are kept in stock or made to order. When in stock, the variance should decrease, when not in stock, the variance should increase to be able to pick the component with the fastest delivery time. The same holds for the freedom of supply chain, where freedom should be given when not in stock in order to find the component with the shortest delivery time. For vertical integration it depends on the in house production time versus the delivery time, the fastest should be chosen when delivery lead time requirements are high. For volatility versus vertical integration it depends on the market strategy, when focussing on innovations vertical integration is recommended as the specific component can be changed with the environment. However, in other cases it is better to have a low vertical integration to be able to order from suppliers being able to obtain what the market at the certain point demands. For maturity versus vertical integration the same holds, if focussing on innovation, increasing vertical integration results in more possibilities to change products to own innovations whereas otherwise components can be ordered from suppliers that are able to move along with the innovations of the product.

Table 4.1: Impact of an increase of external factors on internal factors

	Customization opportunities	Structure (modularity)	Variance of components	Freedom of sales	Freedom of engineering	Freedom of supply chain	Vertical integration
Standardization	↓	↑	↓	↓	↓	↓	↑
External factors:							
Delivery lead time requirements	↓	↑	*Depends*	↓	↓	*Depends*	*Depends*
Volatility	–	↑	–	↑	↑	↑	*Depends*
Customization requirements	↑	↓	↑	↑	↑	↑	↓
Order size and frequency	↓	↑	↓	↓	↓	↓	–
Type of customer (custom requirements)	↑	↓	↑	↑	↑	↑	↓
Variations in regulations and standards	↑	↑	↑	–	↑	↑	↓
Maturity	↓	↑	↓	↓	↓	↓	*Depends*

An upward arrow (↑) indicates the internal factor should increase when the external factor increases, a downward arrow (↓) indicates the internal factors should decrease when the external factor increases. “–” indicates there is no relation between the factors; “*Depends*” means the relationship varies as further explained in the text.

When determining what internal factors to influence in order to adapt the degree of standardization it is thus also important to identify if these changes will negatively influence the external factors. A first insight can be obtained by looking into the table, however, it should be further investigated by looking at the advantages and disadvantages of standardization discussed in Sections 3.3.4 and 3.3.5, as all these factors are very product specific and thus have varying limitations which should not be exceeded.

Furthermore, the engineering hours looked at in activity three can be of added value. It should be investigated what causes big differentiations between engineering hours in various projects. This can indicate potential improvements that can be implemented to reduce engineering hours. Moreover, finding out why engineering hours for some projects are very high and for others are very low might indicate what can be standardized but also what should be avoided as this element might differ for every product. Also, the overall engineering hours can be split into the engineering disciplines to identify where standardization can be achieved and where it should be avoided. To determine what causes the high or low engineering hours, engineers who worked on the specific project for the product can be questioned for the reason of these fluctuations.

In order to achieve the best possible result it is recommended to bring experts of the various departments influenced together. To do this, a session can be organized where employees from the sales department, the engineering department, and the supply chain department come together to discuss the potential adaptations. These departments are particularly important as these will be influenced the most by the potential changes implemented by the new standardization strategy. Furthermore, depending on the order winners, experts in the fields of finance, planning, quality control, service and research and development can be invited to this session as these experts can assess the potential impact the changes will have and if it is useful or not to implement the changes. By discussing the potential improvements of internal factors set up in activity five with these various experts the potential impact of changes can be determined. By doing so, the positives and negatives can be balanced to determine the most suitable standardization strategy for the product family assessed.

4.3. Chapter Conclusion

Chapter 4 translated the theoretical insights from the literature into a practical and actionable framework: the Standardization Strategy Development Procedure (SSDP). The activities defined in this procedure are based on the literature study conducted in Chapter 3. By doing so, this chapter moves from conceptual understanding to practical application, providing ETO organizations with a structured tool to assess and improve their standardization strategies. The procedure is designed for ETO companies that base new projects on previous designs but still face high variability in customer requirements. Importantly, the SSDP is not intended as a one time solution but as a repeatable framework that can be reused to develop a new strategy need due to changes in market conditions and organizational changes.

The SSDP was designed as a six step procedure, each step targeting a specific aspect of standardization. These include:

A1: Determine the market strategy

A2: Define product specific external factors

A3: Analyse current and previous projects

A4: Analyse current internal factors

A5: Analyse potential improvements of internal factors

A6: Generate the applicable improvements into a new standardization strategy

By offering these clear activities the SSDP has successfully been established, aligning standardization with business goals and external factors influencing standardization.

Figure 4.1 presents an overview of the activities, indicating what input is required to develop the output expected from each activity.

	Activity:	Input:	Output:
Activity 1	Determine the market strategy	• Documentation on market strategy • Interviews with sales employees • Advantages and limitations of standardization	• Order winners focused on • Nature of the product • Targeted market and customers • Main goal of the producing the product • Activity system map
Activity 2	Define the product specific external factors	• Market strategy defined in A1 • Documentation from tenders and previous projects • Interviews with sales employees • Interviews with engineers	• Product specific external factors
Activity 3	Analyse current and previous projects	• Engineering hours documented in previous projects • Engineering hours forecasted in current and coming projects	• ETO archetype the product is in • Insights in standardization implemented in previous projects • Insights in relationship between standardization and order size and frequency
Activity 4	Analyse current internal factors	• Documentation from previous projects • Interviews with engineers • Interviews with supply chain employees • Interviews with sales employees	• Current internal factors
Activity 5	Analyse potential improvements of internal factors	• Current internal factors • Standardization maturity model • Expert knowledge	• Potential improvements of current internal factors
Activity 6	Generate the applicable improvements into a new standardization strategy	• All information gathered in the previous five activities • View of experts from affected disciplines • Advantages and limitations of standardization	• A suitable standardization strategy

Figure 4.1: Overview of the activities in the SSDP

5

Case Study at Huisman Equipment

This chapter provides the case study conducted in order to demonstrate the procedure established in Chapter 4. The chapter starts by introducing the main case (Huisman Equipment) and the sub-units (product families) that will be analysed during the embedded single case study. This will be followed by an analysis of the current state of all three products which consist out of the first three activities of the SSDP. After these analyses have been conducted the three projects will be compared to each other in order to identify which of the three products has the highest potential for standardization. After this has been identified, the product with the highest standardization potential will be further elaborated on. This will be done by working out the last three activities of the SSDP which will conclude into a new suitable standardization strategy especially developed for that particular product. Having developed this standardization strategy by applying the SSDP, the functioning of the SSDP to develop this strategy is evaluated. After this evaluation, the chapter is closed by a chapter conclusion.

5.1. The Main Case: Huisman Equipment

As mentioned before, for this embedded single case study, Huisman Equipment will be used as the main case. Huisman designs, manufactures and services heavy construction equipment for the world's leading companies. The companies that Huisman provides equipment to mostly operate in the renewable energy, oil and gas, civil, and naval markets. Most of the products produced are used at sea. The products can be subdivided into four categories: cranes, offshore wind tools, pipelay and drilling equipment, and special equipment (Huisman Equipment, n.d.).

Huisman was founded in 1929 and developed into a key player in the offshore heavy construction equipment industry. Huisman operates globally and has production facilities in the Netherlands, Czech Republic, Brazil, and China. Furthermore, sales and service locations are available in these countries as well as in Singapore, Norway, and the United States of America.

In order to keep focus on the mission, a clear mission statement has been formulated by the company:

"We transform innovative ideas into reliable technical solutions for, and together with our clients in the energy industries"

From this mission statement, the ETO characteristics can clearly be identified as emphasis is laid on working together with the clients. When looking at the product cycle of Huisman, depicted in Figure 5.1, the customer normally penetrates at the engineering stage. Although the customer penetrates at this point, the degree of customisation described by Hicks et al. (2001) is most of the times not 'Pure'. This is the case since Huisman mainly produce products that are based on previously executed projects. However, the products produced are always fully customized to the requirements of the customer, making all produced end products unique.

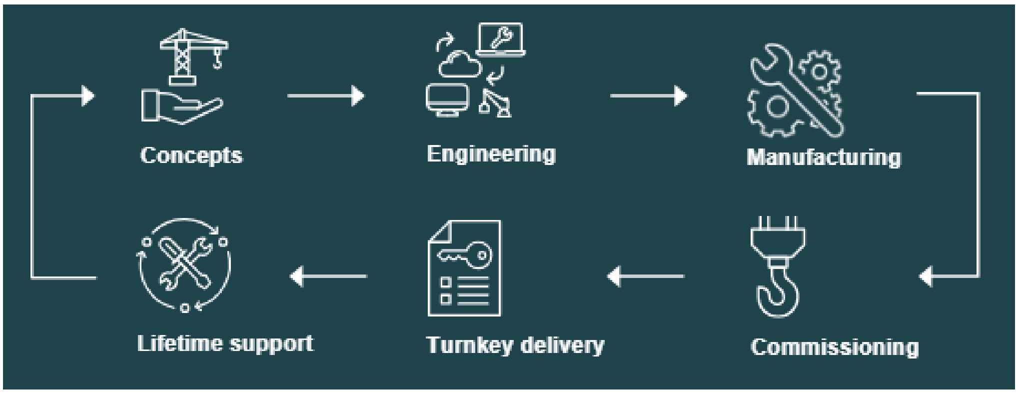

Figure 5.1: Huisman product cycle

5.1.1. Product Cycle

All products produced at Huisman follow the same product cycle which is depicted in Figure 5.1. The product cycle consists out of six stages, starting at the concepts stage. In this stage the concept of the products is designed. At this stage, the values "safety by design", "quality always wins" and "build on innovation" are always considered in every concept made. Innovative solutions are always sought after in order to be relevant currently as well as for the future in order to deliver future proof solutions to their clients. This is mostly done by constantly improving the consisting concepts. Besides this, new concepts and products are also designed by the engineering, and the research and development department.

The next stage is the engineering stage. At this point the customer will be introduced in the process being able to integrate their requirements into the final design of the product. Because of this, Huisman Equipment is an ETO company. The engineering process is split up into four main disciplines: mechanical engineering, electrical engineering, hydraulic engineering, and control system engineering. Although it is split up into these disciplines the engineers closely work together as changes in one discipline will impact the other disciplines. Moreover, the engineers working on these projects are also located at Huisman's different facilities making clear communication between the engineers working on the project important.

In the manufacturing stage the product will be manufactured. This will be done in house and can be accomplished in the various construction facilities located in the Netherlands, Brazil, China, and the Czech Republic. Depending on the product, delivery location, and occupation of the facilities the production location or locations are chosen. It is possible that sub assemblies of the end product are constructed in a construction facility and shipped to another construction facility to assemble the final product.

The commissioning stage mainly consist out of installing the product on the vessel and testing of the produced product. By doing this the value "safety by design" is again tested. This value is really important for Huisman as the equipment is so complex and big any mistakes made can have very large consequences.

After the instalment and all tests of the product, the product will be delivered to the client. This will be done in a turnkey delivery meaning the client can directly use the equipment they ordered.

Lastly, lifetime support is offered to the clients. During the operating time of on average 20 years, Huisman offers 24/7 lifetime support adhering to the value driver "cherish our clients". Service is of high value as the products delivered have to work in rough circumstances requiring the needed maintenance and sometimes repairs when something breaks. This service not only helps customers but also gives new insights into the weak spots of the design indicating what can be improved in future projects delivered. This closes the loop as this knowledge obtained will be processed in the new concepts and designs for future products.

5.1.2. Standardization at Huisman

As mentioned, at Huisman, projects are executed following an ETO procedure. Although working in an ETO environment, standards are set up with as main goal to reduce costs, reduce lead time, and work more efficient overall. This is first of all done by copying the philosophy of previously developed designs. To make this viable, the products are categorized in product families which consist of the same type of product in different sizes. Most cranes for example, have predefined sizes which can be fully adapted to customer needs. In this way, previous projects can be used as basis for the new products designed reducing lead times and costs.

It has been recognized, some of the product families are open to more standardization than other product families. This has been based on experience of producing the product rather than a thorough analysis of the product families. A way to do such analysis is currently lacking.

Using experience gained over the years in producing the equipment, further investigations are done to define where additional standardization is possible. These investigations are mostly done for the product families that have been recognized to be more suitable for standardization than other product families.

Due to the high complexity of the product families produced by Huisman, finding the right standardizations is difficult. The installation of the equipment on vessels that vary in characteristics, as well as the different positions in which the equipment needs to be installed on these vessels, hampers standardization. This is caused by the varying interfaces between vessel and equipment per project.

Furthermore, the products also have to comply with varying Ship Classification Societies depending on what is required by the insurance company of the client. These societies set the technical and operational standards for the vessel and the equipment installed on the vessel. These classifications are founded to ensure safety and security in the maritime domain. Although the varying classification societies are quite alike each classification society does have its own rules and regulations which should be integrated in the design obstructing full standardization (Joshi, 2024). The various societies have overarching regulations prescribing what the design needs to adhere to however the biggest variations are in the process of designing the final design. All designs made by Huisman do thus comply with the overarching standards, the methods can however be a stumbling point. When a different approach is taken than prescribed by the specific society, the engineers will need to go in discussion to convince the society the taken process is as good or even better than the prescribed one. Although this does cost a lot of engineering hours to answer all questions, the design can most of the times stay the same. Although a revision is done every year by the societies, these changes do not really impact the design and is thus not influencing standardization that much.

5.1.3. Introduction to the Sub-Units

As mentioned before, three sub-units will be analysed within this embedded single case study. These sub-units are projects that are currently demanded by clients and which are expected to be demanded in the coming years as well because of the grow in offshore wind and the continuing demand in the oil and gas market (Myles, 2021). The products and their projects that will be analysed are knuckle boom cranes (KBC), leg encircling cranes (LEC) and motion compensated pile grippers (MCPG).

Knuckle boom cranes are relatively small cranes with a jointed boom which are often installed on subsea construction vessels, offshore support vessels or as auxiliary crane on a vessel. Huisman produces KBCs that can lift maximum capacities between 80 and 550 metric tons. KBCs are used to help relocate materials on the vessel and move materials from one vessel to another vessel at sea. Furthermore, KBCs are also used for subsea activities, offshore construction work, and other support at sea. This wide variety of employability makes that this piece of equipment is deployed both in the offshore wind market and the oil and gas market. Because of the joint in the boom, the crane is highly manoeuvrable and space efficient. Furthermore, the boom can be shortened due to the joint resulting in safer load handling which is especially important during vessel motion and when moving heavy objects. Figure 5.2 depicts a visualization of a KBC for clarity.

Figure 5.2: Knuckle Boom Crane (Huisman Equipment B.V., n.d.)

Leg encircling cranes are compared to KBCs far bigger cranes, having a maximum lifting capacity of more than 3300 metric tons. These type of cranes are designed to be used on jack-up vessels. These type of vessels are used in shallow waters and have legs that can be jacked down to the seafloor to push the hull of the vessel above the surface of the water. Doing this, a steady base is created as waves will not have influence on the vessel any more. The LEC is built around one of the jack-up legs and can, if needed, be stored around another leg which is useful to save valuable deck space. These type of cranes are mostly used in the offshore wind industry for the construction of offshore wind turbines in shallow waters. LECs have a long boom which is required to reach the heights needed to instal modern wind turbines. Figure 5.3 depicts a visualization of a LEC for clarity.

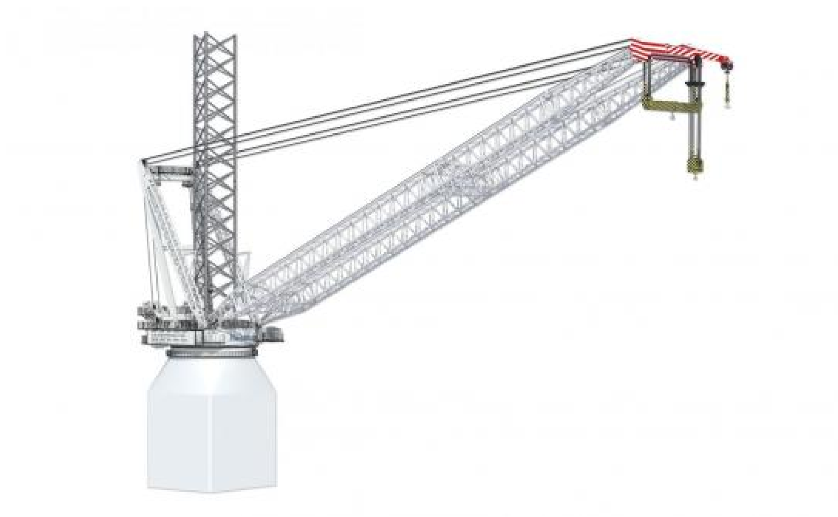

Figure 5.3: Leg Encircling Crane (Huisman Equipment B.V., n.d.)

Motion compensated pile grippers are a different type of product compared to the previous two products introduced. Compared to the previous products, an MCPG is not a crane but a piece of heavy construction equipment that is used to drive monopiles into the seabed. When the monopile is driven into the seabed a wind turbine can be installed on them. An MCPG is a type of pile gripper, the special characteristic of this type is that it is motion compensated. Because of this motion compensation the influence of waves on the vessel can be countered ensuring precise positioning and stability of the pile during the instalment. This technology used is highly innovative and can be seen as a solution for the future. Because of this technology, wind turbines can be installed in deeper waters as a floating vessel instead of a jack-up vessel can be used to install these monopiles into the seabed. This offers more opportunities to instal wind turbines at sea than just the shallow waters using a jack-up vessel. The MCPG is only applied in the offshore wind market as the product is specifically designed for this market. Figure 5.4 depicts a visualization of an MCPG for clarity.

Figure 5.4: Motion Compensated Pile Gripper (Huisman Equipment B.V., n.d.)

These three sub-units will make up an interesting comparison due to their differences in characteristics and application whilst produced by the same company. During the study the differences can give insights into what affects the possible degree of standardization when the products are compared to each other.

5.1.4. Main Markets Huisman Operates in

Huisman is mainly constructing equipment that is employed in the offshore wind energy and the oil & gas industry. As mentioned in the introduction of the subunits, all subunits can be employed in the offshore wind industry where KBCs can also be used in the oil and gas industry. The recent past years and an outlook for the coming years have been plotted by Clarcksons Offshore and Renewables (2024). This is a consultancy company that is specialized in providing market data and analysis on offshore energy. Figure 5.5 shows the plot set up by this company where an overall increase of investments in the combination of the two industries can be recognized after there has been a dip until the year 2021. Compared to this year (2025) an increase is visible in both industries where, for the offshore wind energy a small decrease is forecasted starting in 2027. Although there is a small decrease there will still be a reasonably stable investment each year indicating sufficient need for construction equipment in the coming years. This indicates there will be a stable demand in the future for all three types of equipment used as subunits indicating the products could potentially benefit from standardization.

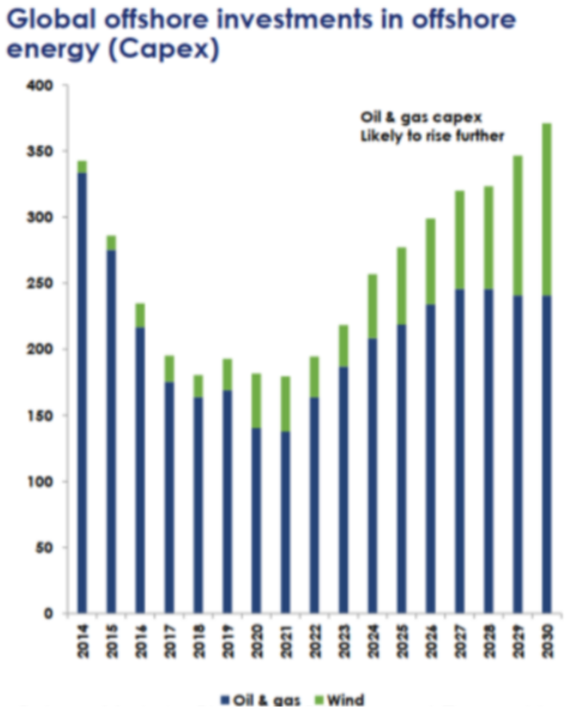

Figure 5.5: Global offshore investments in offshore energy (Capex) (Clarcksons Offshore and Renewables, 2024)

5.2. Knuckle Boom Crane Analysis

5.2.1. A1: Determine the Market Strategy

[This paragraph has been removed in the public version due to company confidentiality]

During this activity, the focus was placed on finding the order winners and the strategic priorities for KBCs. This has been achieved by interviewing a Tender and Concepts engineer and a Sales Manager. Furthermore, the knowledge gained by being embedded in the organization was helpful. To create an overview, an activity system map has also been created, which can unfortunately not be depicted due to confidentiality.

5.2.2. A2: Define the Product Specific External Factors

The next activity to take following the SSDP is defining the product specific external factors. In Section 3.4.1 the market related factors influencing standardization have been established which will now be applied on KBCs with the strategy Huisman is applying on these products.

First of all, **delivery lead time requirements**. Customers always want their products as fast as possible, however, as mentioned in Section 3.7 there are other market winners as well. During the interviews, the average lead time for KBCs could be determined. Comparing the lead time to other products produced by Huisman this time period is relatively short.

The **volatility** in the market is present with an expected peak the coming years. The current demand is caused due to the increase in the markets as well as due to the age of the currently operating KBCs. The currently operating cranes are currently ageing and close to the end of their lifetime (Clarkshons Offshore & Renewables, 2025). This results in owners setting out tenders for new equipment causing an increase the coming years. Moreover, the volatility is also impacted by the volatility of interest on loans. Even though KBCs are relatively small projects the overall investment of a new vessel and a KBC is expensive, resulting in less cranes sold when interest rates are high.

When it comes to **customization requirements**, they are lower compared to other products Huisman produces. This conclusion was drawn from an interview with a sales employee, who explained that KBCs are cranes not used full time, but rather serve primarily as auxiliary cranes on vessels. Because of this, customers have less requirements when ordering these type of cranes.

Concerning **order size and frequency**, typical order sizes are between one and four KBCs per order. The frequency of orders is relatively high. Customers have also returned to order more cranes after they already acquired a or multiple KBCs before. In activity three this is further elaborated on when analysing the projects.

The **type of customers** focussed on is confidential information and can thus not be shared in this public version of the thesis. The type of customer did give insights in the standardization potential of KBCs.

Variations in regulations and standards in the shipbuilding industry are based on the Ship Classification Societies introduced in Section 5.1.2. As mentioned, the varying societies have overarching requirements only with varying methods that need to be taken to reach those requirements. The safety factor that need to be implemented are the same for every lifting appliance however vary based on the expected usage in terms of time and maximum lifting capacity used. These factors do not really influence the geometries of the full design. From this can be concluded, the variations in regulations and standards will, for Huisman, not have a noteworthy impact on the suitability of standardization.

Lastly, the **maturity of the end product** has to be defined. The two types of maturity are the technological maturity and the design maturity. The applied technology stayed practically the same over the years. Although, Huisman designed an alternative solution to the hydraulics used making use of electro motors and cable giving the opportunity to make the cranes able to lift more weight, this technology is not focussed on as this is developed into a new product family called hybrid boom cranes. Generally, the design of KBCs stayed practically the same over the years. KBCs can thus been seen as a mature product.

5.2.3. A3: Analyse Current and Previous Projects

In order to obtain insights into the current degree of standardization implemented in projects, previous and current projects will be investigated. The data of recently awarded contracts been collected and is depicted in Table 5.1.

Table 5.1: Data knuckle boom cranes

Type of KBC	Customer	Engineering Hours
100mt	A	Confidential
100mt	B	Confidential
250mt	C(1)	Confidential
250mt	C(1)	Confidential
100mt	D	Confidential
100mt	D	Confidential
100mt	D	Confidential
100mt	D	Confidential
250mt	C(2)	Confidential
250mt	C(2)	Confidential

From this data could be concluded making copies, and thus standardizing, does pay off as engineering hours decreased when multiple products were ordered. This pattern could be identified in all orders in different magnitudes. A difference between the engineering hours between the same product for different clients was also noticeable. This indicates some client order KBCs that required more customizations than other ones.

As explained in Section 3.5 the current degree of standardization can be estimated by the engineering complexity and the amount of yearly units sold. In order to calculate the engineering complexity the amount of engineering hours spent on each project should be divided by the average annual units sold as defined in Equation 3.2. In total there are 10 projects having spend a joint total amount of engineering hours. In order to obtain the engineering complexity, this sum of engineering hours should be divided by 10 resulting in the engineering complexity. In their 2x2 matrix, Willner, Powell, et al. (2016) divided the matrix into 4 quadrants each being related to an archetype of ETO. The boundary of engineering complexity is at 2000 and the boundary for average annual units sold is at 750. KBCs are above the 2000 boundary for engineering complexity and far below the 750 boundary for average annual units sold, this indicates the archetype fitting with KBCs is ”Complex ETO”. A complex ETO has been defined as an archetype where the implementation of standardization and automation is low.

To summarize, a clear relation can be seen to the degree of standardization and order size where the average engineering hours clearly decreases in larger orders. This indicates standardization reduces the engineering hours when implemented. Furthermore, a significant difference between customization requirements can be recognized between different clients. Moreover, this indicates standardization can thus be applied even though the product is labelled as ”Complex ETO”. This shows further research into standardization will be valuable to identify what exactly could be improved to always keep the engineering hours low.

5.3. Leg Encircling Crane Analysis

5.3.1. A1: Determine the Market Strategy

[This paragraph has been removed in the public version due to company confidentiality]

During this activity, the focus was placed on finding the order winners and the strategic priorities for LECs. This has been achieved by interviewing a Sales Manager. Furthermore, the knowledge gained by being embedded in the organization was helpful. To create an overview, an activity system map has also been created, which can unfortunately not be depicted due to confidentiality.

5.3.2. A2: Define the Product Specific External Factors

Concerning **delivery lead time requirements** there is typically one main requirement by the customer which is to finish the crane at the same time the vessel is finished the crane has to be installed on. This requirement is normally given by the customer as the vessels the LECs are placed on are normally newly constructed. In the construction time of the vessels the LEC can thus be constructed in parallel only requiring it to be installed on the vessel.

As discussed in Section 5.1.4, **volatility** is present in the offshore wind industry. This volatility also affects LECs as these type of cranes are needed to construct the offshore wind turbines. Furthermore, geopolitics plays its part in the volatility of LECs. For example, due to the war between Ukraine and Russia global metal prices increased by 200% decreasing the demand of wind turbines a lot as they become too expensive (The Energy Transitions Commission, 2024) or President Trump halting the construction of offshore wind farms in America (The White House, 2025). Because of this, the global demand for construction equipment like LECs decreases as well causing a volatile environment. As mentioned before, interest rates on loans also impact the volatility, as the investment for LECs is far higher than for KBCs this interest rates will also have bigger impacts. Besides this, the volatility present in the size of wind turbines effects standardization possibilities. As wind turbines are increasing in size new innovations regarding LECs need to be performed in order to install heavier components at higher heights.

A high degree of **customization requirements** is present in the design of a LEC. First of all, the application of the LEC determines some customization requirements concerning what type of turbines will be installed making use of the crane. Furthermore, the vessel the LEC will be placed on will impact the design concerning needed lifting power and length of the boom. The size of vessels varies, as well as the interface where the crane is installed on. Furthermore, the power supply varies per vessel which requires variations in the electrical design of the crane.

The **order size and frequency** are both rather low. LECs are ordered in a maximum of one crane every time. Sometimes, repeat orders are received, where a customers orders a relatively similar crane as they ordered before. Furthermore, there are also returning clients that need to renew or expand their current fleet. On average three LECs are sold every year by Huisman.

The **type of customers** focussed on is confidential information and can thus not be shared in this public version of the thesis. The type of customer did give insights in the standardization potential of LECs.

As mentioned during the assessment of the external factors during the review of KBCs, **variations in regulations and standards** do not have a noteworthy impact on the suitability of standardization for Huisman as all designs meet the requirements of all societies. Only the methods sometimes need to be adapted or the safety factors however, this does not have a genuine impact on standardization. This does not only hold for KBCs but for LECs as well.

Since the product is still changing the **maturity of the end product** is thus not fully mature. Due to the changes in size of wind turbines that need to be installed, LECs develop over time as well. Although the same technologies are used especially the design has to be adapted to be able to lift heavier objects and reach higher heights.

5.3.3. A3: Analyse Current and Previous Projects

Huisman is constructing wind turbine installation equipment since 2002, the data used in this analysis is data collected in more recent years. This timespan is chosen to keep the focus on recent projects as the product is evolving over time. Data of various LEC16 and LEC20 cranes is used, the number indicates the diameter of the slew bearing integrated in the cranes. The data is presented in Table 5.2, in here can be seen that various companies ordered multiple LECs, these are all repeat orders where first one was delivered after which an extra one was ordered.

Table 5.2: Data leg encircling cranes

Type of LEC	Customer	Engineering Hours
LEC20	A	Confidential
LEC16	B	Confidential
LEC16	C	Confidential
LEC16	D	Confidential
LEC20	E	Confidential
LEC20	F	Confidential
LEC20	F	Confidential
LEC16	D	Confidential
LEC20	F	Confidential
LEC20	G	Confidential
LEC20	F	Confidential
LEC20	G	Confidential
LEC20	F	Confidential

From the data, the ETO archetype defined by Willner, Powell, et al. (2016) can be obtained. Dividing the total sum of all engineering hours spent by the total amount of projects gives the engineering complexity. This results in this product being a ”Complex ETO” according to Willner, Powell, et al. (2016) making standardization difficult. Especially since the engineering complexity is this high integrating standardization becomes difficult.

Analysing the data further, two high outliers could be identified. These outliers are caused by innovations since whole new design needed to be made. For this, geometries had to be adapted causing a lot of engineering hours. Furthermore, the value of copying projects and thus applying standardization can be recognized in the return orders where the second and third order decrease heavily in engineering hours needed to accomplish the project.

From the data, the increase in size and lifting capacity over the years can also be seen which is caused by the increase of size of wind turbines. Company A and E were frontrunners which can also be seen from the high amount of engineering hours spent on the projects needed for the innovation of these larger cranes. This all indicates the end product is still maturing due to the volatility present in the market.

To summarize, LECs are characterized as a "Complex ETO" product indicating applying standardization is difficult. Furthermore, the engineering complexity is relatively high caused by the size, customization requirements, and complexity of the product. Besides this, the increase in size can be recognized from the data where the shift in demand for cranes with a higher lifting capacity is visible.

5.4. Motion Compensated Pile Gripper Analysis

5.4.1. A1: Determine the Market Strategy

[This paragraph has been removed in the public version due to company confidentiality]

During this activity, the focus was placed on finding the order winners and the strategic priorities for MCPGs. This has been achieved by interviewing a Sales Manager. Furthermore, the knowledge gained by being embedded in the organization was helpful. To create an overview, an activity system map has also been created, which can unfortunately not be depicted due to confidentiality.

5.4.2. A2: Define the Product Specific External Factors

Delivery lead time requirements can not play a role in these kind of projects. The projects need to be customized to such a high degree at the moment, requiring so much project specific engineering the customer has to except the shortest lead time possible.

The **volatility** in the offshore wind industry will also affect MCPGs as these are produced for this industry. The same thus applies for MCPGs as applies for LECs. Moreover, MCPGs are relatively large investments, negative market times will heavily reduce the demand for this type of installation equipment. This means higher interest rates will also heavily impact the sales of MCPGs. Furthermore, as the specific market for MCPGs is so small making outlooks for the demand of the product is impossible especially because so little products are sold yearly.

Due to the innovative nature of MCPGs, a lot of **customization requirements** need to be implemented in the design. These customizations are also caused by the vessel and the layout on the vessel concerning cranes, auxiliary cranes, storage and off course the MCPG. This causes different positions of the MCPG on different vessels resulting in different requirements for the piece of equipment.

Due to the large investment the **order size and frequency** are low. The order size has a maximum of one. Furthermore, approximately one MCPG is sold every two years, this is so low due to the very long lead time, high costs, specific use, and small demand to this equipment.

The **type of customers** focussed on is confidential information and can thus not be shared in this public version of the thesis. The type of customer did give insights in the standardization potential of MCPGs.

Variations in regulations and standards have little to no impact to the standardization potential of MCPGs just like it has no noteworthy impact on KBCs and LECs. Although for MCPGs it mostly impacts the methods used, the requirements can be achieved for all societies by adding documentation or by convincing the specific society the used method is as good or better than their prescribed method.

The **maturity of the end product** of MCPGs is low as the product is very new and still developing. Especially in terms of design the MCPG changes for every project. Furthermore, the same main technique is used however, integrated features keep changing due to new insights and lessons learnt.

5.4.3. A3: Analyse Current and Previous Projects

As explained, MCPGs are not produced that long yet and there is thus not much data available. At the moment, three MCPG have been taken into use and one more is currently being constructed. In the data, the first MCPG is not considered as it is deemed unrepresentative. The data which is available can be found in Table 5.3.

Table 5.3: Data motion compensated pile grippers

Type of MCPG	Customer	Engineering Hours
MCPG 2	A	Confidential
MCPG 3	B	Confidential
MCPG 4	C	Confidential

The engineering complexity of MCPGs can be calculated by taking the total engineering hours and dividing this by the total amount of projects. The result is relatively high compared to KBCs and LECs, this is mainly caused by the immaturity of the product described in the previous activity, as well as due to the customization requirements and overall size and complexity of the product.

When placing this product in the 2x2 matrix designed by Willner, Powell, et al. (2016) it will be all the way in the left top corner as very little MCPGs are produced per year with a relatively high engineering complexity. This results in the product to be a "Complex ETO" as archetype according to the authors.

Furthermore, the data does not indicate there is a decrease in engineering hours having to be applied in the various projects. This indicates there is no increasing degree of standardization over time visible from the engineering hours.

5.5. Comparing the Sub-Units to Determine the Most Suitable Sub-Unit for Standardization

Due to time constraints, a suitable standardization strategy can only be developed for one of the sub-units. This will be done for the product most suitable for standardization. To identify this product, the three sub-units will be compared to find out what product is best suitable to apply standardization to. To achieve this, the sub-units will first be compared across all three activities, after which a final conclusion can be drawn.

5.5.1. Comparison of the Findings in A1: Determine the Market Strategy

Comparing the market strategy between the three products various differences can be seen that indicate standardization is more applicable in one project compared to the other projects. This is based on the order winners, targeted market, targeted customer and main goal of the product. It could be concluded that on all these components KBCs are as suitable, or more suitable for standardization than LECs and MCPGs.

5.5.2. Comparison of the Findings in A2: Define the Product Specific External Factors

In order to compare the product specific external factors of the three product families, the data gathered has been summarized and placed side by side in Table 5.4. In this table can be seen how the external factors differ per product. Concerning delivery lead time requirements it should be as high as possible, indicating KBCs are most suitable for standardization. For volatility, it has been identified it should be as low as possible indicating KBCs or LECs are most suitable based on this factor. Customization requirements should be as low as possible as this interferes with standardization. The KBC product family is the only one with relatively low customization requirements and thus best suitable to standardize. Order size and frequency is also in favour of KBCs concerning standardization as it should be as high as possible to make the biggest impact. As mentioned, the variations and standards do have little to no impact on the suitability of any of the product families. It has been noted that a product should be mature before standardization is useful, suggesting that LECs, and especially MCPGs, are less suitable for standardization compared to KBCs.

To conclude, for every external factor KBCs are most suitable or just as suitable to standardize as the other two products analysed.

Table 5.4: Overview of the product specific external factors

	KBC	LEC	MCPG	Most Suitable:
Delivery lead time requirements:	Relatively high	Relatively low	Relatively low	KBC
Volatility:	Medium	Medium	High	KBC & LEC
Customization requirements:	Relatively low	Relatively high	Relatively very high	KBC
Order size and frequency:	Relatively high	Relatively low	Relatively very low	KBC
Variations in regulations and standards:	Little to none	Little to none	Little to none	KBC & LEC & MCPG
Maturity of the end product:	Mature	Not fully mature	Immature	KBC
Overall:				KBC

Note. KBC = Knuckle Boom Crane; LEC = Leg Encircling Crane; MCPG = Motion Compensated Pile Gripper.

5.5.3. Comparison of the Findings in A3: Analyse Current and Previous Projects

The data collected concerning the engineering complexity during the review of the sub-units is displayed in Table 5.5.

Table 5.5: Data of the three sub-units

Product	Engineering Complexity	Archetype
KBC	Confidential	Complex ETO
LEC	Confidential	Complex ETO
MCPG	Confidential	Complex ETO

Note. KBC = Knuckle Boom Crane; LEC = Leg Encircling Crane; MCPG = Motion Compensated Pile Gripper.

As previously mentioned, the potential gains of standardization is depended on the complexity of the engineering that has to be applied in the project (Willner, Powell, et al., 2016), (Haug et al., 2009). Furthermore, the more products sold annually, the more beneficial standardization becomes, as its costs can be spread across a larger number of products.

From the data could be determined the engineering complexity of MCPGs is the highest, followed by LECs, followed by KBCs. Besides this, based on average annual units sold, the KBCs also have the best score.

5.5.4. Conclusion on the Most Suitable Sub-Unit for Standardization

From the comparison conducted in this section, it can be concluded that KBCs are the most suitable for standardization. This conclusion is based on the fact that, at every level, KBCs are considered more appropriate for standardization than the other two product families. As a result, the focus for the next three activities of the SSDP will be on KBCs. The investigation of standardization for LECs and MCPGs stops here for now. This does not mean that standardization is impossible for these products; rather, they are less suitable for a high degree of standardization. In future studies, more appropriate standardization strategies may still be developed for these product families.

5.6. Working Out the Last Three Activities for KBCs

5.6.1. A4: Analyse Current Internal Factors

In order to find the status of the current internal factors, the biggest source of data were interviews conducted with an engineering development manager who is engaged closely in the design of KBCs, a sales manager who sold multiple KBCs and the supply chain manager responsible for new built projects like new built KBCs. Furthermore, insights from being present at the company and having talks with other employees resulted in the elaboration of the following factors.

Product Related Factors

Customization opportunities

[This paragraph has been removed in the public version due to company confidentiality]

In this paragraph, the structure of KBCs has been analysed. It has been identified KBCs consist out of a set amount of main components which make up the full product. There are variations in the components resulting in for example higher lifting capacities or hoisting speeds. Besides these main components, there are additional components that are added to these main components due to customer requirements. These additions generally demand many engineering hours as they have to be integrated in the main design of the cranes. Furthermore, customization opportunities have to be provided concerning the layout of the crane, the position the crane will be placed on the vessel, and the type of vessel the crane is placed on. During the analysis of the customization opportunities it has also been defined small customization can be easily implemented as long as they do not acquire changes in the main components and geometries. Bigger customizations should be avoided as this will result in many additional engineering hours.

Modularity (structure)

[This paragraph has been removed in the public version due to company confidentiality]

As mentioned during the analysis of the customization opportunities, there are main components defined for KBCs. Although these various main components exist, they can not be exchanged without consequences for the other main components. This is caused by the fact all main components influence each other. If one main component is changed for another type of this main component, other main components will have to be changed or adapted as well. Furthermore, the interfaces also have to be adapted sometimes due to add ons that are added to the design.

Variance of integrated components

[This paragraph has been removed in the public version due to company confidentiality]

During the analysis it was identified suppliers delivering components to Huisman need to withstand some strict quality checks before components can be ordered from them. This results in a select few suppliers that can deliver each component acquired from a third party reducing the variance. There however still is variance of components as relationships are set up with various suppliers for most components.

Process Related Factors

Freedom in the sales process

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The analysis showed there is some freedom available for the sales employees. Designs are mostly based on previous designs made. Furthermore, standard working procedures are set up regarding the process from a tender to a deal. The freedom is especially needed to win tenders as customizations have to be implemented for customers to accept the deal. Although for small customizations this is generally no problem, bigger customizations induce a lot of additional engineering hours.

The **freedom in the engineering process** is limited by having standard working procedures for everything that has to be done. This is made into flow diagrams where all steps of the design process of the full product are placed in. According to the engineer the interview was held with, it is not possible to fully standardize how a design should be developed as when this is the case, the design has already been made. Some freedom should thus be granted in order to make the final design where everything is integrated in. Besides that, it is not possible to have 100% control over how components are designed and if that is done to the exact standards set. Furthermore, the freedom should not fully be limited as new, better ideas should be implemented to allow room for innovations. There are however regulations for what exact calculations should be used which are partly defined by the classification societies. As multiple KBCs are already designed, the engineers have also created a kind of standard in how the designs look like and should thus be made up for new products.

Freedom in the supply chain process

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As analysed for the engineering process, the freedom in the supply chain is also limited by having standard working procedures. The analysis showed multiple suppliers are selected from which has to be decided which one can deliver the component needed. This selection process is thus following a standard working procedure.

The **degree of vertical integration in the supply chain** can be seen as rather high since Huisman produces most of the components themselves. Small, non-critical components that can be bought from catalogues and steel plates and pipes are, however, bought but are fully processed in assemblies that are part of the final product that will be produced. Besides this, specialistic critical items are bought from third parties as these companies are often specialized in these types of products. These components will be ordered from suppliers and assembled in the end product in-house.

5.6.2. A5: Analyse Potential Improvements of Internal Factors

Analysing the Maturity Model

The maturity model set up by Willner, Gosling, and Schönsleben (2016) is once more depicted in Figure 5.6 (A larger sized version can be found in Figure 3.5 in Section 3.6).

	Level 1 *– Ultimate Freedom –*	**Level 2** *– Product Standardization –*	**Level 3** *– Automation of Tendering –*	**Level 4** *– Automation of Order Execution –*	**Level 5** *– Full Automation –*
Strategies	• Open solution space; customer is free in defining order specifications • No performance management: budget and schedule are not tracked and often exceeded	• Definition of product lines; creation of product structures; product modularization • Distinction between standard, configurable and special components • Basic performance management: budget and schedule are manually tracked	• Implementation of commercial product structures in sales configurators → formalization of solution space • Advanced performance management: budget and schedule are tracked; deviations are monitored	• Implementation of technical product structures in engineering configurators → formalization of solution space • Superior performance management: Budget and schedule are tracked; deviations are monitored and used to define improvement measures	• Fixed solution space that is regularly adjusted to customer needs • Performance measurement used for continuous improvements
Processes	• Ad-hoc processes, occasionally chaotic	• Nascent processes; no clear distinction between processes for standard, configurable and special components • Replication of processes across locations	• Process 1 (standard & configurable components): Tendering guided by sales configurators; automated generation of tender documents (semi-automation) • Process 2 (special components): roughly defined process	• Process 1: Order execution process guided by engineering configurators; automated generation of purchase orders & drawings • Process 2: meta-process for special components	• Fully defined and coordinated processes
					MTO

Figure 5.6: Standardization maturity model adapted from Willner, Gosling, and Schönsleben (2016)

When reflecting the factors analysed in activity four to the matrix there could be concluded at this moment the product family can be placed in Level 2 of the standardization maturity model. This indicates that, momentarily, product standardization is taking place already. In order to move to the next level, Willner, Gosling, and Schönsleben (2016) indicate the solution space should be formalized by implementing product structures and configurators in the strategies dimension. In the processes dimension, a distinction should be created between processes for standard, configurable and special components in order to move to Level 3 of the model.

With this knowledge in mind, the internal factors can be assessed again. Doing this, possible changes of the factors that advance standardization can be developed. These changes will have to help to move to a higher level of standardization in the model. For KBCs it is thus important to change the internal factors in such way the solution space is formalized further. Besides this, distinct processes should be set up for standard, configurable, and custom components.

Analysing the Internal Factors

As mentioned, **customization opportunities** should be limited as much as possible to standardize to a higher degree. To start standardization, first standardized main products should be designed, these products should range in lifting capacity and hoisting speed. This range of products should be the basis where additional configurations and smaller customizations can be added to. To limit the customization opportunities, further the add ons that can currently be provided or have been provided before should be clearly listed in a list of configurations that can be added to the current standardized models of KBCs. These add ons should be engineered in such way they can be added to every type of KBC they could be applicable to in order to prevent additional engineering hours after the order has taken place. Different to add-ons, configurations could also consist of other more general requirements like the layout of the crane. Besides this, further customizations customers tend to require should be integrated into more standard configurations in order to obtain a complete list and move the CODP further downstream. All these engineering configurations should then be translated into sales configurations in such way sales can offer the standard designs and let the customer choose between the available predefined configurations.

To enhance the **structure (modularity)** of the product some additions can also be done to benefit standardization. The modularity of the current designs the products are based on can be increased by standardizing the interface of the main components. These interfaces should be designed in such way the cables and pipes possibly needed for the configurations set up are already implemented or can easily be implemented without making changes to these interfaces. In this way, less or no engineering needs to be done when configurations are implemented in the final design. Although this will cost engineering time before the order, it will result in a higher degree of standardization which, when applied to enough projects, results in less average engineering hours spent per project. Furthermore, the structure of standardized types of KBC should be developed in such way add ons can be easily integrated without having to do to much additional engineering. This is of importance as making standard configurations which can be added during the sales process is how standardization can be advanced when following the maturity model.

To increase the degree of standardization, the **variance of integrated components** should be decreased. The current strategy applied is established around the production of customized end products. When more standardized products are produced, the amount of suppliers can be reduced to one, providing benefits for both Huisman and the supplier. With a higher degree of standardization, it becomes possible to better forecast the number of products that will be sold in the near future, and consequently, how many standardized components need to be purchased for these projects. Using these insights, arrangements can be set up between Huisman and the suppliers as the supply facing end of the supply chain can be transformed in a MTS way instead of a MTO way (Chen-Ritzo, 2006). In these arrangements, a guaranteed amount of components purchased from the supplier can be set up resulting in guarantees for the supplier who can then already start producing the standardized component ahead of the real order. Besides this, a standard price per component can be agreed upon instead of setting up a new price for every order. In this way, the supply chain at the supplier side can be transformed from a pull supply chain more into a push supply chain where the flow is triggered by the forecasted demand (Ambe, 2012). In order to achieve this, communication between the sales department and supply chain department should be very clear as the sales department should indicate the forecasted amount of KBCs that will be sold in the near future. Because of the provided guarantee for the single supplier and the standardized components this supplier has to produce, the average costs per component will decrease as less to no engineering hours are needed. Moreover, the supplier can buy its raw materials in bulk, and risks are decreased for the supplier as they will have a guarantee of orders in the near future. For Huisman, this way of setting up the supply chain will also results in advantages. Besides a reduced cost price per component and thus per project, lead times will reduce as well as the supplier is producing the components in their stock instead of starting to produce it after the order has been placed. Moreover, the interfaces and measurements of the component will always be the same as the same components are used every time. Also, the knowledge about the component will increase when it gets integrated multiple times. Also, the quality of service will increase even further as the lead time of the component can be obtained faster due to the stock of the supplier.

The current **freedom in the sales process** can be limited further in order to enhance standardization. In order to do this, the freedom of sales should be limited to only standardized main products with potential configurations which have to be pre defined in the engineering process. These configurations should be set up based on requirements by customers and should be revised every two years in order to keep them up to date according to the current market. When these configurations are set up, the sales department should only offer these configurations to the clients and should be restricted from deviating from the standard designs with the possible configurations. If the client really requires something which is not in the configuration there should be investigated if this is a configuration worth adding to the list of configurations which can then also be implemented for other customers. When this is not the case, the requirement can not be implemented in the final design which the customer has to accept or a consisting configuration that has for example more capacity should be chosen by the customer. Before this strategy is really possible, time should be invested in defining the configurations and setting these up. When this is done, the design set up during the negotiations with the customer should be set up only from the standard main products with the required configurations chosen from the list of pre defined configurations. Implementing configurations shifts the approach from ETO to CTO, significantly reducing engineering hours since the configurations have already been pre-engineered.

The **freedom in the engineering process** has already been limited to a high degree by working according to specific working procedures. However, a change in the process of engineering could benefit standardization as currently the process is designed especially for custom projects according to the engineer interviewed. This change should happen as the process now takes steps and requires checks that are actually not needed, for example, the main components used are already standardized and have thus been approved before. As suggested by the maturity model, separate processes can be established: one for using standardized items and adding configurations to them, and another for designing special components that fit within the standard designs. In order to do this, the organization would also benefit from making a division between one group of engineers responsible for the standards that will be designed on a MTO basis and another group of engineers responsible for the custom components which have to be designed on an ETO basis (Willner, Gosling, & Schönsleben, 2016). Besides this, a database should be constructed where the standard main components and configurations are stored in. In the working procedures should be integrated that this database has to be used when designs are made. There can only be deviated from this standard database when specialized components are required in the design.

Currently, the **freedom in the supply chain process** is already standardized to a high degree. Standardization will bring opportunities to structure the process in a more optimal way. As mentioned during the analysis of the engineering process, some steps in the process can be skipped when standards are integrated in the designs. For the supply chain process, this can be achieved by setting up arrangements with single suppliers per component type. By doing this the supply chain at the supplier side will transform from a pull supply chain into a push supply chain (Ambe, 2012) where the components are made to stock to the forecasts made by Huisman.

The **degree of vertical integration in the supply chain** can be increased compared to the current status as part of increasing the degree of standardization. To consider what components could possibly be produced in house there should be looked at what expertise is present or can be obtained without making to much costs. By producing components in house, using the in house expertise could result in a reduction of costs; a reduction of risks getting the components delivered in time, as well as more security in the component not changing due to the supplier changing the design or stopping to produce the components. There are two options of increasing the degree of vertical integration according to the engineer interviewed. The first option is to assemble the component in house instead of buying the component as assembly. This will reduce costs and reduce the risk of the full assembly changing. The benefit of not relying on suppliers for the components is however taken away as the components of the assembly still have to be delivered. Moreover, the separate components of the assembly can also change, having to adapt the overall assembly. Another way to increase the degree of vertical integration, which is recommended for standardization, is by setting up a factory to produce the components of the assembly. In this way, Huisman would be only dependent on the raw materials which can be placed in stock to reduce the risk. Establishing such a factory involves substantial investment, its long-term use may justify the cost. This should however be further investigated before the investment is actually made.

Besides this, another advantage of standardization concerning the vertical integration of the supply chain became clear during the interviews with the engineer and supply chain manager. During the interview, it became clear that when items are standardized, the degree of vertical integration can be reduced to optimize the production process. This can be accomplished by letting suppliers work together to deliver assemblies made from the by Huisman chosen standards. In this way, the production process can be sped up as this full assembly can be directly placed in the end product. This is only possible when the components are standardized as the suppliers can make arrangements among each other to create the assembly. This moves the penetration point in the production process to the 'Assemble' sub-flow (Cannas et al., 2019).

5.6.3. A6: Generate the Applicable Improvements into a New Standardization Strategy

Activity six will combine all previous activities conducted into one suitable standardization strategy. To accomplish this, the first three activities will be analysed to determine the standardization potential of the product. This will be reflected on the potential improvements of the internal factors set up during activity five.

Market Strategy

[This paragraph has been removed in the public version due to company confidentiality]

Reviewing the information collected during the market strategy applied for KBCs shows KBCs are relatively open for applying standardization, especially compared to LECs and MCPGs as proven in the comparison in Section 5.5. To conclude, the market strategy operated for KBCs is open to standardization. The only aspect in this strategy restraining standardization are the replies to highly custom tenders.

External Factors

As mentioned, the **delivery lead times** should be as short as possible as customers demand their newly bought KBC as fast as possible. Standardization will result in shorter lead times for the customers. Moreover, standardizing to a high degree could potentially even result in the possibility to produce KBCs on stock according to the product owner of KBCs at Huisman. To identify if this is really viable, a deeper market analysis is required in the future. This deeper market analysis should examine whether customers truly require customization, or if a fully standardized KBC, with the option to add some configurations later, would also be sufficient. Unfortunately, this more detailed market research is outside the scope of this research.

Concerning the **volatility**, there is volatility present in the market. This negatively influences the potential of standardization. Although the market can be partly forecasted several influences like geopolitical impacts can not be predicted. When applying standardization this should be taken into account. Moreover, the volatility in the market also results in changing requirements of customers. Because of this, revisions to the standards of the design and configurations should be conducted every two years according to the interviewees. These revisions should be based on requirements of customers that can be analysed from the tenders received.

Since the cranes are mostly used as auxiliary crane the **customization requirements** are lower than those of LECs and MCPGs. These low customization requirements result in potential for standardization. There are however still some differences between the requirements of customers calling for standardized configurations that can be applied to the standard designs. However, sometimes during negotiations concessions need to be made regarding customizations to win the tender. These customizations can be minor or bigger customizations. Minor customizations have little to no impact on engineering like adding an extra camera or installing additional or special lights. Bigger customizations are also sometimes required where the design of the crane is impacted, these customizations can only be implemented in consultation between the sales and engineering department as they impact the standards heavily.

As could be clearly seen in Section 5.2.3 where the current and previous projects were analysed, the **order size and frequency** of KBCs is relatively high. This is positive for standardization as the costs made to standardize can be spread over these various products sold. Also, the order size is relatively high resulting in copies of the standardized designs, decreasing the spent engineering hours even further. This also means that when customer-specific customizations are needed, they can be more easily integrated in larger orders, as the engineering hours are spread across multiple products.

As previously mentioned, the **type of customers** is confidential and can not be discussed in the public version of this thesis.

Although there is **variation in regulations and standards** due to the different ship classification societies these do not influence standardization of the design. Although they will influence the standardization of the process, they induce a negligible impact on the final design of the product. These regulations and standards are revised every year indicating they should be monitored and compared to the standards adjustments should sometimes be made.

The **maturity** of both the design and technology of the end product can be seen as mature, enhancing standardization. However, as mentioned, due to market changes still variations in the design can be required. Also, technological additions could ask for changes like the current innovations of artificial intelligence that can potentially be integrated in the crane. As stated, this enquires revisions of the standards every two years.

To conclude, the external factors influencing standardization allow for standardization to a higher degree. There are however some aspects that should be kept into consideration when standardizing: First of all, there is volatility present in the market which asks for revisions of the standards every two year. Furthermore, the customer requirements are not always the same. Because of this, standard configurations should be set up. Lastly, the revisions every two years are also required to implement changes in technology that might occur in the future.

Further Analysing Current and Previous Projects

As noticed in Section 5.2.3, the engineering hours decrease heavily for products that are copied from a first version. The products do however still need engineering hours for which can thus not be standardized. To find out what causes part of the engineering process causes the remaining engineering hours the distribution of the total engineering hours has been further analysed.

What could be clearly identified is the decrease that can be obtained in engineering hours when copying the project. When standard designs are thus set up that can be applied for all, or at least multiple customers, these values can be kept low in all coming projects.

From analysing the distributions of engineering hours two remarkable engineering disciplines stood out. For one discipline, the engineering hours reduced a lot in orders of multiple cranes. This indicates that there can be standardized regarding this engineering discipline as these hours are thus not needed any more when a copy is made. Another discipline also stood out, this discipline did only decrease a little bit in bigger orders. This indicates there can hardly be standardized. This remarkable insight has been raised during an interview with the engineer who explained these hours do not decline that much since this part of engineering is needed for every product produced.

To conclude, from the engineering hours can be seen that standardization in the engineering disciplines will have the biggest impact and is best possible in one of the disciplines. However, Another discipline can hardly be standardized. Furthermore, a decrease can be obtained in the other engineering disciplines as well, however, they can not be eliminated fully as small changes need to be applied and support has to be given during the construction of the crane.

Setting Up the Suitable Standardization Strategy

Making use of the insights gained during the first three activities (that have been elaborated on above) the suitable standardization strategy can be defined. This is done by investigating the potential the changes in the internal factors, analysed in A5, have compared to the external factors. In order to do this, experts are consulted from the sales, engineering and supply chain department. As indicated in Section 4.2 it is best to organize a session including at least experts from these three departments. Before this session was held, the potential improvements have first been discussed individually with an expert from the sales, engineering, and supply chain department. During the discussions with the separate experts, the potential improvements of other disciplines have also been discussed as these experts do also have a vision on how other departments should integrate standardization for their own benefit. After these individual sessions, a session was planned where the same experts were brought together as well as other members from different departments to discuss the findings together. In order to do this, a presentation was given by the researcher showing the research method and the results. During and after this presentation there was room for questions and discussions to identify weak spots, potential for further research, and required changes of the standardization strategy. The outcomes of these discussions can be found in Section 5.7 (Evaluation of the SSDP). The overall research of the six activities of the SSDP resulted in the following standardization strategy which has been divided into overall adaptations, and adaptations for the sales, engineering, and supply chain department to achieve these overall adaptations.

Overall adaptations:
Overall, it is important to **further develop standard main types** of KBCs. Furthermore, standardizations should especially be made in the engineering discipline the most benefits can be obtained in which has been identified during the further analysis of the current and previous projects. Besides this, **standard configurations should also be developed** that can be applied or added to the standard designs in the product range when required by the customer. These configurations should be based on requirements of customers which can be seen in tenders, making use of experiences from past projects, and by looking at potential requirements in the future based on, for example, political influences. Besides this, the sales department should indicate if there is a trend of requirements asked for which can then possibly be implemented as standard configuration for future projects. At the start of standardizing, changes to the standards will occur more often as the standards defined are not matured yet. The need for these adaptions will also arise from lessons learnt from the products produced using the standards. Furthermore, as mentioned, the customer requirements also change due to the volatility in the market. For this reason, **the product range and standardized configurations should be reviewed every two years** to ensure they meet current and future market requirements. Moreover, the revisions are also needed due to maturing products which can be new innovations or ideas concerning the overall design of KBCs or innovations in components which can be integrated in the design. Besides this, additional technologies like artificial intelligence should be considered during these revisions. **Since the revisions possibly impact the sales, engineering, and supply chain department these should all be closely influenced during the revisions of the standards.** In order to achieve this, one or multiple sessions should be organized where potential improvements to the standards should be discussed.

To accomplish this overall standardization strategy, department specific standardizations have to be developed for the sales, engineering, and supply chain disciplines. These adaptations have also been discovered during the analysis of potential improvements during activity five.

Adaptations for the sales department:
As depicted in Figure 5.1: ”Huisman product cycle”, the product cycle starts in the concepts phase for which the sales department is responsible. Standardization of the KBC thus also starts in this phase. As mentioned, to improve standardization, the customization opportunities offered to the client should be limited. This should first and foremost be achieved by **only offering the standard range of KBCs** to the customer. Besides this, **the customer should only be offered the standardized configurations** which have been predefined for the standard range. **Only tenders for KBCs close to the standard range and configurations should thus be replied to.** The best scenario would be that the standard range combined with the standardized configurations could fulfil all requirements the customer has. The experience of the sales manager however indicates this will probably not be the case as customer always have specific requirements. For negotiation reasons some of these customizations should be granted. **For small customizations (like additional cameras or lights) that do not impact the main components, sales should still be free to arrange this with the customer to benefit negotiations. Custom requirements that do impact the main components of the crane should be avoided as much as possible. However, when bigger changes have to be made, to for example the main**

components, the engineering department should first be consulted before commitments are made to the customer. The engineering department can then investigate the additional engineering hours and the possibilities of spending these hours. When it is not possible to spent this additional time on the project, the customization can thus not be realized. When the customization can be realized, **the customer has to accept the additional costs and lead time** these customizations will demand. This indicates the penetration point in the sub-flows in the engineering process defined by Cannas et al. (2019) (Figure 3.2 is desired to be at 'Modify (minor changes)'. However, it should sometimes still be placed at 'Modify (major changes)' which is only an option if granted by the engineering department. As recognized during the analysis of the engineering hours of current and previous projects, larger order sizes reduce the average engineering hours per product. This indicates there should be **more room for customizations in bigger orders** than there is when only one KBC is ordered.

Adaptations for the engineering department:
Regarding the engineering department, changes are also needed to enhance standardization to a more suitable degree. The standardizations start working when **the standard product range and standardized configurations are worked out as far as possible.** The engineering department should thus focus on this to make sure as little as possible engineering hours are needed when the product is ordered. To do so, **the interfaces between main components and the interfaces between applicable main components and configurations should be standardized** to make sure the configurations can be like modules installed to the main standard design. This makes sure the configurations are interchangeable in the designs which is important for standardization (Gibb, 2001). The potential of additional pipes and cables for the configurations should thus be incorporated within the standard interfaces of the main components. Besides this, **the engineering process should be split up in two distinct processes. The first process should be designated for standardized components.** In here, various checks can be eliminated as standardized components which are checked already are used. This process should also have **a fixed team of engineers working on the standards**. In this way, the engineers will gain knowledge and learn from previous projects where the standards have been applied. This will result in increased quality and knowledge as discussed in Section 3.3.4. To make sure the standards can be easily found, **a special database should be set up where all standards are included in.** In this way the limitation of inaccessible standards discussed in Section 3.3.5 is taken away. It should be **mandatory for the engineering team set up for the standard components and configurations to use this database. The second process should be especially designed for the customized components** which can sometimes be implemented in the design. This is actually already an existing process as this process is currently used for the entire design of KBCs which is developed for the design of custom products. This team is needed because customizations will have to be implemented in order to win tenders as customizations can not fully be replaced by configurations.

Adaptations for the supply chain department:
Adaptations should also be made to the supply chain process in order to enhance standardization. As a move is made towards a standardized product complemented by configurations, the supply chain should also adapt to fit this strategy. Due to standardization **a single source supplier can be chosen for each component** which can be offered guaranteed work based on the forecasted amount of KBCs sold. Moreover, **arrangements with the suppliers can be established defining the amount of components that will be ordered in the near future and a fixed price per component**. To achieve this, **close collaborations should be set up between the sales department and the supply chain department** to make sure the forecasted amount of components needed is right. Moreover, **arrangements can also be made on production to stock at the supplier**, in this way the components can directly be acquired when demanded. However, for the configurations, **'order configuration uncertainty'** will occur (Chen, 2006), this is uncertainty that arises as no accurate forecasts can be made about what configurations are required by the customers. This causes the critical components of configurations will have to keep following the current process applied. Just like the case for engineering, supply chain will also need **two separate processes where one process is dedicated to standardized critical components and one dedicated to custom and configurable components** that are integrated for which the currently used process can be used. Besides this, the vertical integration of the supply chain can also be adapted. Standardization offers the opportunity to outsource a part of the supply chain by setting up arrangements with multiple suppliers. In this way, a **single supplier can deliver whole assemblies instead of just components** as the supplier can order the by Huisman

approved standard components from a second suppliers and assemble them directly to their own component to create an assembly. This indicates the penetration point in the production process is moved at the end of the 'Assemble' sub-flow (Cannas et al., 2019). Furthermore, **components ordered at this moment can potentially also be produced in house.**

To summarize, a change from ETO towards CTO is recommended. There should however still be room for some ETO to win orders, it should however be decreased as far as possible by setting up the right configurators. To give an overview, the following bullet points are set up. These points together make up all the adjustments and adaptations that have been identified using the SSDP. These points thus make up the suitable standardization strategy that has been identified for KBCs using this procedure.

Overall:

- Limit customization opportunities by limiting the offers by developing standardized product designs. In here, focus mainly on standardizing in terms of the engineering discipline identified that can best be standardized in.
- Develop standardized configurations based on overall customer requirements, experiences, insights by the sales department, and by investigating potential future requirements.
- Revise the product range and the standardized configurations every two years making use of sessions with the sales, engineering, and supply chain department. If necessary, earlier revisions can be initiated based on insights from the sales process or lessons learned.

Sales:

- The freedom in the sales process should be limited to only offering the standard product designs, including standardized configurations.
- Only tenders close to the standards developed combined with configurations should be replied to.
- If, for negotiation reasons, small customizations (e.g. an additional camera or additional lighting) need to be applied to the standard product, the sales department should be free to offer it.
- If the customer requires customizations impacting the design, the engineering department should be consulted to investigate the possibilities. The customer will have to pay an additional fee and will have to accept a longer lead time. There should be more room for customizations when multiple KBCs are ordered at once.

Engineering:

- The standard product range and standardized configurations should be worked out as far as possible.
- Develop standardized interfaces between the main components of the crane that are prepared to add configurations to the standard designs.
- The engineering process should be divided into two separate processes:
  1. A process especially designated for standardized components where various checks can be eliminated.
  2. A process especially designated for customized components which is actually the current process applied.
- Both these processes should have their own specialized team of engineers to work out the specific process.
- Develop an easily accessible database with standard main components and standardized configurations.
- In the process designated for standardized components, the use of this database should be made mandatory for engineers.

Supply Chain:

- The supply chain process should be divided into two separate processes:

1. A process especially designated for standardized components.
2. A process especially designated for configurable and customized components which is actually the current process applied.

- For the new process designated for standardized components, arrangements with single source suppliers have to be set up for each critical component. These arrangements should define a fixed price for the components for the coming year and let the suppliers produce the component on stock based on the forecasted sales of KBCs.
- Further investigate the development of a factory where critical components can be manufactured in house. The result of these investigations should indicate if this will shorten lead times and reduce the average costs per component.
- At last, further investigate the possibilities of setting up arrangements with various suppliers to make sure assemblies are delivered to Huisman instead of separate components. This will also have to be part of the new process designated for standardized components.

5.7. Evaluation of the SSDP

By applying the SSDP in the single embedded case study at Huisman the operation of the SSDP was demonstrated. To evaluate the procedure, first the six activities will be evaluated separately. Next, the requirements of the procedure stated in Section 4.1.1 are analysed. Furthermore, the procedure has been evaluated in an expert session which results will be shown. Lastly, more overall insights gained during the application of the procedure will be shared at the end of this section.

5.7.1. Evaluating the Six Activities of the SSDP

The first activity was to define the market strategy for the various product families, a process that was straightforward for all three product families assessed. It did however become apparent that the market strategy was not as well defined for all product families. On the other hand, the order winners were very clear and could be presented in a clear way by the interviewees.

Activity two analysed the external factors of the product families. During the analysis of these factors it became clear most information could be collected from the sales department and partially from the engineering department. It also became clear the factor 'type of customer' was very closely related to 'delivery lead time requirements', and 'customization requirements'. Although the type of customer is important to identify, during the case study it became evident it is not really a factor but more affecting the two factors just mentioned. In order to enhance clarity, this could be restructured. Furthermore, the low influence of the factor 'variance in regulations and standards' was a surprise for the author as it was expected this would make more impact on the standardization potential. This does however not mean this is always the case as in other ETO industries this factor might have a genuine impact on the suitable degree of standardization.

In activity three the data of current and previous projects was analysed. The advantages of copying previous designs became really clear during this activity. This indicates that if standards are set up and really sold, the engineering hours will also heavily decrease as in that case copies of the standards are actually produced. The engineering hours also clearly depicted the difference in projects between the three product families analysed. Moreover, it showed the archetypes defined by Willner, Powell, et al. (2016) did not indicate anything as, although varying a lot, all were defined as 'Complex ETO'. The engineering complexity alone gave a far better indication on the standardization potential of the designs as this varied a lot and reflected the results of activity two regarding standardization potential. Furthermore, during the interviews was stressed the engineering hours can never be zero since small adaptations, questions from the factory, and setting up the specific control system will always result in engineering hours in ETO projects.

After activity three, the three product families were compared to identify the most suitable product for standardization. This resulted in KBCs to be most suitable for standardization based on all activities. The comparison had to be conducted due to time reasons. When the SSDP is actually applied in practice, this step can be neglected and the SSDP can be worked out individually. Comparing the three products was however deemed relevant since the standardization potential of each product became much clearer when comparing them. This additional step also proved the functioning of the first three activities as the outcome was as what was expected before the SSDP was actually executed.

As mentioned, the last three activities were only executed for KBCs. Executing activity four provided the status quo of the internal factors. For this activity it became clear it is important to understand the product and the way the product is designed. When there is a clear understanding especially the product related factors are more clear which can be used to later in activity five develop potential adaptations to increase the degree of standardization. Moreover, this activity is seen as a development of understanding of the status quo which is the basis of the adaptations and additions done to increase the degree of standardization.

Combining the maturity model with the visions of multiple experts from different departments in activity five has been deemed of high value for the development of a suitable standardization degree. The maturity level gives a clear indication of the direction in which should be moved where the interviews with experts provide the possibilities how this can actually be achieved. What was identified during the interviews however, was not specifically a decrease of freedom in the processes, but more a change of process. This was most clear for the engineering and the supply chain processes as the current processes used are designed for the design and production of customized products on a project basis and do not really fit the processes needed for more standardized products. More research should be done to the change of these processes in order to make the SSDP more complete.

Lastly, activity six has been designed to bring all activities together and form the desired suitable standardization strategy for the product families analysed. First, creating an overview of the boundaries set by the market strategy and the external factors was valuable. This could be made up out of the analysis done in the first three activities. Furthermore, analysing the current and previous projects by including the distributions of engineering hours in the different disciplines was very useful. This gave clear insights in what engineering discipline can best be standardized in when it comes to standardizing the product. Combining these insights, the boundaries defined by the external factors and the standardization possibilities defined together with experts and based on the maturity model resulted in a clear standardization strategy that can be applied to KBCs. Discussing it afterwards with individual experts resulted in a small change for the sales department where was concluded bigger customization should sometimes still be made in order to win tenders. This should thus still be possible however it should always be done in consultation with the engineering department.

5.7.2. Evaluating the Requirements of the Procedure

In Section 4.1.1, the first requirement given is that the procedure should be applicable for ETO 'Type 1' companies that produce their products based on previous designs. By successfully applying the procedure to this type of ETO company, it can be concluded that the requirement was met. Furthermore, A6 of the procedure makes sure the right trade-offs are made between limitations and advantages of standardization by comparing the market strategy, external factors and insights from previous and current projects to the potential adaptations in the internal factors. The effect of executing the procedure multiple times to revise the standards could not be tested as the standards have to be implemented for two years before this is viable. By having discussions with the sales, engineering, and supply chain department about the results of the SSDP the departments were aligned in the resulting standardization strategy. Furthermore, by means of A2, A4, and A5, both external and internal factors have been analysed. In addition, A1 analysed the market strategy and A3 examined the available quantitative data; both were necessary, as they are considered relevant when assessing the suitability of a higher degree of standardization. All requirements stated in Section 4.1.1 have thus been met.

5.7.3. Expert Session Evaluation

As mentioned, to evaluate the SSDP further using the vision of experts, an evaluation expert session has been organized. In this session, 12 experts were present consisting of, among others, a sales manager, an engineering manager, multiple supply chain managers, and a manager of operations. In this session, first the methodology, SSDP overall, and results of the SSDP were presented to the experts in a 20 minute presentation. During, as well as after the presentation there was room for discussions and questions resulting in a meeting of in total one hour. The discussions were not only taking place between the experts and the researcher, but also among the experts highlighting different visions experts sometimes might have, based on their function in the company. These discussions and questions resulted into some new insights and are valuable for the evaluation of the SSDP.

The first point of discussion occurred when the adaptations regarding the sales department were presented. In here, it was shown on the slides a high level of standardization should be achieved by only offering standard products with standardized configurations supplemented with configurations. However, in another line it was mentioned there should be room for customizations especially in consult with engineering and there should even be more room for customizations in bigger orders. These lines contradict and needed some additional explanation to in the end conclude it is right to be open to customization when there is time to develop them. However, using standards always has the preference over selling a customized product. If a more customized product is required, margins should be higher to deal with the risks that have to be taken to realize the customizations and to encourage the customer to choose the standard options offered.

Another point made here was that a differentiation was made between smaller and bigger customizations, where small customizations do not influence the main components and bigger customizations do influence the main components. This is a good starting point according to the experts however there could better be a distinction made in expected engineering hours to determine it a big or small customization. In this way, it is better measurable and easier to get clear insights in what is a big and what is a small customization for the sales department. To this, more research should be done to define what a small and what a big customization is. This should be done in agreement with the sales, the engineering, and the supply chain department.

Besides this, a question was raised on how to define how much more customization can be applied when the order size increases. During the discussion that followed caused by this question it became clear this is dependent on multiple factors: the time the engineering department has, the type of customization, and the size of the order. It was concluded a good way to determine this is by looking at the engineering complexity of the total order and thus the average engineering hours spent per product that is produced. This quantity should as well be agreed on by the sales, engineering, and supply chain department.

Furthermore, it was noticed the procedure lacked financial insights. According to the experts, financial insights are very important, as it is necessary to determine the margins for producing a standard product versus a customized one. Furthermore, this will also give insights in the value of standardization to identify if spending money to develop the standards is really viable or if customization would be more profitable. Although the financial research was out of scope for this thesis, additional research would be valuable according to the experts to define the financial benefit of standardization. To incorporate this into the SSDP, it is recommended to develop an additional activity, as it is a highly complex factor influencing standardization.

Lastly, during the discussions the importance of close collaboration was stressed by all experts. When setting up a standardization strategy it is of importance to consult with other departments to make sure everyone is on the same page as standardization influences all departments and is thus a team effort. It was also stressed the production facility should be closely influenced when developing the standards as they should be able to produce the standard items in a short time. Everything should thus be perfectly clear and easy to produce to make sure standardization also works out well in the realization of the product. The production facility should for the best result thus be added in the SSDP as a department that should be taken into account.

5.7.4. Overall Insights Regarding the SSDP

Overall, the biggest challenge encountered by the researcher whilst implementing the SSDP was finding the right colleagues to collect the needed data from. This challenge was achieved by consulting colleagues working longer at Huisman and knowing who would be able to provide the needed knowledge. Although it was a challenge, all needed information was available. For someone working longer at the company and being more and longer invested in the product family, this challenge will probably not exist. Besides this, during the case study it was highlighted even more the procedure should be repeated every two years to make sure the standardization strategy and the standards defined in this strategy are up to date with the current market to counter the limitation of changing markets. Revising every two years and being open to adaptations to standards when recognized these are needed, will counter the limitation of loss of innovation as well. By implementing the opinions of multiple departments in developing the standardization strategy, organizational resistance is also avoided. Moreover, integrating configurations will work against simplifications of the end product.

If the advantages of standardization are really accomplished is still unclear. This is caused by the fact there was not enough time to really implement the standardization strategy to research the result of implementing the defined standardization strategy. It is however expected the higher degree of standardization will result in the decrease of costs and lead times as well as an improvement in efficiency and predictability. To evaluate this, key performance indicators should be set up. These should be based on the advantages of standardization which are cost savings, reductions in lead time and control over the projects. Besides this, the limitations should also be reflected on to make sure they do not influence the project to much, examples are engineering hours and costs spent to develop standards, loss of innovation, and management of the defined standards. By assessing these key performance indicators there can be evaluated if executing the standardization strategy is really beneficial.

Besides this, a further evaluation can also be done by letting employees implement the SSDP and receive their feedback on the usage of the procedure. This is needed since the procedure has now been executed by the researcher who developed it. The implementation and evaluation by employees should be done within Huisman as well as in other companies working in an ETO 'Type 1' way. This is recommended as different companies might work in different ways identifying changes to make to the procedure to make it more generally applicable to all companies.

All together, although there is room for improvement, it can be concluded the way the SSDP is set up is working well since a standardization strategy managers from the sales, engineering, and supply chain department could agree on has successfully been developed. Besides this, during the session improvements of the SSDP were highlighted however it was noted the version presented is already valuable to make standardization more structured then the approach currently applied.

5.8. Chapter Conclusion

Chapter 5 demonstrated the practical application of the SSDP through an embedded single case study at Huisman Equipment. The case study focused on three distinct product families (KBCs, LECs, and MCPGs), each representing different levels of uniqueness, market dynamics, and standardization potential.

The first three SSDP activities were applied to all three product families to assess their market strategies, external factors influencing standardization, and measurements of current and previously conducted projects. These results were compared to determine KBCs are most suitable for standardization. This is caused by their relatively lower customization requirements, higher order frequency, and more mature product design.

The remaining SSDP activities were then applied in depth to the KBC product family. This involved an evaluation of internal factors, identification of improvement opportunities, and finally the formulation of a suitable standardization strategy. The resulting strategy includes recommendations for the sales, engineering, and supply chain departments. Included in these strategy are: limiting customization options, developing standardized configurations, revising standards periodically, and restructuring internal processes.

Besides defining a suitable standardization strategy for KBCs, the case study was also used to evaluate the SSDP itself. The procedure proved to be an effective, structured tool for aligning standardization with strategic and operational goals within various departments. While some refinements were identified the SSDP was successfully validated as a practical procedure for developing tailored standardization strategies for ETO product families.

6

Discussion

In this chapter, the discussion will be provided. In order to do this, first the findings will be presented that have been gained during the literature and case study. After this, the implications these findings have will be presented in Section 6.2, broken down into theoretical and practical implications. This will be followed by a discussion on the limitations of the research and a recommendation how these limitations can be addressed in future research.

6.1. Research Findings: Addressing the Research Questions and Design Objectives

The findings done during this thesis can be divided into two. First of all, the findings done during the literature study will be discussed which will be followed by the findings done in during the case study.

6.1.1. Findings in the Literature Study

As elaborated on in the Thesis Project Methodology and as depicted in Figure 2.1, the literature study is established to answer the research questions developed that will help achieve the main research objective: *"To determine how a suitable standardization strategy can be established for product families in an Engineer-to-Order environment"*.

Before answers to the questions could be formulated, first understanding was gained about ETO and standardization in general to make sure these terms were well understood. This helped well during the research making sure background knowledge was known when theory was analysed more in depth. Besides this, writing the thesis at the office of an ETO organization where products are designed and produced helped understanding the literature and gave additional insights which have been looked into further during the literature research. Having conversations about standardization with employees particularly helped gaining these insights into topics to look into further.

The first RQ is: *Which internal and external factors influence the possible degree of standardization in ETO projects?*. In Section 3.4, 14 key factors influencing standardization have been defined. These factors have been divided into three categories: market related, product related and process related. All market related factors are seen as external factors as the company has no direct influence on them. Besides these, the maturity of the end product is also defined as an external factor. All other factors are seen as internal factors as direct influence can be exerted on them. Table 6.1 depicts an overview of the factors.

Table 6.1: Overview of all factors influencing standardization

Category	Factors	Factor Type
Market Related Factors	Delivery lead time requirements	External
	Volatility	External
	Customization requirements	External
	Order size and frequency	External
	Type of customer	External
	Variations in regulations and standards	External
Product Related Factors	Maturity of the end product	External
	Customization opportunities	Internal
	Structure (modularity)	Internal
	Variance of integrated components	Internal
Process Related Factors	Freedom of the sales process	Internal
	Freedom of the engineering process	Internal
	Freedom of the supply chain process	Internal
	Degree of vertical integration in the supply chain	Internal

These factors have been set up making use of various articles that defined one or multiple of these factors influencing standardization. The search to these factors was difficult, however, insights gained from writing the thesis at an ETO company gave directions that could be used to find relevant factors. To validate the factors, they have been presented to a Principal Engineer who is focussing on standardizing drive trains at Huisman. Although this increases the credibility of the factors, it was an employee from the same company insights were gained from to find the factors, a broader view could result in additional insights resulting in even more accurate factors. These factors can be used to assess the standardization potential and options of product families to, in the end, establish a suitable standardization strategy.

RQ2 has been developed to find out if standardization is measurable and reads: *How can the current degree of standardization in ETO projects be measured?*. The answer to this question was found in the article by Willner, Powell, et al. (2016). This article presented a way to identify which ETO archetype a product is by measuring the engineering complexity and the average annual units sold. They indicate the engineering complexity which are the average engineering hours spent per product are related to the amount of standardization implemented and the potential for standardization. Using these insights, standardization can be measured in a quantitative way where the lower the engineering hours are the more standardization is applied to the project. Although this approach thus offers a practical metric, it should be recognized it is simplified as engineering hours can still be affected by many other influences as well. Besides this, it is important to implement reliable data to obtain valuable outcomes. Although it is not perfect, it is a good way to get insights into standardization which is required for the scope of this research. By using engineering hours, a quantitative way of measuring standardization is achieved adding value when determining the standardization potential which can be used when establishing a suitable standardization strategy.

The third research question that could be answered making use of the literature study is: *What criteria can be used to assess whether the current degree of standardization aligns with project requirements and goals?*. First of all, the external factors that have been identified in answering RQ1 are criteria that should be consulted when assessing if the current standardization aligns with the requirements. These factors are deemed relevant as they can not be directly influenced and should thus be accepted. Additionally, during the literature research it was identified the market strategy the company applies has impact on the suitable degree of standardization and on the external factors. When investigating if the current degree of standardization aligns with the project requirements and goals it is thus also important to investigate this. This result to RQ3 highlight standardization is not just technical and operational, it is also affected on a strategic level. By analysing the external factors and the market strategy, an assessment can thus be made regarding both the operational and strategic level in order to develop the boundaries of a suitable standardization strategy.

The last research question set up (RQ4) reads: *What project elements should be adapted to achieve a more suitable degree of standardization in ETO projects?*. These elements are the internal factors that can be directly influenced and were identified answering RQ1. These factors include product and process related factors that influence the degree of standardization. To get a first insight in what way these internal factors should be adapted, the maturity model designed by Willner, Gosling, and Schönsleben (2016) was deemed relevant. Although this maturity model was designed for automation in ETO projects, it can also be applied for standardization since standardization is needed to be able to automatize. However, As identified in Section 3.3.5, there are challenges to standardizations that have not been incorporated in here like resistance to change, lack of alignment between departments, and internal resistance to the loss of freedom. It is also good to mention the internal factors are not independent, as they will influence each other and are bounded by the market strategy and the external factors. It is thus of importance to keep these in mind when assessing the internal factors. Doing so will give the right insights towards the development of a suitable standardization strategy for product families.

6.1.2. Findings Developing and Applying the SSDP

Making use of the findings during the literature study resulted in the ability of designing the SSDP in Chapter 4. From this knowledge gained, it was concluded there are six sequential activities needed to develop a suitable standardization strategy for the product family that is assessed. The activities that are found to be of importance are:

A1: **Determine the market strategy:** As identified answering RQ3, the market strategy is of importance as it influences the suitable degree of standardization for the product family. It is thus deemed relevant to investigate it during the procedure. The case study has proven this as insights were gained influencing this degree as can be seen in Section 5.5 where the market strategies are compared to each other. Furthermore, when assessing the external factors the market strategy was also valuable since the targeted markets and customers were known which are the basis of most external factors.

A2: **Define product specific external factors:** RQ1 defined the factors influencing standardization which as found in RQ3 also influence the suitable degree of standardization. It has thus deemed relevant to assess the external factors. Making use of the data collected regarding the market strategy and using the knowledge of experts resulted in these factors. These factors gave a very clear indication as identified as well during the comparison of these results between the three products. Besides this, they also clearly define the boundaries to what degree can be standardized.

A3: **Analyse current and previous projects:** This activity was relevant to implement quantitative data to the SSDP for which a method is found as an answer to RQ2. The engineering hours needed for this activity were well documented and easily accessible. For some projects, the forecasted engineering hours have been used which are less reliable than actual data. This activity provided a clear first indication into the suitable degree of standardization since the product families assessed varied heavily in engineering complexity. This is useful information and an additional source besides the qualitative data gathered during the first two activities to confirm the standardization potential of the product family.

A4: **Analyse current internal factors:** RQ4 highlighted that these internal factors influence the degree of standardization. First defining the current status of these factors was valuable to later in A5 define how these factors can be influenced. As mentioned, especially expert knowledge was valuable to identify these factors.

A5: **Analyse potential improvements of internal factors:** As mentioned, following the findings on RQ4, the internal factors need to be influenced to increase the degree of standardization. First, the maturity model gave a good indication after which the direction could, together with the knowledge of experts, be applied to create potential adjustments to increase the degree of standardization. Although during this activity the directions to these changes are defined, it is not defined in detail how this is reached as this was outside the scope of this research. To identify what exactly needs to be changed, more research has to be done knowing the directions given by the SSDP. As an example, it was defined configurations have to be set up but not specifically which configurations for which more research is needed.

A6: **Generate the applicable improvements into a new standardization strategy:** The final activity is designed to set up the suitable standardization strategy. To do so, evaluating the engineering hours further was deemed relevant, this could potentially also be conducted during A3. It was especially valuable to discuss the result with experts as they have better insights on the impact the changes have. As mentioned, the resulting standardization strategy gives an indication to the changes that need to happen and is a guideline to standardize to a higher, more suitable degree.

During the evaluation of the SSDP in Section 5.7 the findings done regarding the implementation of the SSDP have been elaborated on. To summarize, the SSDP is a well working procedure with still some room for improvements. One of those potential improvements is to research and implement how processes should be redesigned when standardizing from full ETO towards CTO, MTO, or MTS. Moreover, the factor "type of customer" was found to be more of an influencing variable than a stand alone factor. Furthermore, it was identified the procedure should be executed by someone familiar at the company and with the product family analysed, knowing where to find the information needed, an example could be the product owner of the product family. Lastly, during the interviews, the interviewees stressed it was of importance to reapply the procedure periodically to align the standardization strategy with market and organizational changes showing the potential of the SSDP as a repeatable framework instead of a one time tool. The importance of reevaluating the standards periodically matches with the findings done during the literature study..

By setting up the SSDP and by demonstrating and evaluating it, the design objective *Establish a structured procedure to asses a suitable standardization strategy for product families in an ETO environment*, set up in Chapter 2 has successfully been achieved.

6.2. Implications

The implications of the research can be split in two, theoretical implications and practical implications. Both of these will be discussed below.

6.2.1. Theoretical Implications

Regarding theory, this thesis can be seen as an extension of standardization theory into the ETO context. The theory of standardization, that is mainly based around the production industry, is used to supplement the more scarce standardization theory for the ETO industry. This is especially accomplished by collecting and developing the factors influencing standardization in the ETO context which could be applied in the SSDP. This conceptual framework is another addition to the theory developed regarding standardization in the ETO domain. The presence of this procedure supplements theory by fulfilling the gap identified in determining a suitable standardization strategy in the ETO environment. The development of the procedure has brought different models like the model used to measure standardization, and the maturity model for standardization and automation together to combine their strengths regarding standardization. Besides this, it is clearly explained and demonstrated how the standardization potential can be assessed, as well as how the degree of standardization can be increased for product families in the ETO environment. This results in a comprehensive understanding and insights that can be implemented in further research in this domain.

6.2.2. Practical Implications

In practice, there was a lack of a method which could be used to define a suitable standardization strategy for the ETO environment. By designing the SSDP, a procedure has been established that can easily be applied by ETO organization willing to configure a more suitable standardization strategy. By applying the six activities defined in this thesis these companies can develop their own standardization strategy without the need for a consultancy firm to assist them. By applying the SSDP, a standardization strategy is developed that gives guidelines to standardize to a more suitable degree for the product family it is applied to. Although the procedure provides clear directions, additional research is needed into the exact adaptations of the product and the related processes to reach the most suitable standardization strategy. Moreover, the SSDP is designed in such way the different departments most affected by standardization are all analysed during the procedure to make sure the departments are all on the same level of standardization to achieve the best result. Furthermore, alignment with the current operations of the firm are taken into consideration as the currently applied market strategy and the external factors are assessed to make sure the developed standardization strategy fits to the product and the organization. Although the SSDP is developed in collaboration with Huisman it is not solely produced for this specific company. The SSDP has been designed to be used for ETO companies that design their products based on previously conducted projects and are operating as a 'Type 1' ETO organization, which are vertically integrated companies. The procedure could also be used in other types of ETO, however, adaptations and/or additions should possibly be done for the best result. At last, the SSDP is not a tool that should only be applied once but a tool set up for continuous improvement, it should be applied every two years in order to revise the standards developed in order to move with the market conditions, technologies, and organizational capabilities that evolve over time.

6.3. Limitations and Recommendations for Future Research

While this research provides valuable insights into the development of a suitable standardization strategy for Engineer-to-Order (ETO) projects, several limitations must be acknowledged. These limitations also offer opportunities for future research which are also discussed. The limitations have been separated to limitations regarding the research and testing of the SSDP and limitations regarding the SSDP itself.

6.3.1. Limitations of the Research

Limitations of the research regard limitations that were present in the method of conducting the research. These limitations will be discussed in this subsection.

First of all, the scope and generalizability of the case study can be seen as a limitation of this research. As the case study has been conducted as a single embedded case study the focus was only on one company. Although this enabled an in depth analysis of the practical relevance it limits the generalizability of the findings in this case study as it has not been tested in different ETO organizations having different organizational structures, product types, or market conditions. For future research, it is thus recommended to apply the SSDP in a multiple case study across various ETO industries to further validate the model and test its applicability.

Besides this, the final steps of the SSDP have only been applied to one product family due to time reasons. As the time for writing a thesis is limited, the implementation and results of the proposed suitable standardization strategy whilst using the SSDP can not be monitored over time. The long term impact of the applying the strategy developed using the SSDP has thus not been validated. Future research could conduct a research where key performance indicators for standardization can be developed and analysed after a suitable standardization strategy developed making use of the SSDP is implemented. Examples of such key performance indicators are cost, lead time, and customer satisfaction.

Next, the embeddedness of the researcher in the company has introduced a potential bias. Since the researcher was conducting the study at Huisman Equipment he was closely involved in the products and the ideas of standardization at this company. This might have introduced a bias in data interpretation, stakeholder interactions, and research to, for example, the factors influencing standardization. This might have affected the objectivity of the research, especially during the design and assessments of the interviews. In future research, this problem can be eliminated by doing a multiple case study where the SSDP is tested at multiple ETO companies.

At last, during the case study it would have been valuable to look at the market as a whole. This could have been especially useful when evaluating the market strategy and internal factors of the company, to indicate how the company is doing compared to the overall market and what market share it has. Although there was an attempt to obtain this data, it could not be analysed because the organizations that collect it charge a high fee to access the information. In future research and application of the

SSDP it is recommended, when financially possible, to buy access to this data to get a better overview of the current status in the market of the company and the variation in the market.

6.3.2. Limitations of the SSDP

Limitations of the SSDP regard limitations of the procedure itself. These limitations are discussed in this subsection.

The first limitation of the SSDP that must be acknowledged is that it gives a first indication of what in the product and process should be standardized however not exactly how this should be done. In Section 1.3 it has also been mentioned this was out of scope of this research. The SSDP gives an indication what should be adapted after which additional research has to be done into, for example, how to adapt the processes regarding sales, engineering, and supply chain to increase the degree of standardization according to the possibilities outlined by the SSDP. A valuable extension of the SSDP that can be developed in further research could be to set up additional procedures to assess how the product specific processes and product itself should exactly be adapted to the degree specified by the current SSDP. This additional research should therefore explore ways to adapt the sales, engineering, and supply chain processes to achieve a higher degree of standardization. Besides this, it is also valuable to set up a procedure to create a deeper understanding of the product where all components of the product should be analysed finding out what components connect to each other and to analyse the current degree of standardization of the separate components.

This limitation was also partly recognized during the research as it was found out the processes within the departments have to be adapted instead of reduced in freedom to better fit standardization. This was the case as the processes were currently set up for designing custom products as the company is a custom project driven organization. For future research it will be valuable to investigate how these processes can change and why the processes should change from one process into another process.

In the SSDP, the structure of the organization is not taken into account. Since structures can vary between different organizations, this might have impact on the standardization strategy or might imply a change in structure to better fit the suitable degree of standardization. Further research could investigate how the structure of a company influences standardization.

Another drawback of the SSDP is the limited use of quantitative data. Within the procedure only engineering hours are used as quantitative data to identify the potential of standardization. Furthermore, most information is gained making use of interviews where the subjective opinions of experts. This will cause variability and inconsistency as different experts might have other answers to the questions proposed. Additional statistical validations would increase the reliability of the model. For future research it is thus recommended to evaluate how additional quantitative data could be used throughout the SSDP to enhance reliability of the procedure.

Furthermore, the SSDP currently only analyses the processes of three departments: sales, engineering, and supply chain. To further develop the procedure it could be valuable to integrate other departments, like project management, finance, and research and development, as well.

Lastly, as mentioned before, the SSDP has been designed for ETO organizations basing new products on previous projects and are vertically integrated ('ETO Type 1'). For future research, it would be valuable to investigate the applicability to other types of ETO organizations operating differently. This research will have to demonstrate what additions and adaptations have to be implemented in the SSDP to make the procedure work for these type of ETO organizations as well.

7 Conclusion and Recommendations

This chapter holds the conclusion and recommendations that can be established after doing the research. First of all the conclusions will be presented in Section 7.1. This will be followed by the recommendations for Huisman, as well as for the ETO industry in general. To conclude this chapter and the thesis as a whole, a final remark is presented in the closing section.

7.1. Conclusion

This thesis set out to answer the main research objective:

"To determine how a suitable standardization strategy can be established for product families in an Engineer-to-Order environment"

ETO environments are characterized by low repetition, high product complexity, and strong customer specific requirements. These conditions make standardization challenging, as introducing standardization conflicts with the need for customization to adhere to the customer requirements. Nevertheless, the research has shown that integrating standardization in ETO environments can be done by following a systematic procedure, taking the right factors into account.

The main contribution of this research is the development of the Standardization Strategy Development Procedure (SSDP). This procedure has been designed making use of the literature study. This procedure provides a structured approach for determining a suitable standardization strategy for product families in ETO environments by integrating product specific data, information regarding organizational processes, and expert knowledge and experience. Important to note is that the SSDP is not a single use procedure but instead offers a repeatable framework that can be reapplied for the same product family, and be applied to different product families.

The SSDP consists out of six activities that together guide organizations in developing a suitable standardization strategy for the product family that is assessed. The first activity is designed to establish a clear understanding of the market strategy of the product. In here, it should be determined what the order winners are and what the strategic priorities are when selling the product. Building on this, organizations should take external factors influencing standardization into account which have to be defined in activity two. External factors are the factors the organization can not influence. These factors are thus the boundaries within which standardization is possible. In order to integrate quantitative data, activity three is designed to analyse current and past data of projects. It is concluded making use of existing literature this can be done by analysing the engineering complexity which are the average engineering hours spent per project. The lower the engineering complexity is, the more suitable the project is for standardization making this value an indicator for the suitability of standardization. The following activity is set up to define the current internal factors influencing standardization. These are the factors that can potentially be influenced by the organization. It was concluded these are the factors that should be influenced when an increase or decrease of the current degree of standardization is desired. In activity five, the SSDP looks into potential improvements of these current internal factors. It can be concluded this can best be identified making use of a maturity model in combination with expert knowledge. This is important since experts can use their experience to come up with ideas to influence standardization and foresee the effect these changes will have on the product, project, and customer. Finally, activity six combines all previously conducted activities into a suitable standardization strategy for the product family assessed. In this way, the tailored strategy integrates the possible improvements and aligns them with the market strategy, external factors and overall suitability of standardization for the specific product family. In the process of doing this, it is deemed important to again consult experts to indicate the impact the adaptations will have and to ensure a realistic strategy where efficiency is balanced with the required flexibility.

By applying the SSDP to three product families at Huisman Equipment knuckle boom cranes (KBCs), leg encircling cranes (LECs), and motion compensated pile grippers (MCPGs)) demonstrate the practical use of this thesis. All these product families were assessed through the first three activities, the KBCs were elaborated further since this product family was deemed the one with the highest potential for standardization. This application confirms the first three activities of the SSDP can be used to distinguish the suitability for standardization of product families. Furthermore, developing a more suitable standardization strategy for KBCs keeping market strategy and external factors into account confirms the practical ability of the SSDP.

Theoretically, this thesis contributes to the literature by extending the current literature regarding standardization in the ETO environment. Especially the 14 factors influencing standardization and the implementation of these factors in a tool to determine suitable standardization strategies is a contribution to the current literature. Practically, this thesis provides a replicable tool that can be applied by ETO organizations. By using the SSDP, these companies can improve efficiency and hereby reduce lead times and costs of their projects. The procedure will help give insights into adaptations that have to be done for different departments of the company to achieve this.

Despite its contributions, the research has limitations as well. The SSDP is a procedure that needs additional research after it has been applied, it does only indicate in what directions should be standardized but not exactly how. Furthermore, The single embedded case study and partial execution of the SSDP reduce the generalizability of this study. Additionally, the designed standardization strategy during the case study is not really implemented and thus not tested. Besides this, the embeddedness of the author in an ETO organization could have resulted in a bias during the literature study as well as during the design and demonstrating the SSDP. Moreover, the majority of data collected when executing the SSDP is qualitative data which results in potential variability and inconsistencies of the procedure. At last, the SSDP has been designed for vertically integrated ETO organizations that base their products on previously conducted processes. This ensures potential adaptations have to be done when it has to be applied to ETO organizations that work differently.

These limitations offer opportunities for future research. Future studies should test the SSDP across multiple ETO organization to assess its generalizability. Long term applications will help evaluate long-term effects of strategies designed making use of the SSDP on, for example, lead time, cost, and customer satisfaction. Additional research could also focus on integrating more quantitative data in the procedure. Finally, future research could also look into how processes should change when moving from ETO more towards CTO or MTO due to the standardization applied as result of the SSDP.

To conclude, this thesis developed the SSDP to address the challenge of balancing customization and standardization in ETO environments. The study identified key internal and external factors affecting standardization and demonstrated the SSDP through a case study at Huisman Equipment. The SSDP offers a structured, replicable approach for ETO organizations to develop suitable standardization strategies, contributing both to academic literature and industry practice. By successfully developing a suitable standardization strategy for KBCs making use of the SSDP, the main research objective, *'to determine how a suitable standardization strategy can be established for product families in an ETO environment'*, has been achieved. Despite limitations in scope and generalizability, this research provides a foundation for further improvement and wider testing of the SSDP to help increase efficiency and reduce costs in ETO environments.

7.2. Recommendations for Huisman Equipment

7.2.1. Recommendations Regarding the Results of the Case Study

First and foremost, Huisman is recommended to implement the findings from activity six in Section 5.6.3. As described, this will imply adaptations and additions within various departments to make sure KBCs get standardized to a suitable degree. This should start at the engineering department where the standard range should be first worked out further into fully standardized designs which should not be adapted any more to fit customer requirements. Furthermore, the standard configurations should be developed for which collaboration is needed between the sales and the engineering department to define what should exactly be included in these standard configurations. These configurations should then also be fully worked out so they can be included in the standard designs without having to add any or at least very little engineering hours. For this, the engineering department should design interfaces between components designed to add the required connections for the configurations.

During the process of setting up the configurations, the sales department should already start limiting their offers to the standard range of KBCs and the upcoming configurations. In this way, the configurations can directly be implemented in the final design. Moreover, when configurations are missing this can partly be discovered during the sales process as customers will require add ons which are not in the list of configurations. This can directly be implemented as feedback to design additional configurations.

Furthermore, when the final designs of the standard range of KBCs are finished, the supply chain department can start negotiations with suppliers to establish single source suppliers for the critical components. As mentioned, forecasted sales should be communicated which have to be provided by the sales department. Moreover, fixed prices and lead times should be discussed with the applicable supplier to develop fitting arrangements.

Besides this, activity six concluded the possibility of setting up a factory to start producing more components in house, this should be further investigated. It is thus also recommended to start these investigations as soon as possible. The same accounts for the investigations to suppliers willing to collaborate to supply assemblies together instead of separate components which have to be assembled at Huisman.

By implementing these recommended activities, the suitable standardization strategy defined by implementing the SSDP will be applied to the KBC product family. This will result in reduced lead times and costs for KBCs produced compared to the previous design and production of KBCs. Moreover, it is recommended to begin implementing this appropriate standardization strategy as soon as possible to take advantage of its benefits without delay.

Lastly, as mentioned, the standard products and configurations should be revised every two years to keep them up to date. When implementing the strategy, it is recommended to apply it more frequently at the start of using it, as the initial phase will provide many lessons regarding the standards. This can then be integrated into the standard designs as fast as possible. For the revisions executed every two years, it is advised to execute the whole SSDP again as conditions regarding market conditions, technologies, and organizational capabilities are constantly changing. By reevaluating the full procedure the best results will be obtained.

7.2.2. Recommendations Regarding the Implementation of the SSDP

When it comes to the implementation of the SSDP into the operations of the company there should someone or a team be made responsible for executing the procedure. For Huisman it is recommended that the product owner of the product family is made responsible for conducting the SSDP and arrange the further sessions to revise the standards that have been developed. This person is recommended as he or she will know most about the product family and will know exactly who to consult for the required data. Furthermore, the knowledge a product owner has regarding the product is useful during the activities as this can be used to assess the impact standardization will have on the product family as well as on the departments working on the product.

Besides implementing the standardization strategy defined for KBCs, it is recommended for the product owners of other product families to conduct the SSDP to investigate standardization potential in other product families. Doing so will give insights in the suitable degree of standardization that should be implemented within the product family. This investigation can be conducted whilst current operations still go on to develop a more suitable standardization strategy for the future. It is thus not recommended to stop producing products of the product family to first standardize them further as this will result in loss of sales. For the LECs and MCPGs the first three activities of the SSDP are already executed, the SSDP can for these product families thus be continued from activity four.

7.3. Recommendations for the ETO Industry

The SSDP can also be implemented in other companies working in an ETO industry. As mentioned in Chapter 4, the SSDP has been designed especially for ETO companies designing new products based on previous projects. Hicks et al. (2001) set up various types of ETO organizations which is further elaborated on in Section 3.2.3. The SSDP has been designed for 'Type 1' ETO organizations which are *'Vertically Integrated Companies'*. This entails design, manufacturing, assembly, and project management is done in house resulting in complete knowledge about the product family and the process that is needed to realize such product. Since the SSDP is designed for these type of companies, the activities can directly be applied to these types of organization. It is thus highly recommended for these type of companies to start applying the SSDP in order to benefit from the advantages of standardizations whilst limiting the drawbacks. Companies working according to such type of ETO can be found in for example shipbuilding, engineering, and construction. As just mentioned, when the SSDP is in use it is advised to revise the procedure every two years. This should make sure adaptions are implemented that better fit the market conditions, technologies, and organizational capabilities. It is recommended when revising the developed standards to execute all six activities of the SSDP again to obtain the best results.

For ETO companies working differently then just described and are defined as another type of ETO, it is advised to make adaptations and additions to the activities presented in this thesis. This will be needed as certain parts of the activities might not be applicable for the specific way of working. Furthermore, additional factors might be useful for other types of ETO to better assess the specific type of ETO. Although changes need to be made, it is still recommended to do so and start using the adapted version of the SSDP.

Besides this, it is recommended to assess if a higher degree of standardization could fit the the organization or at least certain product families produced. In this way, the advantages of standardization can be used to the highest potential resulting in shorter lead times as well as lower costs. It is however of importance to keep the disadvantages of standardization in mind, the SSDP is doing so by checking the market strategy and external factors that apply to the product family.

7.4. Final Remark

To make a final remark, this thesis has contributed to decrease any confusion present in determining how a suitable standardization strategy can be developed in an ETO environment. First off all, the literature study in Chapter 3 set the basis of knowledge. Using this basis, the SSDP could be designed and developed. By integrating theoretical insights with a real world application, this study not only contributes academically but also provides practical value to the ETO industry. By designing, demonstrating and evaluating the SSDP, this thesis provides a structured, practical, and repeatable procedure that guides these organizations to develop their own suitable standardization strategy for the product families they produce. Doing so, these ETO organizations can asses their current practices, identify improvement opportunities, and align standardization efforts with strategic goals and external factors. From this can be concluded the main research objective *'to determine how a suitable standardization strategy can be developed for product families in an ETO environment'* has successfully been achieved, reducing the existing confusion regarding standardization in the ETO environment.

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Appendix A: Interview Guide Product and Engineering Process Standardisation

The document of the interview guide set up to identify the current and potential product and engineering process can be found on the next two pages. Since the interview has been conducted in Dutch, the interview guide is in Dutch as well.

Interview guide: product en engineering process standaardisatie

Introductie:

- Confidentiality uitleggen
- Uitleggen waar ik mee bezig ben: SSDP kort introduceren en factoren kort uitleggen
- Doel van het interview uitleggen: Uitvinden wat de factoren die met engineering te maken hebben momenteel zijn en hoe die mogelijk verbeterd kunnen worden

Deel 1: Product standaardisatie

Huidige standaarden in het product + mogelijkheden

- Welke standaarden zijn er momenteel opgesteld in KBCs?
- Hoe strikt zijn deze standaarden, kan er nog van afgeweken worden?
- Wat kan er momenteel nog aangepast worden door de klant: wat is niet gestandaardiseerd?
- Zijn er configuraties opgesteld waar de klant uit kan kiezen?
- Wat zijn volgens u nog mogelijkheden om verder te standaardiseren?

Belemmeringen voor standaardisatie

- Wat voor vragen zijn er momenteel nog qua customizations die klanten willen en wat misschien nog een struikelblok is voor standaardisatie?
- Zijn er nog andere dingen die standaardisatie tegenhouden?

Modulariteit

- Is er een modulaire structuur toegepast in het design van KBCs?
    - Welke modules zijn er?
    - Kunnen losse modules veranderd worden met weinig tot geen impact op de rest van het design?
    - Zou modularisatie verder toegepast kunnen worden?
    - Wat houdt modularisatie mogelijk tegen?

Variatie in onderdelen

- Worden er voor verschillende types KBCs verschillende onderdelen gebruikt voor hetzelfde doel? (Eg. Verschillende motoren)
    - Zou dit (meer) kunnen of is er iets dat dit tegen houdt?

Deel 2: Proces standaardisatie

Huidige standaarden in het proces + mogelijkheden

- Welke standaarden zijn er opgesteld in het engineering proces?
    - Zijn er databases met standaarden?
    - Zijn er standaarden qua standaard documentatie dat opgesteld moet worden?
    - Is er een standaard werkprocedure qua stappen die genomen moeten worden om bijvoorbeeld een design van een component te maken?
    - Zijn er standaard configuraties in het proces?
    - Zijn er standaard andere informatie flows? (Meetings of gedeelde documenten ect.)
- Hoe vrij zijn de engineers om aanpassingen te doen aan standaarden of vorige projecten?
- Zijn er verschillende opgestelde losse processen voor standaarden en custom onderdelen?
- Hoe kan er mogelijk verder gestandaardiseerd worden naast deze standaarden?

Vertical integration

- Welke onderdelen worden er ingekocht en wat wordt er zelf gemaakt?
    - Is er een mogelijkheid om zelf ook ingekochte componenten te maken?
    - Zou het voor sommige producten sneller zijn om zelf iets te maken dan te kopen en laten bezorgen?

Klasse bureaus

- Hoe ga je daar om met de verschillen tussen klasse bureaus?

Afsluiting

- Zijn er nog andere punten die niet besproken zijn maar wel belangrijk zijn voor standaardisatie naar uw mening?
- Wat zijn nog verdere risico's en/of nadelen die u ziet wanneer er meer gestandaardiseerd wordt?