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Managing Supplier Delivery Performance in Engineer-to-Order Manufacturing

A Case Study in Maritime Industry

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Abstract

Purpose – Engineer-to-Order supply chains are known to consist complex networks with numerous suppliers in different roles that may have high impact on the operational excellence of an ETO company and their competitive advantages. Therefore, supplier delivery performance is widely recognized as a critical challenge among ETO companies. This thesis contributes in delivery performance management research by studying how an ETO company may manage their procurement processes in order to improve their suppliers' delivery performance. The underlying problem of the thesis emerges from high uncertainty and variability inside the supply chain which is evident for ETO companies.

Research design – This thesis approaches supplier delivery performance by trying to identify the costs associated with supplier untimeliness due to the delivery variance, the causes of untimeliness and process variability and to eliminate the sources of variability and causes of untimeliness in supplier's order fulfillment process. The thesis is conducted by using a case company in a single case study. The case study consists of a data analysis on supplier delivery data, interviews and a supplier development project on delivery variance reduction that provide the required information for the improvement suggestions and discussion in the end of this thesis.

Findings – ETO companies should emphasize the importance of supplier development and control on supplier process times in order to improve suppliers' delivery performance. This is particularly important with strategically important suppliers that are considered as partners instead of replaceable suppliers. Furthermore, increased and more effective communication between buyer, supplier and third parties is also found as a central improvement area when trying to reduce the delivery variance. Finally, since the delivery performance should be measured financially, this thesis suggests a new performance indicator that considers supplier's statistical delivery variability and provides an expected cost for untimeliness.

Research limitations – Most significant limitations were found in discussion on delivery variance reduction that is purely based on single supplier performance and the results may be somewhat exceptional and cannot be used directly with other suppliers. Also, the suggested KPI can be considered to be limited due to its complexity when calculating the estimated cost of supplier untimeliness.

Keywords – Engineer-to-Order, supplier delivery performance, supplier development, cost of delivery untimeliness

Table of Contents

List of Abbreviations

ETO	Engineer-to-order
BTO	Buy-to-order
MTO	Make-to-order
ATO	Assemble-to-order
MTS	Make-to-stock
STS	Ship-to-stock
CODP	Customer decoupling point or order penetration point (OPP)
CoGS	Cost of goods sold
JIT	Just-in-time
OTD	On-time delivery
R&D	Research & development
ERP	Enterprise resource planning
FAT	Factory acceptance test
KPI	Key performance indicator

List of Equations

List of Figures

List of Tables

1 Introduction

During the past decades suppliers and their capability to operate with high performance have become increasingly important factors determining overall performance of a company. Manufacturing companies have more and more realized the importance of supplier performance in order to establish and maintain their competitive advantages. Along with the importance of supplier performance, the level of outsourcing has been increasing which reflects to the fact that companies focus more on their core competencies while rest of the operations are to be sourced from suppliers. This is particularly typical for engineer-to-order companies which have complex supply chains with multiple suppliers in different tiers. As a consequence of all these factors Engineer-to-Order (ETO) companies must be able to maintain a network of capable and reliable suppliers.

In order to maintain high operational excellence in ETO manufacturing, the incoming material flow to the factory should receive plenty of attention so that component deliveries would be as reliable as possible. The punctuality of component deliveries play a major role in determining if an ETO project is on-time or not and how profitable it will become in terms of additional quality and untimeliness costs. Too early component deliveries lead to excess inventory and more capital employed in the production project. While late component deliveries may cause production stoppages and delays when delivering to the end-customer. By improving the delivery performance and reliability of suppliers the overall supply risk is reduced which refers to improved working capital, smaller inventory levels and internal buffers and less penalty costs from customers.

However, achieving high supplier delivery performance is easier said than done because ETO companies are identified to operate in complex supply chains with high uncertainty. Therefore, the motivation for this thesis lies in the challenges that ETO companies' experience in their suppliers' delivery performance. This thesis demonstrates the challenges associated with supplier delivery performance in ETO manufacturing in a case study in maritime industry. The case company in question is ABB Marine and their factory located in Shanghai. Further, the industrial motivation for this thesis can be extended to the fact that a significant share of ETO company spending is sunk in component procurement. The proportion of purchased goods from the cost of goods sold in ETO manufacturing is argued to be up to 80%. Thereby, it can be concluded that suppliers have major impact in value creation in ETO and their performance is a critical factor in the overall ETO supply chain.

From the academic perspective, the motivation of this thesis is to apply existing delivery performance models which are yet to be tested in empirical studies. The field of supplier delivery performance, in general, is widely recognized as an important issue when managing manufacturing companies. However, based on the literature review the authors have not yet studied supplier delivery performance from an empirical perspective by applying different delivery performance models in a case company. According to several authors who have introduced delivery performance models for evaluating suppliers suggest that further studies would be approached by case studies. Furthermore, the literature has not purely focused on the connection between ETO manufacturing, supplier delivery performance management and the causes for variability in an order fulfillment process at the supplier. Even though high process uncertainty and variability and complex supply chain structures are recognized as key characteristics in ETO manufacturing.

This thesis approaches case company’s current practices by testing new more advanced model when measuring suppliers’ delivery performance which aims to reveal the actual impact of untimeliness in terms of cost. This data-driven model along with qualitative interviews are then used as a basis for further analysis on the selected case suppliers. As a result of the analysis, a set of improvement suggestions are made in order to improve suppliers’ delivery performance and drive the consistency of suppliers’ order fulfillment processes.

1.1 The problem statement

The underlying problem of this thesis emerges from the fact that ETO companies’ supply chains are characterized to include a high level of uncertainty and they are typically highly dependent on the delivery performance of numerous components. For these reasons, and that the delivery performance to the customer is a key competitive factor at the ETO markets, the supplier delivery performance is seen as a major concern and has a direct impact on the entire ETO supply chain. The challenge of reaching high supplier delivery performance and managing their delivery performance effectively are evident and problematic in ETO manufacturing. This thesis seeks to contribute how an ETO company may improve their supplier delivery performance by more effective and appropriate management in order to increase customer satisfaction and supply chain reliability and profitability.

A real life example of the problem statement would be the fact that the case company of this thesis has experienced significantly large variances in their strategic A-class component deliveries which leads to difficulties in keeping up the project schedules and to deliver for the end customer on-time. Especially the untimeliness of strategic supplier has resulted to overtime work at the case company plant and excess capital employed in the projects due to earliness.

1.2 Research objective and questions

The primary objective of this thesis is to contribute in delivery performance management research by studying how an ETO company should manage suppliers delivery performance by measuring and reducing the variability in their order fulfillment processes and internal procurement processes. The focus is set on on-time delivery and costs associated with untimely delivery and the process improvement that will guide the improvement suggestions for the procurement process. This thesis aims to provide an answer on how these costs could be reduced and the supplier delivery performance can be increased.

In order to reach the objective a case study of four ETO suppliers is conducted in which historical delivery performance of suppliers is collected and the expected costs of untimeliness and the cost of continuous improvement are calculated which will provide the basis for an analysis on how to manage suppliers' process variability in delivery performance more effectively.

This study approaches the research questions by first conducting a comprehensive literature review on five theoretical themes: ETO supply chain, supplier development, just-in-time in the context of delivery performance, supplier delivery performance and supplier delivery performance models. Afterwards the research questions are answered in Chapter 5: Analysis and Chapter 6: Discussion and Suggestions for Improvement. The research questions of this thesis are:

RQ1. What are the main causes and implications of untimely deliveries in ETO manufacturing?

Based on the conducted interviews and the literature review and one delivery performance improvement project, the main causes and implications of untimely delivery are identified.

RQ2. How can the cost of untimely supplier delivery and continuous improvement in supplier development be determined?

The historical delivery performance of the case suppliers is illustrated in a histogram from where the expected cost of untimeliness and the cost of continuous improvement in supplier development are defined in terms of the delivery variance. The costs are then presented in a graph to show the current state and optimal values.

RQ3. How can an ETO company increase their suppliers' delivery reliability by improving their internal ordering procedures and supplier development?

The thesis aims to discuss how an ETO may improve their suppliers' performance measuring, procurement procedures and supplier development all of which should result to increased delivery reliability. A case study provides answers on the supplier development aspect while improvements to procurement procedures are suggested based on conducted interviews, the delivery performance improvement project and the analysis results.

1.3 Research scope

Supplier delivery performance plays highly important role in the overall supply chain delivery performance of ETO companies. Since purchased components and sub-assemblies are argued to represent up to 80% of the total contract value, it is clear see that ETO companies are highly dependent on their suppliers' performance. In ETO manufacturing, the supplier delivery performance has a significant impact on the operational excellence and the ability to serve the customer. In other words, if a supplier is not able to deliver ordered goods to the promised date, the buying organization will consequently have problems in keeping up to their promised delivery times to the customer.

The supplier delivery performance can be divided into two parts: delivery lead-time which refers to the speed of order fulfillment and delivery reliability which refers to percentage of untimely orders (Milgate, 2001). Related to delivery reliability, the concept on-time delivery is an important aspect of delivery performance which determines whether a perfect delivery has taken place or not (Gunasekaran, Patel, & Tirtiroglu, 2001). All deliveries outside the on-time delivery window are considered as waste and poor delivery performance since they always lead to additional costs. Typically the costs associated with untimely delivery are inventory handling and production disturbance cost at the buyer and ultimately penalty cost from the end-customer if the buyer fails to deliver on time to the end customer.

The main focus of this thesis is to study the supplier delivery performance in terms of delivery window and delivery variability. It is common in industry that manufacturers measure suppliers' performance to deliver on-time as a percentage of all deliveries, however companies may experience challenges in analyzing the actual impact of untimely delivery and the delivery variability in their order fulfillment process. Therefore, this thesis aims to make an approach to this challenge by applying a cost-based model to support their supplier development actions and improvement in procurement procedures from statistical perspective in thesis case company.

This study does not intend to analyze all components and suppliers in the case company supply base due to restricted timeframe and scoping to complete the master's thesis on time. Therefore, this thesis rather aims to present the impact of untimely delivery of four focus supplier in terms of cost and how their delivery performance could be managed in a more effective manner. The cost impact is proposed based on a supplier delivery performance model that analyzes the case suppliers' delivery performance by the delivery variance and suggests more optimal variance in a trade-off with the cost of continuous improvement. The model is as well used as an argument for what action should be taken in order to reach the more optimal performance level. The other delivery performance models proposed in the literature are excluded from this thesis because they do not directly deal with delivery windows and the on-time delivery.

Poor delivery performance do not necessarily mean that the supplier has alone performed poorly. Since ETO companies are characterized as project-based manufacturers the untimely delivery from suppliers may also occur due to buyer's delays in ordering or rescheduling in their projects which lead to shorter lead times for suppliers to response purchasing orders. Therefore, the costs associated with untimely delivery are not entirely suppliers' fault, but a shared issue in buyer-supplier cooperation. For this reason this thesis considers delivery untimeliness both from the buyer's and supplier's perspective when analyzing supplier delivery performance.

After the cost-based approach, a qualitative study is carried out which aims to identify current challenges and variability factors in suppliers' order fulfillment. The challenges are discussed based on the introduced cost-based framework for supplier delivery performance, interviews and a pilot project for supplier delivery performance improvement. In this light, the scope is set to an action plan and improvement suggestions which are not to be assessed or evaluated due to the thesis timeframe. Thereby, the thesis discussion solely provides a more desired future state for case company's procurement processes and supplier management.

As a summary, this thesis has a data-driven approach to the supplier delivery performance and delivery windows where the delivery variance and costs associated with untimeliness are calculated and which drive to improved performance levels. On the other hand, the qualitative part of this thesis aims to reduce these costs and the variance behind by improving case company's purchasing processes and supplier's order fulfillment processes.

1.4 Thesis structure

The structure of this thesis is divided into five main parts. The first part, methodology, provides the reader understanding on how the research is conducted in terms of acknowledged research methods. The methodology shows how the literature review and the empirical part are designed. The empirical part is divided into quantitative part and qualitative part are designed. The methodology is followed by the literature review which compiles the related theory and frameworks and establishes a foundation for the empirical part in this thesis.

The literature review starts by first characterizing the operational environment of ETO manufacturing. After the operational environment is identified, the review proceeds to one of the main processes in supplier management, supplier development, which aims to show the relation between improved operational excellence of the buyer and supplier development. This subchapter presents why supplier development is needed and what are the different types of supplier development. The third part of the literature review introduces just-in-time concept which is considered as one of the central principles in modern manufacturing. The concept of just-in-time is used as an approach to the thesis theme and the fourth subchapter, supplier delivery performance management. In this part, the supplier delivery performance is first defined and the need for it in ETO manufacturing is established. Then the focus is set deeper onto delivery window, on-time delivery and delivery variance control. The last part of the literature review briefly introduces central models for managing supplier delivery performance from which the model for determining the cost associated with untimely delivery is taken into more detailed discussion. In this model it is taken into account the costs of untimely delivery and continuous improvement in supplier development at certain delivery variance. This model is later on used in the analysis and discussion parts of this thesis.

The third part of this thesis is the case company presentation. In this part, it is presented the case company business, order fulfillment process, key supply chain processes and current supplier delivery performance practices. The goal of the case company presentation is to provide the reader a concrete understanding on what kind of business the case company is running, how they fulfill their customer orders, how they control their material flow from suppliers and what are the supplier delivery performance tools that they are using at this moment.

The case company presentation is followed by analysis which starts by discussing the main causes for untimely delivery and its implications in case company's project delivery. Afterwards, the root cause analysis is made for one supplier as an experiment which provides the most significant causes for untimely delivery and how these root causes can be eliminated. Finally, the historical delivery performance of the case suppliers is illustrated in delivery histograms which works as a foundation for applying the model which was introduced in the literature review. Based on this model, the costs associated with untimely delivery and delivery variance reduction are calculated.

In the part five, discussion, it is suggested improvements for case company's current practices in supplier delivery performance. This suggestion are made based on the analysis and findings in the literature review and divided into quantitative optimization of the delivery performance and qualitative ideas and initiatives for improvement in case company's practices with the suppliers.

The whole research is summed up in the conclusion which ends the thesis. The conclusion will also provide suggestion for further studies and explain the limitations of this thesis.

2 Methodology

It is argued in the literature that there should be a fit between the organizational processes and the environment and that the configurations which match the environmental requirements should perform more successfully than those that do not (Chris Hicks, McGovern, & Earl, 2001). Furthermore, the companies that under-perform should adopt new configurations that fit better their environment. Based on these arguments this thesis aims to establish a comprehensive understanding on the operational environment (engineer-to-order) before proceeding to the organizational processes.

According to Flynn, Sakakibara, Schroeder, Bates, and Flynn (1990) study on empirical research in operations management there are often gaps between operations management theory and practice. Moreover, the research is argued to fail sometimes in recognizing the applied nature of operations management and therefore might not be very useful for operations management practitioners (Flynn et al., 1990). However, by using an empirical study approach the gap between theory and practice can be made smaller. Therefore, based on the arguments of Flynn et al. (1990) on the nature of operations management research and the cooperation with a case company the research method of this thesis is empirical case study. Furthermore, an empirical study is an appropriate method for answering the research questions that are based on the analysis on the case company. The strategy for answering the research questions starts by first testing the applicability of the selected cost-based supplier delivery performance model in quantitative analysis that provides new more advanced way to assess suppliers' delivery performance by their order fulfillment process variability. This is followed by the answers to research questions two and three in the qualitative analysis. The both quantitative and qualitative analysis are explained in detail further in this chapter.

The methodology chapter is divided into two parts; literature review and empirical study, in order to emphasize the gap between theory and practice. The literature review is used as support and baseline for further analysis and observations in the empirical case study. The complete research design of this thesis is viewed on a timeline in Figure 1.

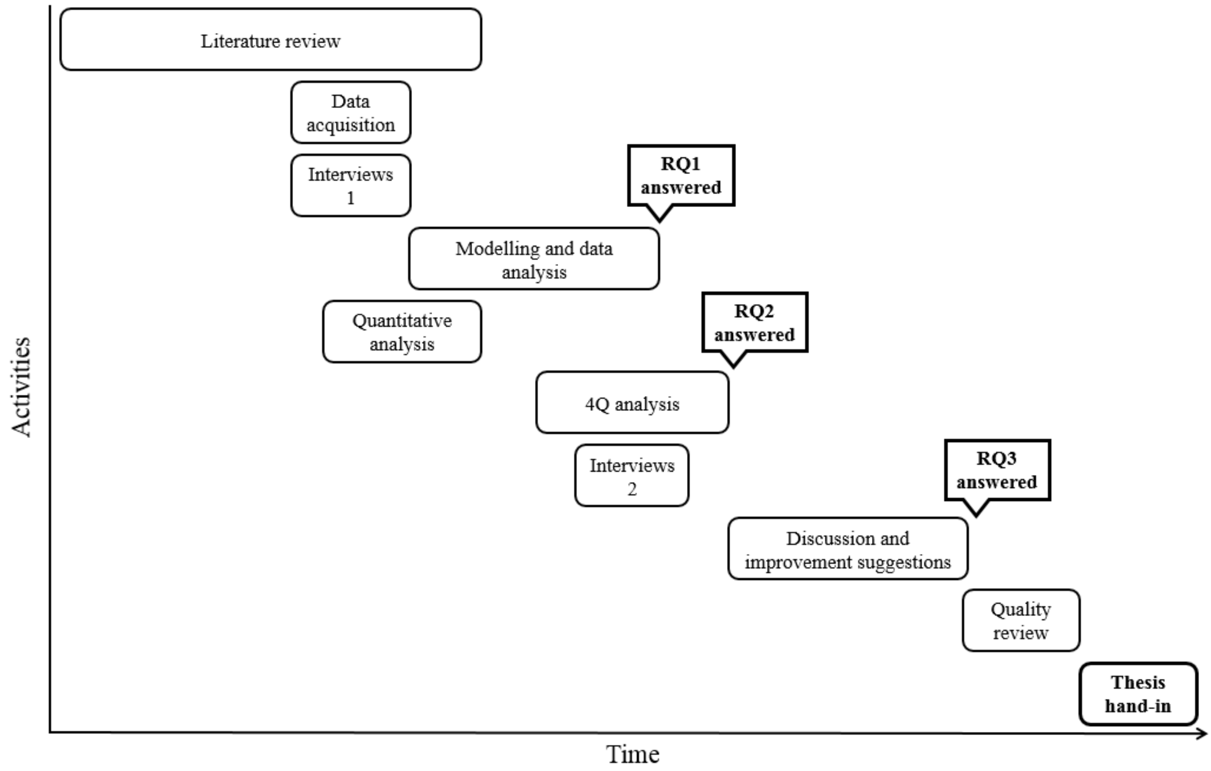

Figure 1: The research design

2.1 Literature review

Before the empirical case study, a literature review is conducted in order to provide a foundation for the thesis. The literature review helps to understand the topic from the academic perspective and suggest a feasible scope for the research.

The thesis literature review begins with a keyword search, which was conducted in several databases such as Scopus, NTNU Oria and Google Scholar. The goal of the keyword search is to find all relevant literature on a specific field. In this thesis, there were used four sets of keywords. The keywords are listed in Table 1.

Table 1: Used keywords in the literature search

Set 1: ETO supply chain		**Set 2: Supplier development**	
Level 1	Level 2	Level 1	Level 2
Engineer-to-order Make-to-order Configure-to-order Design-to-order Project-based manufacturing	Supply chain Characteristics Definition	Supplier development Supplier management	Activities Definition Categories Direct development Indirect development
Set 3: Supplier delivery performance		**Set 4: Delivery performance models**	
Level 1	Level 2	Level 1	Level 2
Delivery performance Delivery variance Delivery window On-time delivery	Definition Characteristics Requirement Untimeliness	Delivery performance model Delivery window	Cost Supplier

After the keyword searches, the relevance and quality assessment was done based on the following list:

1. Is the paper relevant to one of the following themes (a-j) based on its topic and abstract?
    a. Definition of engineer-to-order
    b. Characteristics of engineer-to-order
    c. Supplier development theory
    d. Just-in-time principle
    e. Role of supplier development in engineer-to-order
    f. Definition of delivery performance
    g. Delivery window
    h. On-time delivery
    i. Delivery variance
    j. Delivery performance models
2. Is the paper supported by other scholars? (number of citations)
3. Is the scientific message of the paper up to date based on citations in newer publications?

First, the papers were filtered by their topics and abstracts. After the first filtration, it was checked whether the papers had citations in order to prove their quality among other authors. Finally, the scientific message is checked if it is up to date and not overruled by newer research. However, in some cases, the papers where accepted even though they weren't cited by other authors or that the scientific message had been updated by new research. In these cases, the paper was either new and had not yet been cited or the historical developments in literature were needed in order to provide the broader base for the argument.

When the relevant literature was found by keyword searches, the search method shifted to the snowball effect. With the term snowball effect it is meant the connecting literature which were found by searching new papers based on citations and references in the already found literature. Since the literature related to the thesis topic was somewhat unfamiliar for the author, these connections between articles played a critical role in order to cover the academic field comprehensively. After establishing the literal foundation for the thesis, it was easier to understand connections between the terms and phenomena under a particular theme.

2.2 Empirical study

The empirical part of the thesis consists of three chapters: case company presentation, AS-IS analysis and improvement suggestions for supplier delivery performance. First, in the case company presentation, it is presented the order fulfillment process from the project perspective and then more specifically the key procurement processes. Furthermore, the presentation chapter, introduces current delivery performance management practices, such as penalty fee policies and key performance indicator (KPI) measuring. In the analysis chapter, four case suppliers were chosen to be analyzed both qualitatively and quantitatively. These case suppliers are used as same examples throughout the entire empirical part. Since the scope of the thesis must be restricted in order to complete the thesis in its timeframe, only four case suppliers are covered in this thesis. The suppliers are chosen based on the historical and current status of the supplier delivery performance and as well as according to the case company wishes. Moreover, all four case suppliers represent different component types which in other words mean that they are not direct competitors with each other. The chosen components have lots of potential in the terms of improvement in delivery performance and they are and have been historically a challenge in case company’s material flow control.

The analysis starts with the qualitative part that provides answers to causes and implications of poor supplier delivery performance based on interviews with ABB employees and root cause analyses. The quantitative part is based on historical enterprise resource planning (ERP) data and the supplier delivery performance model introduced in the literature review. The first step of the quantitative part is to acquire relevant on-time delivery data for the analysis. Second, the histograms and delivery distributions are drawn based on suppliers' historical delivery performance. The information from the histograms is later used in the supplier delivery performance cost model. After the historical performance is visualized, the costs of untimely delivery and continuous improvement are determined. Finally, the supplier delivery performance model is used to illustrate the current status and improvement potential of the supplier. The descriptions of both qualitative and quantitative parts are explained in detail in following Subchapters 2.2.1 and 2.2.2. In Figure 2, Figure 3 and Figure 4, it is shown summarizing flowcharts to describe the process in answering the thesis research questions by using the qualitative and quantitative studies.

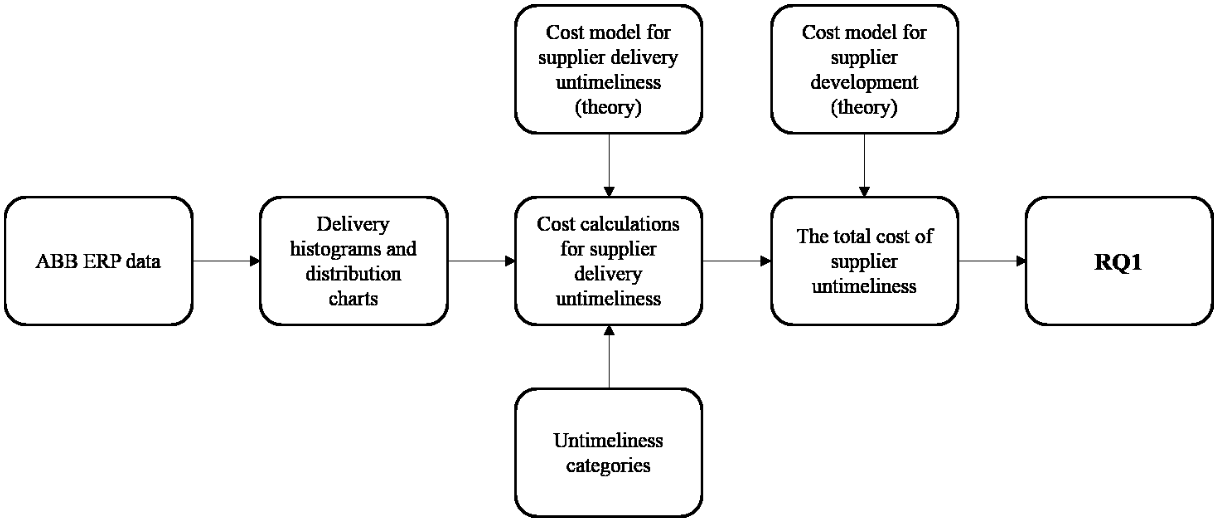

Figure 2: Answering process for RQ1

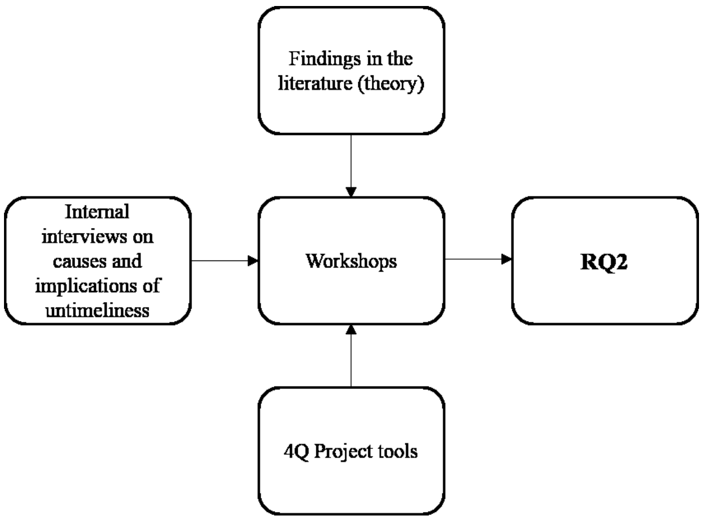

Figure 3: Answering process for RQ2

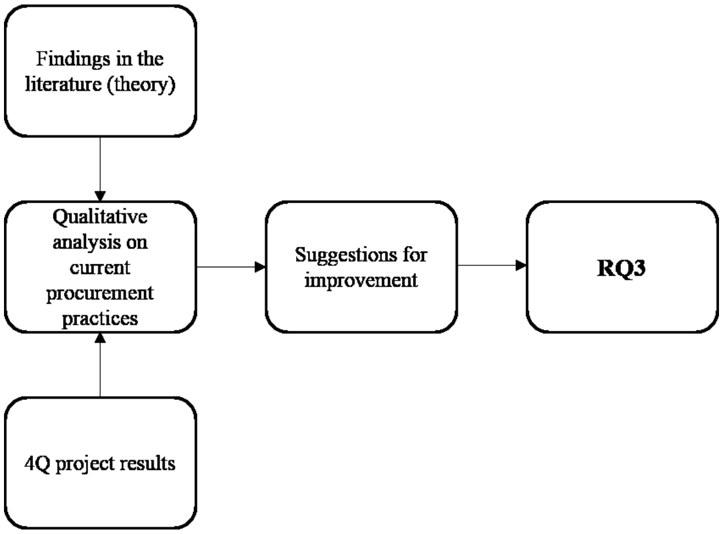

Figure 4: Answering process for RQ3

In the last main part, Chapter 6, the results of the analysis are discussed and improvement suggestions are proposed. The suggestions focus on improving the supplier delivery performance by optimizing delivery windows and delivery performance and as well as proposing improvements in case company's current management practices. Chapter 6 aims to identify the optimized delivery windows and delivery performances in terms of delivery variance in case of the four suppliers.

2.2.1 Quantitative analysis

This subchapter provides a specific explanation of the quantitative analysis in this thesis. The goal of this part is to use quantified information on current supplier delivery performance in terms of delivery variance and the cost associated with untimely delivery. The quantitative analysis consists of following steps:

1. On-time delivery (OTD) data is acquired from the ERP-system.
2. Delivery window is presented in a histogram with probability density distribution. OTD date represents the Azipod® delivery project milestone date between purchasing and production.
3. Categorization of different classes of earliness and lateness is made to simulate the actual impact of untimeliness
4. Determine the cost for untimely delivery (early and late)
5. Determine the cost for continuous improvement in delivery performance

6. Present the total cost due to untimely delivery in a graph to visualize the findings

2.2.2 Qualitative analysis

While quantitative part of the analysis provides metrical information on the delivery variance, costs related with poor delivery performance and investment requirement in internal processes, qualitative part seeks to identify what performance-driving processes and procedures could be improved and what are the implications of poor supplier delivery performance. The qualitative part contributes in following:

1. Conduct interviews
    a. What are the main causes for poor supplier delivery performance?
    b. What are the implications of poor supplier delivery performance?
    c. What are the current supplier delivery performance practices?
2. Execute 4Q analysis on OTD as an example for supplier improvement in terms of supplier delivery performance

As listed above, the qualitative analysis consists of two parts. The first part is interviews in order to establish an understanding on the main causes and implications of poor delivery performance of the four case suppliers. The second part, however, is a case study on how the delivery performance could be improved. In this case study a so called 4Q analysis is performed which aims to identify what are the root causes for the selected theme and how, by eliminating the root causes, the improvement could be achieved. The 4Q analysis follows the common PDCA-cycle (Plan-Do-Check-Act) but is though customized particularly for the case company use. Figure 5 presents 4Q analysis template which later used in solving how supplier delivery performance could be improved.

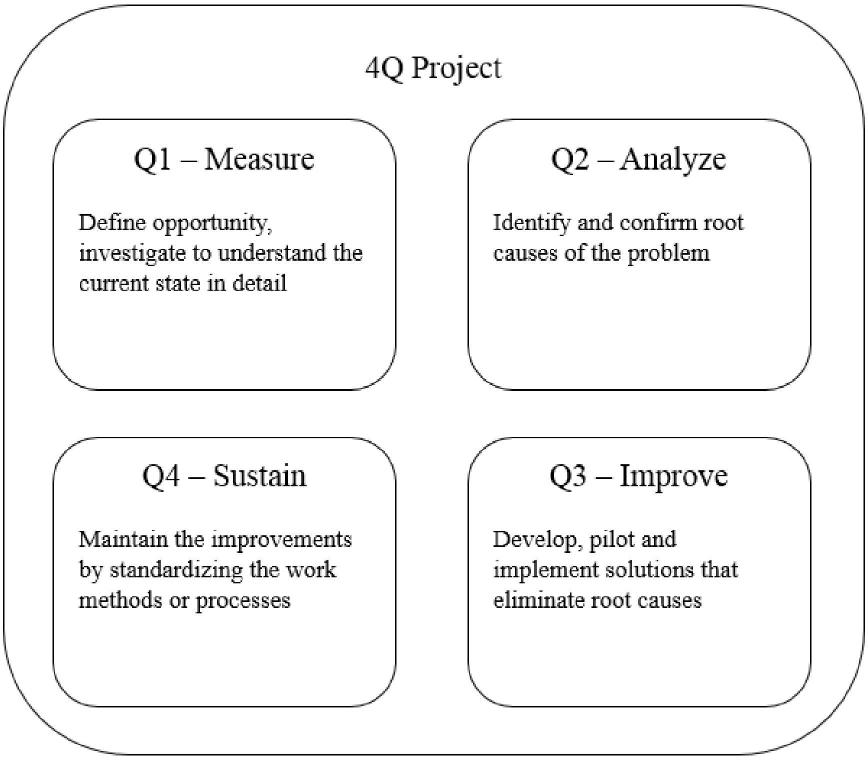

Figure 5: 4Q Process template

3 Literature review

In this part it is presented the theoretical frameworks that support the empirical analysis in later chapters. Therefore, in order to discuss about supplier delivery performance management, a comprehensive literature review is required to provide understanding on the earlier research on the thesis theme. The objective of the literature review is to explain theoretical frameworks that are later on used and discussed in the empirical analysis that can support the arguments of the author.

The following subchapters approach supplier delivery performance management from different perspectives. The review begins by defining ETO supply chain and what are the characteristics of such operational environment. The second part approaches supplier delivery performance management from the supplier development angle. Supplier development is argued to play very important role in improving delivery performance. Third, the most central theoretical framework, just-in-time, is presented which can be considered as one of the founding management philosophies of modern manufacturing. After presenting just-in-time philosophy, the literature review is taken deeper to supplier delivery performance management. This subchapter starts by defining, establishing the need of the delivery performance management and introducing the main types of delivery untimeliness in ETO manufacturing which are followed by explanations on terms delivery window, on-time delivery and delivery variance. The literature review ends with an introduction to existing delivery performance models. One of the introduced models is presented in more detail since it is applied in the empirical analysis when trying to determine costs due to delivery untimeliness. Overview of the literature review is presented in Figure 6.

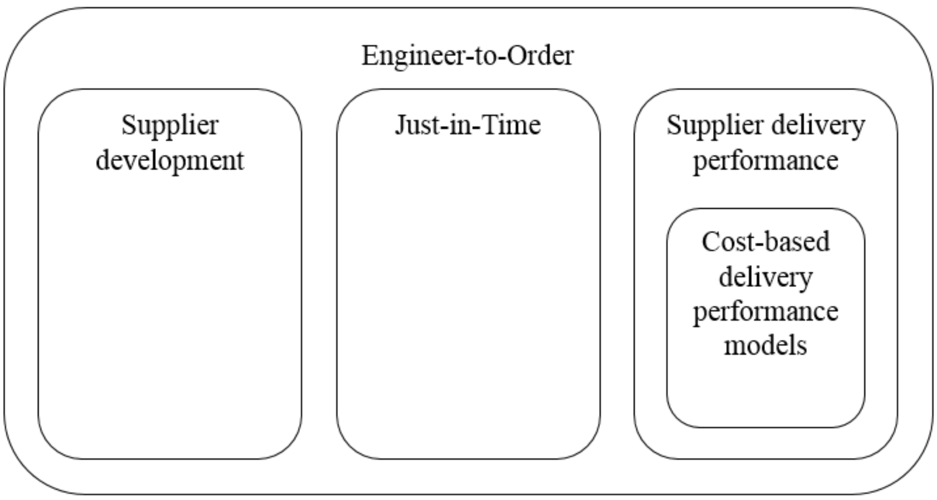

Figure 6: Overview of the literature review

3.1 Engineer-to-Order Supply Chain

In order to understand how ETO supply chains differ from other supply chains it is important to comprehend its definition and characteristics. This chapter introduces how ETO is defined in the literature and what are the characteristics that describe ETO manufacturing. Based on a literature review on ETO supply chain management (Gosling & Naim, 2009), supply chains can be classified into six defined structures: engineer-to-order (ETO), buy-to-order (BTO), make-to-order (MTO), assemble-to-order (ATO), make-to-stock (MTS) and ship-to-stock (STS). These supply chain structures represent highly different manufacturing environments from pure process industry such as paper production to project-based industries such as construction business and shipbuilding. ETO represents the latter.

3.1.1 Definition of Engineer-to-Order

The literature shows that there are many definitions introduced for Engineer-to-order. A common approach in order to define ETO is in the terms of customer decoupling point (CODP) concept (Lampel & Mintzberg, 1996; Martínez-Olvera & Shunk, 2006; Olhager, 2003; Rudberg & Wikner, 2004; Yang & Burns, 2003). The position of CODP in an ETO supply chain is agreed to be in the engineering phase of the manufacturing time as illustrated in Figure 7. CODP is a commonly used concept which aims to match supply chain to the marketplace by identifying the point that separates upstream supply chain from downstream supply chain (Gosling & Naim, 2009; Olhager, 2010). Upstream supply chain refers to operations that are produced to forecast and downstream supply chain to the part that responds directly to customer order. The CODP is considered as a strategic buffer against demand fluctuations and an efficient way of scheduling standardized parts whilst reacting to uncertain orders (Olhager, 2010; Wikner & Rudberg, 2005). Some authors call the CODP as order penetration point (OPP) (Olhager, 2003; van Donk & van Doorne, 2016).

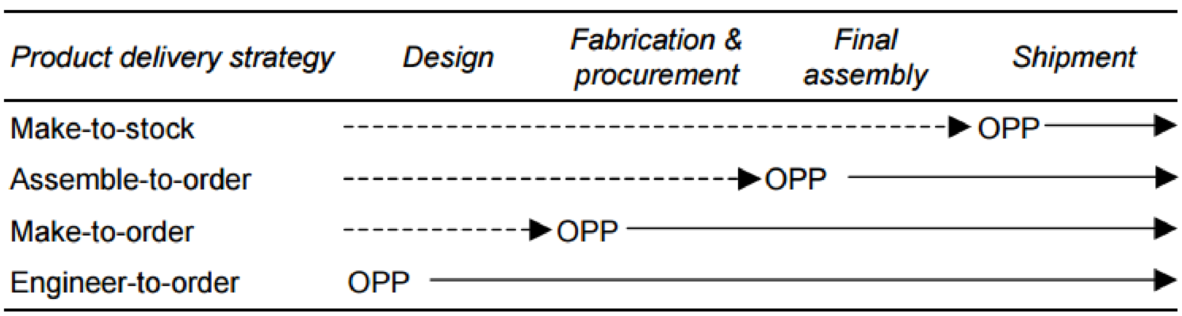

Figure 7: OPP of different supply chain types (Olhager, 2003)

Further definitions of ETO are somewhat contradictory since the authors use different terminology and approaches in their definitions. Based on the literature review by Gosling and Naim (2009), a relatively wide spectrum of different types of supply chains in ETO is one of the main reasons for such contradictions among authors and therefore an universal definition does not exist. However, this thesis aims to clarify and conclude the differences in the definitions and eventually find a fit between them and the case company. The chosen fit then acts as a baseline for the entire thesis.

Lampel and Mintzberg (1996) propose a continuum of strategies that aims to rationalize standardization and customization of products, processes and customer transactions. They argue that key processes of a manufacturing company can be configured in the terms of five strategies: pure standardization, segmented customization, customized standardization, tailored customization and pure customization. Based on these five strategies, ETO is considered to represent either pure or tailored customization. By the term pure customization one means that the production process is completely customized while tailored customization meets product specific requirements for each customer order.

Porter, Little, Peck, and Rollins (1999) approach by introducing design-to-order (DTO) alongside with ETO. According to their study, the difference that separates DTO from ETO is entirely new product introductions with design, engineering and manufacturing based on each new customer order. In contrast, an ETO company has a standard product range where modifications and customizations are added according to customer requirements. The connection between Lampel and Mintzberg (1996) and Porter et al. (1999) approaches is that DTO is similar to pure customization and ETO to tailored customization.

Based on Rudberg and Wikner (2004) ETO is a special case of MTO and in both cases production flow is entirely driven by actual customer orders. However, the design and engineering which are also driven by customer order in ETO are not part of the production flow. Therefore they have introduced an extended two-dimensional CODP typology in which the dimensions are: production (PD) and engineering (ED). According to Wikner and Rudberg (2005) the term ETO_{ED} is used to depict a situation where a new product is designed and engineered to order while adapt-to-order (ATO_{ED}) refers to engineering modifications to existing products and is somewhat equivalent to DTO in Porter et al. (1999) definition. MTO_{PD}, on the other hand, refers to ETO production flow that is fully driven by customer order. The two-dimensional CODP is presented in Figure 8.

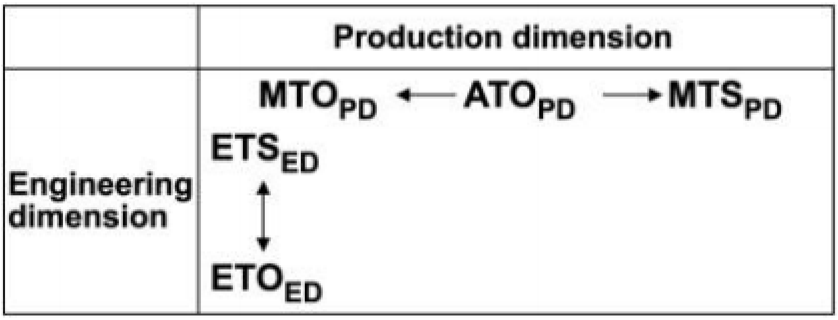

Figure 8: Two-dimensional CODP typology

Finally, some authors such as Martínez-Olvera and Shunk (2006) and Chris Hicks et al. (2001) define ETO companies to operate in a project environment and that every customer order has project specific requirements.

Table 2: Summary of ETO supply chain definitions

Definition	Supporting literature
CODP of ETO supply chains is located at the design phase and production dimensions are customized.	Lampel and Mintzberg (1996); Olhager (2003); Yang and Burns (2003); Rudberg and Wikner (2004); Martínez-Olvera and Shunk (2006)
ETO supply chains offer customized products where existing designs are modified to order.	Porter et al. (1999); Rudberg and Wikner (2004); Wikner and Rudberg (2005)
ETO supply chains offer customized products where completely new designs are developed to order.	Rudberg and Wikner (2004); Wikner and Rudberg (2005)
ETO supply chains operate in a project environment with project specific demands.	Chris Hicks et al. (2001); Martínez-Olvera and Shunk (2006)

Table 2 provides an overview of ETO supply chain definitions. The commonalities among authors are that an ETO supply chain operates in a project environment and the production flow is completely customized and driven by customer order (Gosling & Naim, 2009). Further, the authors agree that the CODP is positioned in the design phase. However, the literature shows disagreements regarding the engineering dimension. Some authors argue that an ETO company develops new designs to order while others claim that existing designs are only modified to order. In addition to this, ETO supply chains have industry related differences such as shipbuilding is depended on the same shipyard while construction projects move to new locations (Gosling & Naim, 2009).

As a conclusion to the different definitions of ETO, it is chosen a definition that fits best the case company and is then used further in this thesis. Since the case company customizes existing product designs to order and new product designs are introduced infrequently, the definition on completely new product designs to each new customer order is not valid. On the other hand, the production flow is project-based and entirely driven by customer order which is in the line with all proposed definitions in Table 2. According to Wikner and Rudberg (2005) definition the case company supply chain can be summarized as ATO_{ED} and MTO_{PD}.

3.1.2 Characteristics of ETO

When analyzing a supply chain, it is important to understand how the company operates and in what kind of operating environment is surrounding the business. Therefore, a study of supply chain characteristics is conducted. The characteristics are divided into four groups; product, process market and supply, in order to cover different areas of the company. However, typically researchers identify characteristics by merging market and supply or alternatively demand and supply into one group as for instance Stavrulaki and Davis (2010) have done in their analysis on alignment of products with supply chain processes and strategy. The reason why market and supply is divided is that this thesis aims to emphasize supply related characteristics. The identified characteristics of an ETO supply chain are summarized in Table 3. As an overall characteristic, ETO companies struggle with an optimization trade-off between operational efficiency and customization (Duchi, Maghazei, Sili, Bassan, & Schönsleben, 2015). This trade-off is considered as a core competence in ETO manufacturing (Christian Hicks, McGovern, & Earl, 2000).

The identified characteristics in Table 3 are later on used as reasoning for why supplier delivery performance is particularly important in ETO manufacturing and what are the challenges in the improvement.

Table 3: Characteristics of ETO supply chain

Group	Characteristics	Supporting literature
Product	High level of customization	Christian Hicks, McGovern, et al. (2000); McGovern, Hicks, and Earl (1999); Olhager (2010); Bertrand and Muntslag (1993); Caron and Fiore (1995); (Duchi et al., 2015)

	Low production volume	Christian Hicks, McGovern, et al. (2000); McGovern et al. (1999)
	Deep and complex product structure	Christian Hicks, McGovern, et al. (2000); McGovern et al. (1999); Bertrand and Muntslag (1993); Caron and Fiore (1995); Gosling and Naim (2009)
	Uncertainty in product specification	Christian Hicks, McGovern, et al. (2000); McGovern et al. (1999); Caron and Fiore (1995)
	Mix of customized and standard components varying from low to medium or high volumes	Christian Hicks, McGovern, et al. (2000); Caron and Fiore (1995)
	Components are purchased for project specific needs	Christian Hicks, McGovern, et al. (2000); Mario Henrique Mello, Strandhagen, and Alfnes (2015a); Wikner and Rudberg (2005)
	Long and uncertain lead times	McGovern et al. (1999); Mario H Mello and Strandhagen (2011)
Process	Core capabilities are tendering, design and contract management	Christian Hicks, McGovern, et al. (2000)
	Primary processes of ETO are tendering, design, engineering, procurement, manufacturing, assembling and commissioning	Bertrand and Muntslag (1993); Caron and Fiore (1995); Christian Hicks, McGovern, et al. (2000)
	High variation in vertical integration between ETO companies	Christian Hicks, McGovern, et al. (2000); McGovern et al. (1999)
	Complex supply chain structure which involves multiple companies	Christian Hicks, McGovern, et al. (2000); Mario Henrique Mello et al. (2015a)
	High process uncertainty	Christian Hicks, McGovern, et al. (2000); Bertrand and Muntslag (1993)
	Level of outsourcing is increasing	Christian Hicks, McGovern, et al. (2000); McGovern et al. (1999); Wagner (2010); Mario H Mello and Strandhagen (2011)
	Production processes are job-shop or project	Bertrand and Muntslag (1993); (Chris Hicks et al., 2001)
Market	Key competitive factor is delivery performance; reduced lead time and increased reliability of lead-time estimates	Christian Hicks, McGovern, et al. (2000)
	High flexibility	Caron and Fiore (1995)
	Competitive edge is based on design capability, price and fast response to customer orders	McGovern et al. (1999)
	Fluctuating demand which is difficult to forecast	McGovern et al. (1999); Bertrand and Muntslag (1993)
	Each unit represents a large proportion of production capacity	McGovern et al. (1999); Bertrand and Muntslag (1993)
Supply	Supplier relationships vary and are complicated	Christian Hicks, McGovern, et al. (2000); McGovern et al. (1999)

High dependence on suppliers due to highly specified components	Christian Hicks, McGovern, et al. (2000); McGovern et al. (1999)
Multi-sourcing	McGovern et al. (1999)
Purchased items represent a large proportion of the contract value	McGovern et al. (1999); Mario H Mello and Strandhagen (2011)

Product

ETO products are highly customized and characterized to have complex and deep product structures which include high uncertainty in product design (Bertrand & Muntslag, 1993; Caron & Fiore, 1995; Duchi et al., 2015; Gosling & Naim, 2009; Christian Hicks, McGovern, et al., 2000; McGovern et al., 1999; Olhager, 2010). Due to complex product structures and high level of customization ETO products have generally long lead times and are expensive to build (Christian Hicks, Earl, & McGovern, 2000; McGovern et al., 1999; Mario H Mello & Strandhagen, 2011). ETO products commonly consist of a mixture of customized and standard components in low to medium or high volumes (Caron & Fiore, 1995; Christian Hicks, Earl, et al., 2000). Furthermore, it is common that the components and sub-assemblies, especially complex ones, are purchased for project-based needs (Christian Hicks, Earl, et al., 2000; Mario Henrique Mello et al., 2015a; Wikner & Rudberg, 2005). In other words, these components are allocated to specific use and cannot be used in other projects. ETO companies produce generally in low volumes (Christian Hicks, McGovern, et al., 2000; McGovern et al., 1999). Based on identified characteristics and the fact that ETO products are typically produced as large projects in construction and capital goods sectors (Gosling & Naim, 2009), it is clear to detect a strong link between the position of CODP and identified characteristics.

Processes

The primary processes in an ETO supply chain are tendering, engineering, design, manufacturing, assembly and commissioning (Bertrand & Muntslag, 1993; Caron & Fiore, 1995; Christian Hicks, McGovern, et al., 2000). However, Christian Hicks, McGovern, et al. (2000) argues that the core capabilities of an ETO company are tendering, design and contract management. Although some authors illustrate the six primary processes as a linear timeline, they may often overlap each other and be processed concurrently (McGovern et al., 1999; Mario Henrique Mello et al., 2015a). For instance, the case company of this thesis must purchase long lead time components before the final design of the product is completed in order to shorten the total project lead time in the order fulfillment process.

The level of vertical integration and outsourcing in ETO companies may vary significantly based on their capabilities in order to control financial pressure and seek cost reductions (Christian Hicks, McGovern, et al., 2000; McGovern et al., 1999). Some companies may have most of production processes in-house while others focus purely on design and contracting. However, the literature shows that there is a trend pattern of increasing level of outsourcing (Christian Hicks, McGovern, et al., 2000; McGovern et al., 1999; Mario H Mello & Strandhagen, 2011; Wagner, 2010). Furthermore, ETO supply chains have complex structures which involve many companies which have high uncertainty in their processes (Christian Hicks, McGovern, et al., 2000; Mario Henrique Mello et al., 2015a). Therefore, the authors have identified that the coordination throughout the order fulfillment process is highly important (McGovern et al., 1999; Mario Henrique Mello et al., 2015a). In general, ETO production can be characterized by job-shop or project production with high complexity and uncertainty (Bertrand & Muntslag, 1993; Chris Hicks et al., 2001).

Market

The key competitive factor at ETO markets is high delivery performance (Christian Hicks, McGovern, et al., 2000). The term delivery performance consists of two components: reduced lead times and reliability of lead time estimations. Based on the supply chain management challenges of the case company of this thesis the requirement for high delivery performance can be extended to supplier end of an ETO supply chain. In addition to delivery performance, the core competitive advantages are considered to be design capability, price and responsiveness (McGovern et al., 1999). High degree of responsiveness is particularly important in the tendering phase. Caron and Fiore (1995) and Gosling and Naim (2009) have also identified that the overall flexibility in the order fulfillment process is a crucial factor in ETO companies' strategies.

A central challenge at ETO markets is fluctuation in demand which is difficult to forecast (Bertrand & Muntslag, 1993; McGovern et al., 1999; Mario H Mello & Strandhagen, 2011). When fluctuating demand patterns are combined with the fact that each produced unit is a large proportion of the capacity, financial and business risks are considered as significant in ETO companies (Christian Hicks, Earl, et al., 2000; McGovern et al., 1999).

Supply

Purchased components represent a large proportion of contract value in ETO companies. Some authors claim that the proportion of purchased components of the total contract value may account for more than 80% (McGovern et al., 1999; Mario H Mello & Strandhagen, 2011).

A major challenge in managing suppliers in ETO companies is that supplier relationships are complicated and may vary significantly (Christian Hicks, McGovern, et al., 2000; McGovern et al., 1999). In the article by McGovern et al. (1999) it is explained that a reason for this is uncertain demand which limits cooperative long-term supply chain relations. In order to reduce purchasing uncertainty many ETO companies use multi-sourcing (Christian Hicks, McGovern, et al., 2000) which is characterized by mutual mistrust and "win-lose" transactions (McGovern et al., 1999). Furthermore, the literature argues that ETO companies do not have the same power against their suppliers as for instance in automotive industry where the buyer is economically stronger and supplier is smaller and dependent on the buyer. Suppliers in automotive industry mainly supply standard components in high volumes which usually equals to more valuable contracts while in ETO supplier contracts are considered less valuable and in lower volumes (Christian Hicks, McGovern, et al., 2000). However, it is identified that ETO companies have recognized the importance and advantages of developing suppliers in long-term collaboration (McGovern et al., 1999). Based on Wagner (2010), while ETO companies are focusing more on their core competencies and their projects are increasingly complex, they are more dependent on external supplier and their capabilities.

3.2 Role of supplier development in ETO delivery process

Since the purchased components and sub-assemblies represent typically a major share of cost of goods sold (CoGS) in ETO companies, suppliers are considered to have a significant effect on the overall performance of the ETO supply chain (Humphreys, Li, & Chan, 2004; McGovern et al., 1999; Mario H Mello & Strandhagen, 2011). In addition to the value creation aspect of suppliers in ETO, the supply chains are often very complex and involves many different type of actors and the nature of high customization in ETO products leads often to high dependencies on certain suppliers that emphasizes the role of suppliers in the supply chain (Christian Hicks, McGovern, et al., 2000; McGovern et al., 1999; Mario Henrique Mello et al., 2015a). Furthermore, the trend of focusing more and more on core-competencies and increasing proportion of outsourcing at the manufacturer has emphasized the role of supplier development initiatives and programs (Dalvi & Kant, 2015; Christian Hicks, McGovern, et al., 2000; Routroy & Pradhan, 2014). Due to these factors, among other things, supplier performance is seen as a major impact on the buyer's competitive advantages and the scholars have focused on supplier development programs and how these initiatives may improve buyer and supplier performance (Humphreys et al., 2004; Routroy & Pradhan, 2014).

In case the buyer is faced with insufficient supplier performance, it can choose one of three options (Wagner, 2010). First, the buyer can switch the supplier by searching alternative sources of supply. However, this option might not be feasible if an alternative supplier is not available or the switch involves costs that are excessively high. The second option is producing the outsourced component or product in-house by acquiring the supplier or setting up the required capabilities and resources internally. This option is also called as vertical integration and might be contradictory to the intention of the company by leading the focus out of their core competencies. The third option is to help poorly performing suppliers to upgrade to the desired level. This option, supplier development, may often be the only choice for the buyer and therefore it is brought up in this thesis as a key process in order to improve suppliers' performance or more specifically their delivery performance (Wagner, 2006).

Based on Krause (1997) the supplier development is defined as *an effort of a buying firm to increase the performance and capabilities of the supplier*. However, it is important to understand that the supplier development initiatives do not solely aim to improve buyer's competitive advantages or supplier's capabilities, but mutual buyer-supplier performance (Humphreys et al., 2004). In the literature, supplier development either deals reactively with poor supplier performance (Wagner, 2010) or strategically ensures that suppliers' performance and capabilities exceed needs of the buyer organization in long-term (Humphreys et al., 2004; Wagner, 2006). According to Wagner (2010) literature review on supplier improvement relates to delivery performance and/or supplier capabilities. The performance and capabilities may be improved by:

1. Increasing supplier performance goals
2. Providing the supplier with training
3. Providing the supplier with equipment, technical support and even investments
4. Exchanging personnel between the two organizations
5. Evaluating supplier performance

6. Recognizing supplier progress in the form of rewards

As listed above suppliers may need an investment in order to improve their processes (Dalvi & Kant, 2015). Such investments may be either human or capital resources (Modi & Mabert, 2007; Wagner, 2006) e.g. training of technical staff or providing on-site consultation. In general, the buyer's support in capital investment is defined as transaction-specific investment (Humphreys et al., 2004) or direct supplier development (Wagner, 2006). The other approach or set of supplier development activities is called indirect supplier development (Wagner, 2006) which is similar to infrastructure factors of supplier development in Humphreys et al. (2004) differentiation of supplier development activities. These two types of supplier development activities are presented more specifically in subchapters 0 and 3.2.2.

The literature indicates that both transaction-specific supplier development and infrastructure factors have direct impact on the performance of both purchasing and supplying organizations in terms of supplier performance improvement, buyer's competitive advantage improvement and buyer-supplier relationship improvement (Humphreys et al., 2004). However, simultaneous use of both types of supplier development efforts is found less effective (Wagner, 2010). Based on a literature review by Dalvi and Kant (2015) and an article by Wagner (2010) supplier development is greatly beneficial for the purchasing organization in order to improve their suppliers' delivery performance both in short and long term and therefore it is considered as a major driver for supplier delivery performance.

3.2.1 Direct supplier development

Direct or transaction-specific supplier development is considered as the core practice of supplier development, which represents direct involvement of the buyer in developing suppliers (Humphreys et al., 2004). Direct supplier development includes activities such as on-site consultation, training programs, temporary personnel transfer, inviting the supplier's personnel to visit at the buyer and provision of equipment or capital (Wagner, 2006). It is noted that such investments could make suppliers more willing to customize items for customers, allow more efficient mutual communication and reduce procurement costs (Humphreys et al., 2004). Direct supplier improvement is found to strongly improve supplier's capabilities (Wagner, 2010). In addition to the transaction-specific investment Humphreys et al. (2004) discuss that direct involvement in developing suppliers may be approached by increasing supplier expectations and thereby motivating them to improve which can as well be considered as indirect supplier development. Apart from the advantages in direct supplier development, it is argued that it may fail to realize the potential of opportunistic behavior on supplier's side (Wagner, 2006). The direct supplier development is later on presented in practice within a cost-based optimization model for untimely delivery in Chapter 3.5.2.

3.2.2 Indirect supplier development

On the contrary, indirect supplier development or in some research infrastructure factors of supplier development (Humphreys et al., 2004) aims to influence suppliers by offering incentives or enforcing supplier improvement (Wagner, 2006). This can be done by assessing suppliers, communicating supplier evaluation results and performance goals, increasing supplier performance goals and instilling competition by the use of multiple sources or promising future business (Wagner, 2006). Thereby the buyer can use communication and external market forces to achieve performance improvement on the supplier's side (Wagner, 2010). Based on Wagner (2010) findings, indirect supplier development has a direct impact on delivery performance, product and supplier capabilities.

3.3 Just-in-time approach to supplier delivery performance

When discussing supplier delivery performance a certain manufacturing philosophy and its principles are often mentioned as a foundation. The philosophy is called just-in-time (JIT) which provides an idealistic approach to the delivery performance theory. Before proceeding to the supplier delivery performance theory it is important for reader to understand from where roots the modern delivery performance thinking. This subchapter briefly explains the development and main aspects of JIT and their relevance to supplier delivery performance management.

Based on Cheng and Podolsky (1996) the history behind JIT management philosophy starts from Japan in early 1970s when many manufacturing firms had begun to implement its principles. The first developments and implementations of JIT took place at Toyota automotive plants by Taiichi Ohno who is often referred as the father of JIT. In the beginning JIT was considered as a method for reducing inventory levels but nowadays has evolved to a management philosophy containing a comprehensive set of principles and techniques (Cheng & Podolsky, 1996). The objective of JIT is considered to be threefold:

1. Increasing the organization's ability to compete with rival firms and remain competitiveness over the long run,
2. Increasing the degree of efficiency within the production process,

3. Reducing the level of wasted materials, time and effort involved in the production process (Cheng & Podolsky, 1996).

The objectives above are applicable in every organization, however the goals achieved by JIT may be organization specific. Based on Cheng and Podolsky (1996) the goals of JIT include following:

- Identifying and responding to the customer need
- Aiming for the optimal quality/cost relationship
- Eliminating unnecessary wastes
- Aiming for the development of trusting relationships between the suppliers
- Designing the plant for maximum efficiency and ease of manufacturing
- Adopting the Japanese work ethic of aiming for continuous improvement

As it is discussed later on in subchapters 3.4: Supplier delivery performance management and 3.5: Cost-based supply chain delivery performance models all the named goals of JIT play are important aspects for improvement in supplier delivery performance. Particularly, the goals of eliminating unnecessary wastes, development in supplier relationships, maximum production efficiency and continuous improvement represent the motivation for managing supplier delivery performance. For instance Guiffrida and Jaber (2008) cost model for untimely delivery (in subchapter 3.5.2) and JIT both consider early and late deliveries as sources of waste and additional costs which can be eliminated by continuous improvement (Gupta & Sivakumar, 2007). In this example, a model is developed aiming to increase the share of on-time delivery by decreased delivery variance which has a direct impact on plant efficiency.

Even though JIT is considered as one of the founding management philosophies in modern manufacturing it has its limitations and weaknesses. The main weakness in the context of the case company operational environment is cultural differences (Cheng & Podolsky, 1996; Phan & Matsui, 2010). This is indeed truly relevant aspect since the case company plant is in China, but managed by Finns and Finnish standards of plant efficiency, safety and working skills. The cultural differences of JIT production were studied in an article by Phan and Matsui (2010) where they found relatively significant differences in JIT practices in Japanese and for example German companies.

3.4 Supplier delivery performance management

As identified in before, outsourcing of components can represent up to 80% of the total contract value in ETO manufacturing. The value creation at suppliers is even likely to rise since the degree of outsourcing in ETO companies is perceived to increase. These facts support the statement that suppliers have a significant impact on the delivery performance of ETO. When revisiting Chapter 3.1.2, the delivery performance is characterized as a key competitive advantage in ETO manufacturing. This thesis extends the importance of high delivery performance to ETO suppliers by emphasizing their capability to deliver on-time as a critical aspect of overall suppliers' performance. Poor supplier delivery performance leads consequently to decreased operational excellence of an ETO company due to excessive buffers in the project delivery or delayed deliveries to the end customer. While the competition is getting more and more intense at the markets the emphasis of delivery performance is increasingly important. For instance delivery reliability which is often considered as one of the main aspects of delivery performance has shifted from an order winner to an order qualifier factor in many manufacturing industries (Pinto, Mettler, & Taisch, 2013).

This chapter concentrates on the most central aspects of supplier delivery performance management. First it is provided an understanding on what it is and how it can be measured, established the requirement for supplier delivery performance management and presents what are the common causes for poor delivery performance in ETO manufacturing. After the founding subchapters, it is drilled deeper into the delivery window and on-time delivery which can be seen to determine the framework for supplier delivery performance. The chapter ends to control of supplier delivery variance.

3.4.1 Definition and metrics of supplier delivery performance

In general, the delivery performance is one of the key metrics in overall supply chain performance (Bhagwat & Sharma, 2007; Guiffrida & Jaber, 2008; Gunasekaran et al., 2001; Milgate, 2001; Stewart, 1995) and competitiveness of an organization since it has direct impact on sourcing decisions and customer satisfaction (Bhattacharyya & Guiffrida, 2015; Stewart, 1995). The importance of high delivery performance is highly appropriate in the context of ETO supply chains as it was identified as one of the key market characteristics. In addition to this, increased delivery performance has a positive impact on the overall uncertainty which is considered to be a major challenge in ETO manufacturing (Mario Henrique Mello, Strandhagen, & Alfnes, 2015b).

In order to quantify supplier delivery performance, it should be measured. As Garvin (1993) expresses it: “if you can’t measure it, you can’t manage it”. The need for delivery performance measurement and its relationship with the supply chain management is well recognized in the literature (Bushuev & Guiffrida, 2012). There are several quantitative measures presented for measuring the delivery performance. Based on the study by Stewart (1995), there are two key measures: delivery-to-request and delivery-to-commit. The first of the two is the percentage of fulfilled orders by the original customer requested date and the second is the percentage of fulfilled orders by supplier’s original schedule or commitment date. Later, Milgate (2001) suggested that the delivery performance consists of four variables, with the first two measuring speed and the last two measuring reliability. The speed variables are delivery lead time which measures actual time that elapses from the order placement until it is received at the customer and throughput time which measures the time from the start of the production to its completion. The delivery lead time is defined as elapsed time from the receipt of an order by supplier to the receipt of the order by the customer (Guiffrida & Jaber, 2008). The reliability variables, on the other hand, are percentage of late deliveries to the customer and the average lateness of the late deliveries. The reliability variables can be extended by earliness which is also recognized to be disruptive to the supply chains (Alfred L. Guiffrida & Rakesh Nagi, 2006). Both early and late deliveries introduce waste in form of excess cost into the supply chain.

However, in the Gunasekaran et al. (2001) framework for measuring the performance of a supply chain, the delivery performance and reliability are classified separately on different levels of management. The framework defines the delivery performance as a strategic performance measure while delivery reliability is viewed as tactical measure. Furthermore, Gunasekaran et al. (2001) suggests that both the delivery performance and reliability should be measured financially and non-financially. For instance companies should measure not only on-time delivery percentage of all supplier deliveries, but also what is the cost of poor OTD. Failed financial measurement of the delivery performance leads to both short and long-term difficulties (Guiffrida & Jaber, 2008). In the short-term, the buyer-supplier relationship may be negatively impacted. If the financial performance is not measured, a norm value of presumed performance is established that stays constant with time and is generally higher than the actual delivery. In long-term, the failure to measure delivery performance in financial terms leads to impediments in capital budgeting process which is necessary in order to support the improvement of the supplier operations. The literature has proven that supplier evaluation systems have a positive impact on the buyer-supplier relationships (Guiffrida & Jaber, 2008).

The literature has identified that delivery performance measuring has had historically three limitations (Guiffrida & Jaber, 2008), nevertheless relatively extensive research on the field. The first limitation is that the measures are not cost-based. Second, delivery performance measures ignore process variability. Third, delivery performance measures often fail to take into account penalties due to both early and late deliveries.

3.4.2 Requirement for supplier delivery performance management in ETO

This subchapter establishes an understanding on why suppliers' delivery performance management is particularly important in ETO manufacturing based on the characteristics identified in Chapter 3.1.2., and delivery performance literature. First it is explained the pressure and requirement for supplier delivery performance set by the markets. In general, the supplier delivery performance is considered to have a critical role in the total operational performance of a company (Bhattacharyya & Guiffrida, 2015). Moreover, the Bhattacharyya and Guiffrida (2015) argument on the role of the delivery performance applies particularly well in ETO manufacturing since it is viewed as the key competitive factor at the markets. Guiffrida and Jaber (2008) states that improved delivery performance when delivering to the end customer can lead to new business from existing customers and works as a basis of competitive advantage to gain new customers. This statement can be as well extended to the suppliers in an ETO company since improved supplier delivery performance has a direct effect on buyer's operational excellence and the delivery to the end customer (Bhattacharyya & Guiffrida, 2015).

Pinto et al. (2013) have identified that MTO companies in general are highly sensitive to problems that may influence delivery performance negatively. However, it is important to understand that the delivery performance problems are not purely internal at the supplier but chain reactions in multi-tiered environment. This and the sensitivity to negative delivery performance are particularly relevant for ETO companies since they are characterized to have more uncertainty due to supply chain complexity and product specifications and processes (Christian Hicks, McGovern, et al., 2000).

From the product and component perspective, ETO companies operate in an environment with high uncertainty and customization (Caron & Fiore, 1995; Christian Hicks, McGovern, et al., 2000; McGovern et al., 1999) associated with product specification and long lead times in procurement phase which mean that high supplier delivery performance is extremely important in improving the operational efficiency and the competitive advantage. As argued before, ETO companies struggle with an overall trade-off between operational efficiency and customization which is also considered as one of the core competencies in ETO manufacturing. In addition, the purchased components are usually ordered for specific production projects (Christian Hicks, McGovern, et al., 2000; Mario Henrique Mello et al., 2015a; Wikner & Rudberg, 2005) which means that the components cannot be loaned or used in other projects. The fact of project based material requirement emphasizes that the supplier's must have high delivery performance in order to avoid project delays.

Based on the characteristics of ETO processes, the level of outsourcing is increasing (Christian Hicks, McGovern, et al., 2000; McGovern et al., 1999; Mario H Mello & Strandhagen, 2011; Wagner, 2010) and the supply chain structure is complex involving many actors (Mario Henrique Mello et al., 2015a) along with high degree of process uncertainty. Therefore, in order to manage ETO supply chains effectively, the supplier delivery performance should be on a high level. Even though, the technical ability and customization describe ETO environments well, the efficiency side of the overall trade-off cannot be neglected when competing at the markets.

Finally, from the supply perspective the value of purchased components represent a large proportion of the total contract values in ETO manufacturing (McGovern et al., 1999; Mario H Mello & Strandhagen, 2011) which means that the suppliers play an important role in deciding the overall operative performance of an ETO company. Furthermore, it can be stated that the high dependence on suppliers due to complex and specified components (Christian Hicks, McGovern, et al., 2000; McGovern et al., 1999) emphasizes that the requirement for supplier delivery performance management is evident.

3.4.3 The main causes of delivery untimeliness in ETO

The occurrence of delays in ETO projects is a major problem that impacts the performance of a supply chain. Based on surveys conducted in construction business (Assaf & Al-Hejji, 2006) 70% of the projects experienced time overrun which indicate that the untimeliness is a serious and common phenomenon in project-based production. These surveys also found that on-time delivery is an indicator of efficiency.

Mario Henrique Mello et al. (2015b) argue that the overall problem in controlling ETO delivery timeliness is lack of coordination in the interface between engineering and production. They have also found in the literature that the problems lay especially in coordinating multiple organizations, not coordination in single organization. Furthermore, the current trend of outsourcing into low-labour cost countries and retaining engineering as a core expertise has resulted to larger gap between engineering and production and occurrence of protracted delays leading to poor on-time delivery (Mario Henrique Mello et al., 2015b). This phenomenon can as well be found in the case company presentation. Based on Mario Henrique Mello et al. (2015b), the list of found causes which delay ETO manufacturing projects is summarized in the following:

- Procurement phase delayed due to missing designs and poor quality of documentation
- High number of quality problems at the supplier
- Information flow not integrated between supplier and buyer
- Little visibility of processes, difficult to follow up the processes
- Optimism in business partner's skills
- Poor delivery documentation
- Long lead times increase a change of occurrence of unpredicted events (e.g. strikes, new trade regulations etc.)
- Changes in technical requirements after production starts

Most of these causes may be considered to root from process and product uncertainty. As discussed earlier ETO supply chains operate in a relatively uncertain environment which reduces the effectiveness and increases the variability in the processes (Atkinson, Crawford, & Ward, 2006). The uncertainty is controlled with buffers that reduce directly operational efficiency (Duchi et al., 2015; Alfred L. Guiffrida & Rakesh Nagi, 2006). However, from time to time to become more efficient, ETO companies must take certain risks and reduce their buffers which may lead to untimeliness in the project delivery due to the variability caused by uncertainty. Therefore, it can be stated that uncertainty is one of the main causes of untimeliness in ETO supply chains (Mario Henrique Mello et al., 2015b).

3.4.4 On-time delivery and delivery window

A critical aspect of delivery performance is on-time delivery. In competitive business environment, ETO companies are dependent on on-time delivery from their suppliers in order to achieve high operational performance and deliver customer on-time (Mario Henrique Mello et al., 2015b). As argued in defining delivery performance, on-time delivery determines whether the delivery is perfect or not. Based on Shin, Benton, and Jun (2009) the delivery failure or imperfectness of a supplier is classified into two categories: delivery earliness and delivery tardiness. In some literature delivery tardiness is replaced by delivery lateness (Alfred L. Guiffrida & Rakesh Nagi, 2006). Early deliveries cause buyer excess inventory holding costs, while late deliveries may lead to production stoppages (Alfred L. Guiffrida & Rakesh Nagi, 2006; Shin et al., 2009) and late deliveries to the end-customer (Bhattacharyya & Guiffrida, 2015) which result to poor customer satisfaction and penalty fees. It has become more common for customers to penalize their suppliers for untimely deliveries (Alfred L. Guiffrida & Rakesh Nagi, 2006). In general, companies often reactively inflate buffers throughout their processes in their supply chains in order to protect against untimely deliveries which results to additional sources of variance into the supply chain (Alfred L. Guiffrida & Rakesh Nagi, 2006).

A delivery window is defined as the difference between earliest accepted delivery date and the latest acceptable delivery date (Alfred L. Guiffrida & Rakesh Nagi, 2006). According to Johnson and Davis (1998) the use of metrics based delivery windows in supply chain management capture the most important aspect, reliability or variability, of the delivery process. It is argued that delivery reliability is the key component to improve the delivery process. Metrics based delivery window enables tracking of the performance delivery of a delivery process by measuring the percentage of order delivered within the given target (Johnson & Davis, 1998). The delivery window is usually modelled as a normally distributed probability density function as illustrated in Figure 9, which shows probabilities for delivery earliness, lateness and on-time delivery (Alfred L. Guiffrida & Rakesh Nagi, 2006; Shin et al., 2009). Based on Figure 9 the customer supplies benchmarks in time which are used to classify deliveries as early, on-time and late. Delivery lead time (X) is a random variable with probability density function f(x). The on-time proportion of the delivery window is defined by the difference of c_2-c_1 or Δc. Delivery windows are an effective tool for modelling the expected costs due to untimely deliveries.

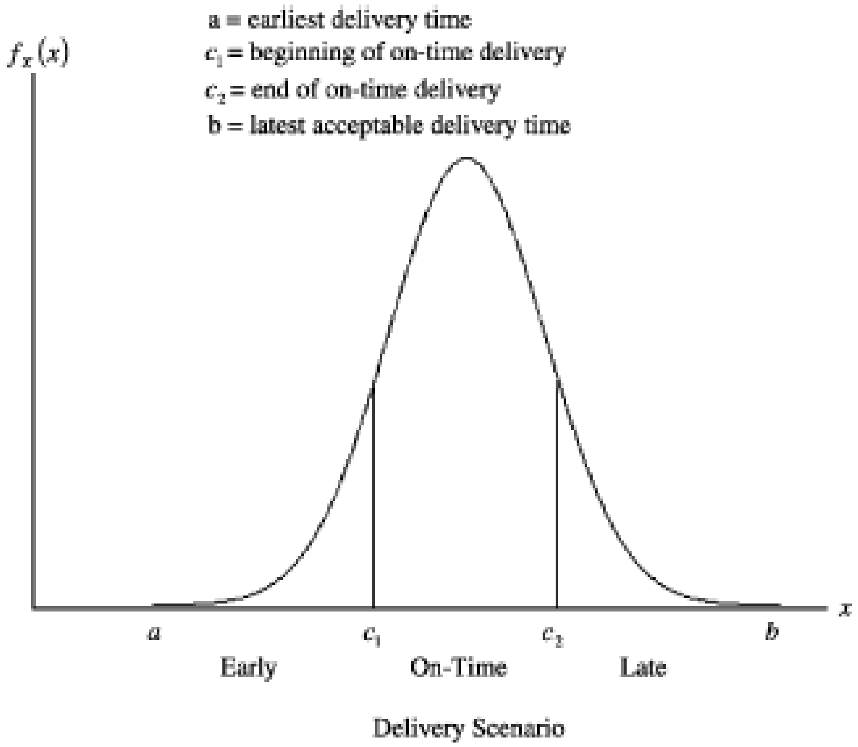

Figure 9: An example of a delivery window for normally distributed delivery

However, the delivery window has also received critique since it does not necessarily have a direct impact on supplier's delivery variance, tardiness and probability of on-time delivery. Grout (1998) found that the delivery window alone does not achieve the desired on-time delivery proportion, but it has been proven to have a positive impact on delivery variance.

Despite the given example in Figure 9, the delivery window is not necessarily fixed or follow Gaussian distribution (Bushuev & Guiffrida, 2012; Tanai & Guiffrida, 2015). Nevertheless, this thesis uses Gaussian distribution when modelling delivery windows because it is the most used distribution model in the literature (Tanai & Guiffrida, 2015). Therefore, all delivery time distributions are assumed to be bell shaped.

According to a study by Bushuev and Guiffrida (2012) the delivery window can actually be optimized to find an optimal position by minimizing the expected cost of untimely delivery. In this optimization model the cost of early and late deliveries is considered as penalty cost of untimely deliveries. The cost of early deliveries refers to the inventory holding cost and the cost of late deliveries to production or other process disturbances and eventual penalty fees from customers due to delayed deliveries. The delivery window may be measured in hours, days or weeks depending on the industrial situation (Guiffrida & Jaber, 2008).

In order to find the optimal position a cost analysis is needed to provide expected cost of late and early deliveries. The ratio between the early and late penalty costs determines whether it is more profitable to set the delivery window closer to the actual production day (Bushuev & Guiffrida, 2012). The expected costs are on ad hoc basis since in some cases the penalty cost for delayed deliveries is higher than the penalty cost for early deliveries and vice versa. The delivery window is considered as an effective tool for modelling expected costs associated with untimely delivery (Guiffrida & Jaber, 2008).

3.4.5 Delivery variance

In general, the literature shows that the reduction of variance is a key component in improving the performance of a system (Blackhurst, Wu, & O'grady, 2004; Sabri & Beamon, 2000). As the delivery variance is reduced the probability of on-time delivery increases and the probability of early and late deliveries decreases (Guiffrida & Jaber, 2008). This has naturally a direct positive impact on the delivery performance which leads to increased operational performance.

The delivery variance may be defined as the measure of the spread between deliveries in a timeline. I.e. the delivery variance calculates the magnitude of divergence from the mean value in the delivery data set.

Based on the framework proposed by Guiffrida and Jaber (2008) supply chain managers can use delivery variance reduction in order to improve delivery performance in a similar way as quality managers have historically used the reduction of process variation to improve product quality. In this model, the delivery variance is traded off against investment in continuous improvement of OTD. In other words, reduced delivery variance leads to reduced penalty costs due to untimely deliveries while investment in continuous improvement increases the total cost of untimely delivery. This model is presented in detail in Chapter 3.5.2. According to the literature (Guiffrida & Jaber, 2008; Alfred L Guiffrida & Rakesh Nagi, 2006) the delivery variance in the delivery distribution can be reduced as a result of:

- the supplier gaining tighter control over process flow times
- enhanced coordination of freight transport
- more efficient material handling of outbound stock by the supplier and inbound stock by the buyer

- Improved communications between both parties, e.g. implementation of electronic data interchange (EDI).

3.5 Cost-based supply chain delivery performance models

Based on the fact that supplier delivery performance should be measured financially (Gunasekaran et al., 2001), the need for cost-based models can be considered evident. This chapter provides an introduction to these models and how to manage cost in supply chains from the different perspectives providing competitive advantage. In the first subchapter it is briefly presented a set of central models for MTO environments proposed by the literature. The second subchapter, however, goes deeper to a model which is selected later in this thesis to determine the costs associated with supplier delivery variance and improvement in delivery performance. This model was first introduced by Alfred L. Guiffrida and Rakesh Nagi (2006).

3.5.1 Introduction to cost-based delivery performance models

The first model to be presented is proposed by Roy, Gupta, and Dasgupta (2013) and aims to find the optimum logistic service provider mix associated with minimum end to end delivery lead time within specific delivery window. In this model, the supply chain is considered multi-stage and there are multiple available service providers whom cost per component, mean processing lead times and process variance are known. This technique provides a solution with minimal cost, which fulfils the constraints related to timely delivery. The model excludes demand variability and inventory levels. The main reason why this model is excluded from the thesis scope is that the purchasing agreement and delivery terms (Incoterms) of the case company declare that the suppliers are responsible for shipping of their products to their factory, this model is not applicable. Furthermore, the Roy et al. (2013) model does not take account to the cost impact associated with supplier untimely delivery which is the key objective of this study.

Paul, Babu, Reddy, and Perati (2013) approach delivery performance analytics from two perspectives. The first model is deterministic model and is based on the number of days taken for the delivery while the second is probabilistic model and based on various stages of the product development which follow exponential distribution. However, the expected penalty cost due to untimely delivery is only applied in the second model. In addition, the second model only takes into account delays in delivering service or product to the customer. This is due to the case study which is made in software business where early delivery is not storable in an inventory. As explained in Chapter 3.4.4 early delivery is as well considered as type of waste in a manufacturing environment.

The third model, based on article by Rao, Rao, and Muniswamy (2011) focuses on manufacturing environment considering four elements of delivery performance: supplier on-time and in full delivery, manufacturing schedule attainment, warehouse on-time and in full shipment and transportation provider on-time. All elements are calculated by dividing successful occurrences by the whole sampling. The overall delivery performance is derived from multiplication of fractions of the four elements. The cost aspect of this model considers the overall delivery performance and penalty costs from the customer (as a percentage of total contract value) to calculate optimal cost at a certain delivery performance. Even though the Rao et al. (2011) model provides a comprehensive overview of all elements related to delivery performance, it lacks buyer's perspective in order to identify the impact of supplier's untimely delivery on the production and project progression in ETO manufacturing. Therefore, this model is considered to be outside the thesis scope. The occurred cost for the buyer due to untimely delivery is necessary information in revealing the actual cost which lays in their internal processes.

Shin et al. (2009) propose a different approach to supplier delivery performance and cost-based metrics. In their study, they consider different sourcing policies in order to find the optimal quality and untimeliness cost. Both earliness and lateness are recognized as sources of waste which together constitute the total cost associated with untimely delivery at certain probabilities. However, this model is not fully applicable in this thesis since we are interested in finding not only the penalty costs associated with untimely delivery but also the process improvement aspect which drives to improved delivery performance. In addition, the fact of which sourcing policy gives the most optimal results is outside of the scope.

Finally, Choudhary, Singh, and Tiwari (2006) propose a probabilistic model which is based on allocation of tolerances on lead times of internal business processes in a supply chain. The target of this model is to find the minimum total cost of a supply chain network by considering various linear and nonlinear constraints. Yet, the model lacks the supplier-buyer interface and only focuses on the internal processes in the supply chain. It also fails to illustrate the direct delivery reliability or distribution of the supplier.

3.5.2 Cost-based supplier delivery performance optimization framework

As earlier stated, it is highly important to measure delivery performance financially in order to achieve improvement. Along with that fact and the historical three limitations of delivery performance measuring found by Guiffrida and Jaber (2008) this subchapter presents a delivery performance model which aims to overcome these issues. Furthermore, since the scope of this thesis is set on delivery windows, time-based delivery performance and variability in delivery performance, the model about to be presented represents accurately the requirements for financial measuring. The foundation for this cost-based supplier delivery performance model is based on penalty costs due to untimely deliveries, delivery variability and delivery process investment cost.

The model in question is proposed by Guiffrida and Jaber (2008) which is based on the earlier introduced delivery window approach. As discussed in Chapter 3.4.4 the delivery window is an effective tool for modeling expected costs associated with untimely delivery. The model assumes that the delivery performance is stable enough so that modal delivery time is within the on-time portion of the delivery window, the mean and on-time portion of the delivery window remain fixed and the probability of a negative delivery time under the normal density is limited essentially to zero. Ideally the expected costs for untimely delivery equal to zero, which implies that the waste is eliminated from the system (Guiffrida & Jaber, 2008).

The decision variable in the Guiffrida and Jaber (2008) model is the delivery variance. I.e. the objective of the model is to determine variance level that minimizes penalty costs for untimely deliveries and the investment cost required for reducing the delivery variance. This model considers that supplier development in terms of delivery variance reduction is achieved through direct supplier development which requires an investment in supplier's order fulfillment process as argued in Chapter 3.2. In Figure 10 it is presented graphs for the expected cost due to untimely delivery Y(v), the investment cost for delivery variance reduction C(v) and total costs G(v) as a sum of Y(v) and C(v). However, first it is explained the components of the Y(v) formula. Table 4 summarizes all notations used in the following cost formulas.

Table 4: Used notations in cost formulas

Notation	Meaning
G	The total cost supplier untimeliness
Y	Expected cost of untimely delivery
C	Investment cost for delivery variance reduction
Q	Delivery batch size
H	Holding cost
K	Penalty cost due to delayed delivery
v	Delivery variance (in C(v) the target delivery variance)
μ	Mean of the delivery distribution (average delivery)
c_1	Beginning of the on-time delivery window
c_2	End of the on-time delivery window
Φ	Cumulative distribution function
ϕ	Probability distribution function
λ	Investment cost
h	Delivery variance reduction % per λ
v_0	Original delivery variance

In first component of Y(v) it is calculated the cost of delivery earliness by assigning a cost for inventory holding H and an average order quantity Q which are multiplied with the expectancy term where v = variance of the delivery distribution, μ = mean of the delivery distribution and c_1 = beginning of the on-time delivery window. The expectancy term considers all deliveries on the early side of the delivery distribution curve by calculating from minus infinite to the beginning of the on-time window. Equation for cost of delivery earliness is presented in following:

$$QH\left[\sqrt{v}\phi\left(\frac{c_1-\mu}{\sqrt{v}}\right)+(c_1-\mu)\Phi\left(\frac{c_1-\mu}{\sqrt{v}}\right)\right]$$

The second component of the Y(v) function is cost of delivery lateness which multiplies penalty cost due to late delivery K with an expectancy term. This time the expectancy term considers all deliveries which are after the delivery window to infinite where the limit for in-time delivery is c_2 = end of the on-time delivery window.

$$K\left[\sqrt{v}\phi\left(\frac{c_2-\mu}{\sqrt{v}}\right)-(c_2-\mu)\left(1-\Phi\left(\frac{c_2-\mu}{\sqrt{v}}\right)\right)\right]$$

When these two components are combined, the formula for calculating the expected cost for untimely delivery at a certain delivery variance can be written as following:

$$Y(v) = QH\left[\sqrt{v}\phi\left(\frac{c_1-\mu}{\sqrt{v}}\right) + (c_1-\mu)\Phi\left(\frac{c_1-\mu}{\sqrt{v}}\right)\right] + K\left[\sqrt{v}\phi\left(\frac{c_2-\mu}{\sqrt{v}}\right) - (c_2-\mu)\left(1-\Phi\left(\frac{c_2-\mu}{\sqrt{v}}\right)\right)\right] \quad (1)$$

Equation 1: The formula for the expected cost for untimely delivery at a certain delivery variance (Guiffrida & Jaber, 2008)

On the other hand, the formula for continuous improvement or the investment cost follows exponential curve since every new improvement is more difficult to achieve when the optimal zero is approached. The function for investment cost required for delivery variance reduction is as following:

$$C(v) = \frac{\lambda}{\ln\left(\frac{1}{1}-h\right)}\left[\ln(v_0) - \ln(v)\right] \quad (2)$$

Equation 2: The formula for investment cost in delivery variance reduction (Guiffrida & Jaber, 2008)

Where each reduction in delivery variance h (percentage) requires an investment cost λ. The original delivery variance is v_0 and the desired delivery variance is v.

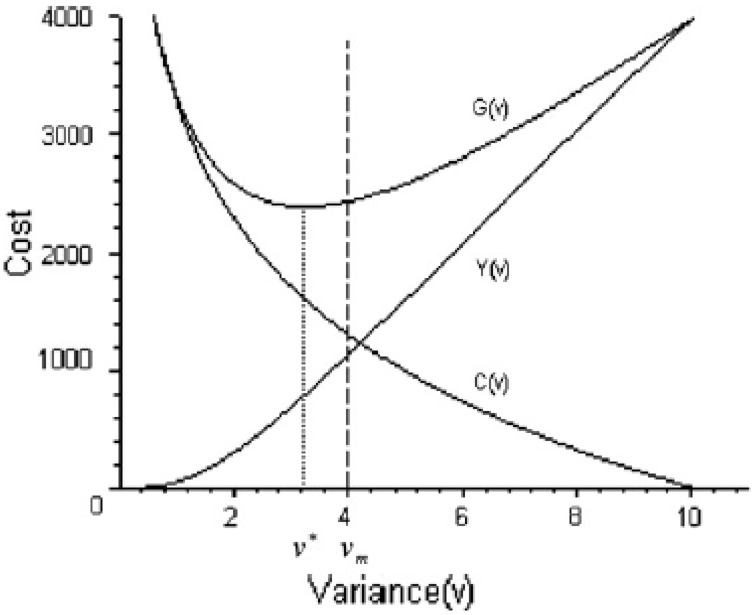

Figure 10: Optimal delivery variance model (Guiffrida & Jaber, 2008)

In further studies, based on the Guiffrida and Jaber (2008) model, Bhattacharyya and Guiffrida (2015) propose an optimization framework model for supplier delivery performance. This framework takes into account four new aspects when compared to the Guiffrida and Jaber (2008) model. First, the framework considers the time value of money by realizing the true present worth of penalty costs to a buyer due to future untimely deliveries from a supplier. Second, the benefit is shown to supplier delivery performance when the penalty cost of untimely deliveries are reduced. Third, the model incorporates continuous improvement in delivery performance from an integrated buyer-supplier perspective. The continuous improvement of the buyer is considered to be an opportunity cost of failing to improve delivery performance when costs due to untimely delivery are incurred. Finally, guided by a budget constraint, the investment for spending on continuous improvement is optimized as a means to assess supplier's ability in meeting an optimum improvement rate and the optimal point in time is determined where delivery improvement should start by minimizing overall cost to the buyer while maximizing supplier delivery performance.

Ideally, the penalty cost due to untimely delivery decreases after each supplier delivery because of continuous improvement and learning in the delivery improvement. In this case, the decreasing penalty cost trend leads to more competitive supply chain. This phenomenon is defined as improvement at the supplier's end (Bhattacharyya & Guiffrida, 2015). Yet, in reality the improvement is not ideal and the penalty cost is not necessarily decreasing due to supplier learning. In this case, the buyer may invest in the process development to improve supplier delivery performance. The penalty cost reduction is dependent on supplier's ability in improvement which is called supplier improvement rate. However, if the buyer fails to invest in supplier delivery performance by delaying continuous improvement the consequences can be critical. Bhattacharyya and Guiffrida (2015) call this "buyer neglect" which is defined as the opportunity cost of buyer's failure to introduce improvement in supplier delivery performance in proper time. In Figure 11 it is illustrated what is the implication of delayed improvement in penalty costs due to untimely delivery.

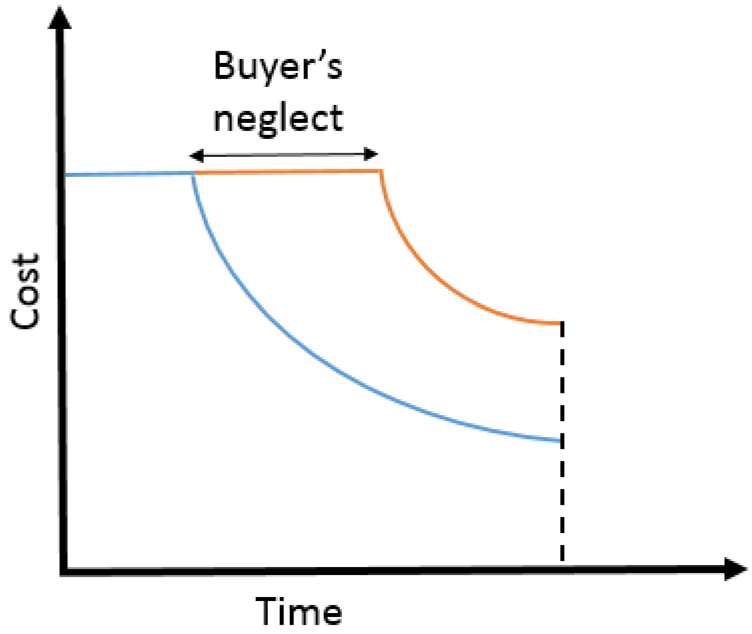

Figure 11: Buyer's neglect in investing into supplier development

Thus the investment in improvement comes at a cost to the buyer which is an important feature to understand in order to optimize supplier delivery performance. In this framework, the investment cost is allocated for each delivery which means that longer the buyer neglects to invest longer the price for investment remains zero. Thereby, the optimal spending in supplier delivery performance in terms of minimized total cost is determined by the impact of opportunity cost of delaying improvement in penalty cost and price of investment in continuous improvement. The supplier improvement rate is a key variable when determining the optimal total costs and delivery performance. Furthermore, the budget constraints may guide buyer spending for supplier improvement depending on what are the company goals in supplier delivery performance. For instance, if a supplier has already acceptable delivery performance the spending may be guided to suppliers which still have insufficient delivery performance.

The presented framework provides an analytical approach when making decision in supplier selection and developing suppliers. For instance if the supplier delivery performance is not improving despite the investment the results of the optimization framework may suggest to change to other supplier while on the other hand, the buyer might be better off with neglecting the continuous improvement actions if supplier's delivery performance is improving without the investment. As a conclusion, this framework can be used as a basis for future development programs and historical performance analysis of suppliers based on the collected data.

Even though this optimization framework is would provide more advanced means to analyse supplier delivery performance and its development in terms of costs, it is nevertheless excluded from the empirical part of this study. First reason for this is that the case company has not conducted OTD improvement yet and therefore the cost of improvement cannot be accurately determined. In addition to this, the case company has not directly determined funds or a budget for supplier development.

4 Case company presentation

This chapter provides an introduction to the case company, ABB Marine, which is a part of ABB Group and a manufacturer of advanced propulsion systems and electrical systems serving the global shipbuilding industry. From the business unit perspective, ABB Marine has six business hubs and numerous smaller locations with service operations. The six business hubs are Helsinki (Finland), Houston (United States), Oslo (Norway), Shanghai (China), Singapore, Västerås (Sweden). Even though ABB Marine is a global actor in maritime business, this thesis focuses purely on the factory in Shanghai, China, which produces Azipod® thrusters. The product name Azipod® relates to azimuth principle of 360 degrees turning rudder propulsion devices. The Shanghai plant is responsible for producing smaller C (in Figure 12) and D (in Figure 13) propulsion units of the Azipod® product family. Large Azipod® V and X are produced in Helsinki, Finland. From the sales perspective, the propulsion systems represent only a part of maritime business at ABB since the company delivers electrical systems to ships as well. ABB Marine has globally 1500 employees with a revenue of 1,5B$.

Figure 12: Azipod® C (Source: ABB Intra)

The Shanghai plant is a relatively new facility in ABB Marine and it has gone through a rapid production ramp-up during the past years. Due to market developments in Asia it became vital to establish an Azipod® factory closer to customer and therefore the production started in Shanghai in 2011. The plant covers following operations: production, supply chain management, project management, project engineering and a few supportive functions such as business controlling, quality management. The top management, sales, R&D and commissioning of Azipod® C and D thrusters are located either globally or in Helsinki, Finland. The Shanghai plant is purely an assembly plant which means that all components are purchased from the suppliers. ABB Marine uses mainly local suppliers with few exceptions that are sourced from Europe.

Figure 13: Azipod® D (Source: ABB Intra)

In order to understand the supply chain characteristics and supplier delivery performance practices of ABB Marine (later on ABB) in detail, a description of the order fulfillment process, key supply chain processes and current practices in managing the supplier delivery performance are provided in this chapter.

4.1 Order fulfillment process at ABB

The manufacturing of Azipod® propulsion systems is purely based on engineer-to-order where the production flow is fully project-driven and the engineering is based on customization of existing designs for each customer order. A well-known means to recognize all activities from the customer order to the delivery is the order fulfillment process (Roy et al., 2013). In Figure 14, it is presented the order fulfillment process at the project execution and control phase at ABB that represents the new building phase of the company. Before this phase the sales contract is made and the project is handed over from sales to the project team. The project execution and control is followed by project close-out in which the delivered project is handed to the warranty organization. In order to effectively manage and follow project progress ABB has implemented a milestone system by setting gates to key milestones in a project. The project gates are presented in Figure 14. However, in some exceptional cases the project is not executed according to the gate system to reduce the overall lead time. For instance some components which have long lead times are ordered before the engineering gate is accepted so that the purchasing step is more compressed and the delivery performance to the customer is increased.

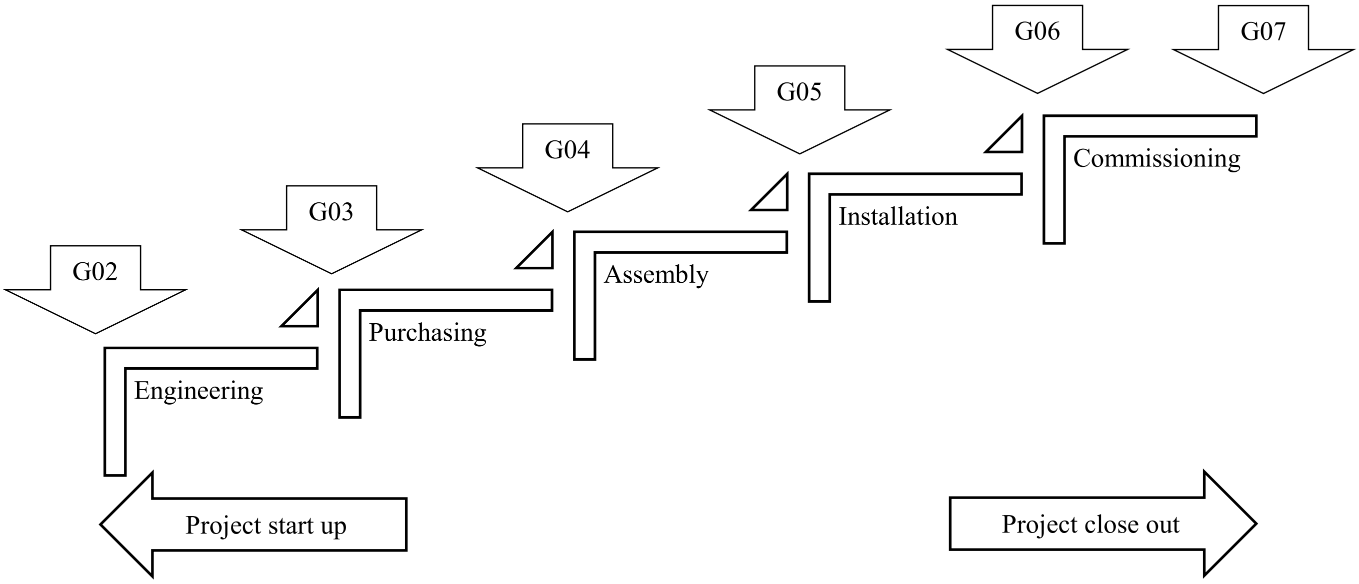

Figure 14: Order fulfilment process of Azipod® propulsion system with project milestones

In the context of this thesis, the two most important gates or interfaces between project phases are G03 (Engineering completed) and G04 (Purchasing completed). In G03, the engineering department has finished product design and the purchasing process can begin. If G03 is delayed or some designs are otherwise incomplete, it may have critical consequences further for the start of the production and overall delivery to the customer. This can be seen as a result of delays in the production even though the supplier OTD has been good in general. Therefore, it is important understand the impact of major differences between the required delivery date and confirmed delivery date. However, the delivery performance can also be measured by lead time which means that supplier should be able to reduce it and thereby, despite minor delays, deliver on time.

In practice, all gates have a certain buffer which are determined in order to minimize operational risk. As stated before this thesis aims to reduce currently needed buffer between purchasing and assembly by reducing the variance in suppliers' delivery performance. Therefore, G04 can be seen as even more important since the engineering processes are not included in this thesis. In G04, it is reviewed if all needed components have been delivered to the factory. The untimeliness of supplier deliveries in this gate depends not only on upstream project delays but also suppliers' delivery reliability.

4.2 The procurement process and material flow

This subchapter presents how procurement process and material flow from suppliers are arranged at ABB. When revisiting ABB's order fulfillment process and Figure 14, the scope in this subchapter it set on Purchasing –phase and milestone G04 in which the component procurement is carried out. The approach for analyzing ABB's procurement activities and inbound material flow is control model for all case suppliers in this thesis which frames all actors and steps from placed purchasing order to production phase at Shanghai plant. After presenting control models, it is taken deeper look at the delivery window at ABB.

For Supplier A, the control model is relatively complex since the engineering phase is outsourced to the supplier which complicates the order process. The purchasing order is placed in purchasing department at ABB when engineering department has released technical specifications. After the order is sent to the supplier their engineering department starts to design the component. Before releasing the design to procurement and production the supplier needs approval from ABB and third party classification agency. If the component design is successfully accepted the procurement and production may begin. When the component is finished and factory acceptance test (FAT) is approved again by third party classification agency, it is shipped to Shanghai plant where the shipment is received and inspected. If the components of the shipment are accepted in arrival inspection it is registered in ERP and placed into inventory. Finally, when the component is needed in the production it is moved to the assembly line. The control model for Supplier A is presented in Figure 15.

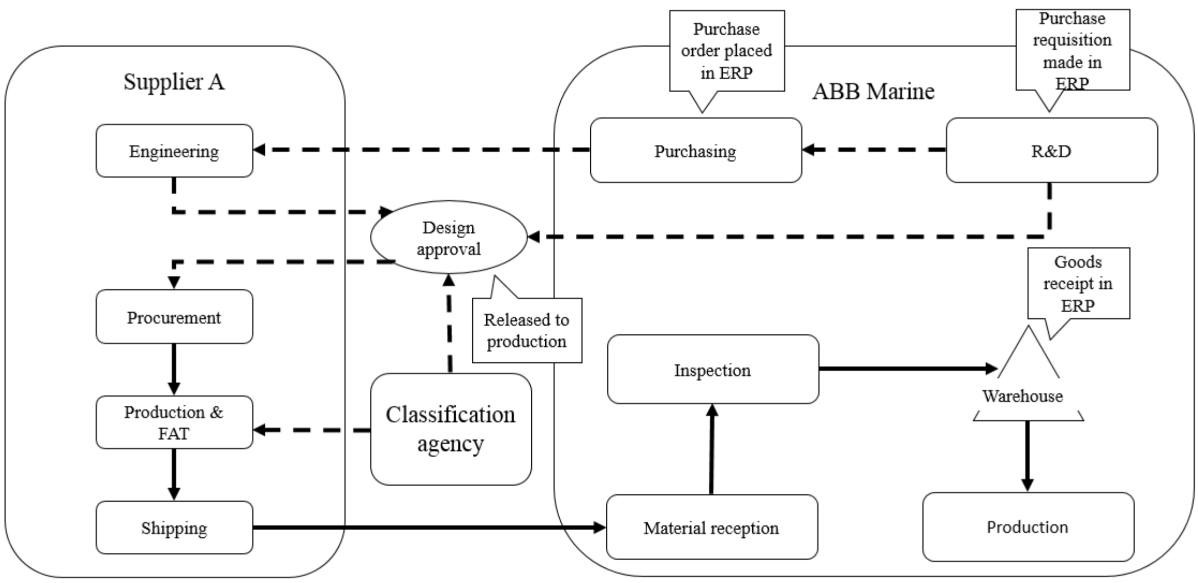

Figure 15: Control model for Supplier A

However, in more normal case, the control model is less complex which applies to rest of the case suppliers B, C and D. Yet, the beginning is the same where R&D releases the component design to procurement. This time the placed order is already engineered and specified which means that the supplier can directly forward the order to production phase starting with material procurement. If required, the components are classified and inspected in supplier's production before shipping to ABB. When the shipment is received at ABB, it is inspected, registered in ERP and placed in inventory. The component is then moved to the assembly line when needed. In Figure 16, it is presented control model for suppliers B, C and D.

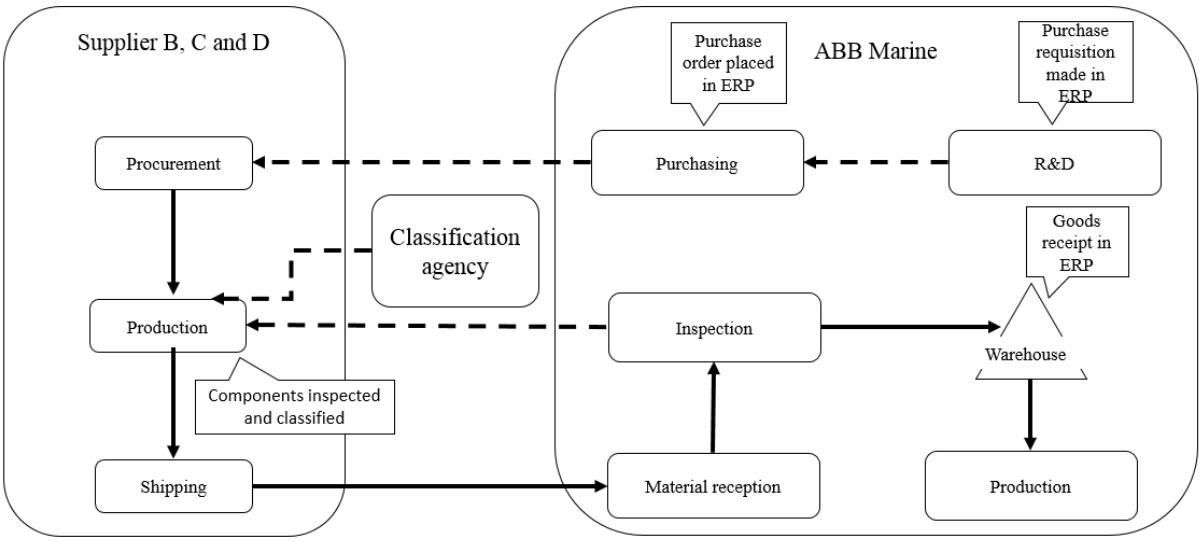

Figure 16: Control model for suppliers B, C and D

When purchaser places an order to supplier, a delivery date is requested. The supplier answers to the request by giving the promised delivery date which is ideally same as the request date. As default, ABB requests delivery dates, just-in-time, as close as possible to G04 milestone date. For internal calculating ABB has set earliest and latest acceptable dates which frame the on-time delivery window. The on-time window is set from 14 days early to 7 days late as presented in Figure 17. The buffer between G04 project milestone and production start is 14 days which means the deliveries inside the buffer period will not cause production stoppages.

However, in theory the absolute buffer between G04 and production requirment may be even longer because all components are not needed in the beginning of the production.

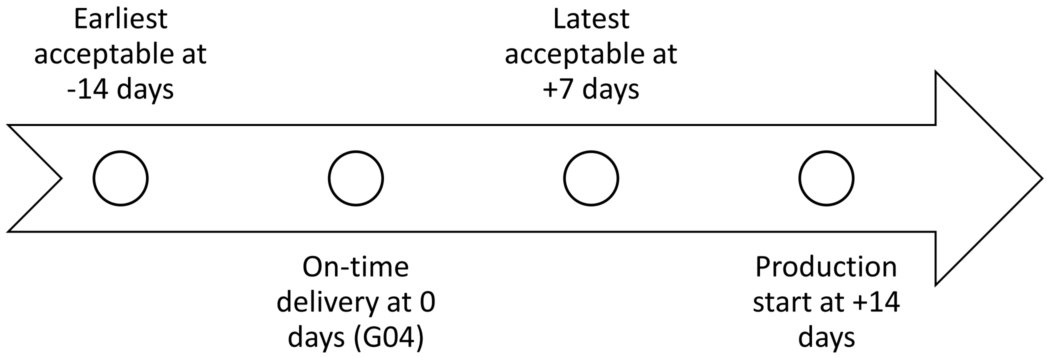

Figure 17: Supplier delivery window in Azipod® project

4.3 Delivery performance management practices

Currently ABB has one operational KPI concerning supplier delivery performance, supplier OTD percentage. The suppliers are also measured by their order acknowledgment response ratio, purchasing prices and quality issues but these do not measure directly the delivery performance. In addition to OTD percentage KPI, the supply chain department at ABB has implemented OTD value performance indicator which measures what is the value of components that are delivered outside the OTD window.

In addition to the indicators, ABB manages their suppliers' delivery performance by setting requirements on delivery window and consequences for poor performance. As explained earlier, the on-time delivery window in ABB's internal calculations is set from 14 days early to 7 days late. The on-time window is not directly communicated with suppliers as they are always asked to deliver by the on-time date. From this year onwards, in addition to late deliveries, ABB has started to focus on reducing early deliveries which generate unnecessary holding in inventory and increases their net working capital (NWC). For late deliveries ABB has a clause in their purchase agreement which entitles them to charge suppliers for penalties. The highest penalty fee percentage of contract value is 10%. However, ABB is not using clause of late delivery often as a favor for long term cooperation and if the suppliers have showed them a sufficient effort in delivering the order.

From the supplier development perspective, ABB has not implemented pure delivery reliability improvement projects in order to improve suppliers’ delivery performance. The only improvement initiatives that supply chain department at ABB has executed have concerned component quality. ABB has, however, invested in certain suppliers by for example purchasing machining tools and molds in order to improve supplier’s capabilities.

5 Analysis

In this chapter, it is analyzed delivery performance of four key suppliers for ABB in order to provide an example on how to calculate the costs associated with untimely delivery and demonstrate the advantage of identifying the cost aspect of the delivery performance. The suppliers are selected based on historical delivery performance and interviews conducted with supply chain management staff at ABB. The selection process of the suppliers was based on following criteria:

- Each supplier has underperformed the expectations and targets set by ABB during the past years
- Suppliers deliver different kind of components which have a significant impact on the operational performance of ABB
- Both European and Chinese suppliers are included

In general, this case study aims to cover different suppliers and thereby to include different causes and types of untimely deliveries. Furthermore, by including different suppliers the applicability of the mathematical delivery performance model which is used in this analysis may be tested more comprehensively. The delivery performance model to be introduced in this chapter is based on the model by Guiffrida and Jaber (2008) in Chapter 3.5.2.

The qualitative part of this analysis is based on several interviews. The interviews also provide a foundation for information on suppliers and supply chain processes at ABB. The interview questions are presented in Appendix A. Some of the information on supply chain processes is based on writer's own experience from the past five years in employment at ABB.

Supplier A is an European company producing slip ring units for ABB steering units in Azipod®. Their R&D and production of main components are in Europe while rest of the production process is completed in China. When ordering from Supplier A, ABB sends their technical requirements to the main office in Europe where they design the ordered product. The product requires approval from ABB and third party classification agency before it can be released to the production. The production starts in Europe by key component manufacturing which is followed by component shipped to China and assembly. After the product is finished it is delivered to ABB.

Supplier B manufactures struts for Azipod® propulsion units. The production process can be divided into two phases. Both phases are carried out at the same plant in separate facilities. When ABB issues an order to supplier B the strut is first is casted which is followed by machining. After the strut is machined to its final dimensions it is shipped to ABB. The components are partly made-to-stock in the casting phase and made-to-order in the machining phase.

Supplier C is responsible for machining several key components. In this case study, it is analyzed three components: machinery deck, propeller and thrust bearing shields. Supplier C ships components directly to ABB after the production. All components are classified as make-to-order.

S**upplier D** delivers numerous types of hydraulic systems components such as hoses, couplings and connectors. The supplier is based in Finland from where they ship all their components to ABB in China. The hoses are made-to-order while the rest of the components are standard and directly shipped from the stock.

The structure of this chapter is divided into five parts. First, the main causes for untimely delivery are identified. This is followed by the implications of untimely delivery in the order fulfillment process of ABB. The third part presents the calculations for cost associated with untimely delivery based on the models presented in the literature review and historical ERP data. The forth part, concentrates on the costs with continuous improvement and the delivery variance reduction which is considered as the turn side of the delivery performance improvement. Finally, in the part five, it is conducted root cause analysis for the main causes of untimely delivery in the terms of delivery variance reduction initiations and supplier development types identified in the literature review.

5.1 Causes for delivery variance at ABB

This subchapter presents the main causes for untimely deliveries of the case suppliers. Each supplier is analyzed individually in order to identify the supplier specific challenges concerning the delivery performance. The findings in this subchapter are based on the interviews conducted with the supply chain management staff at ABB.

Supplier A

In the case of supplier, the supply chain is highly complex since the manufacturing is taken place in two continents and including many parties. Moreover, the slip ring unit the supplier is producing is considered as complex. According to the supply chain manager of ABB, the main cause for untimely delivery of Supplier A is at the design phase of the order fulfillment process since the designs must be approved by both ABB and third party classification agency. In other words the cooperation between the research and development (R&D) department of ABB in Finland and supplier's R&D has been the main bottleneck in delivering components on time. The issues of delayed manufacturing has led to significant delays in delivering the component to ABB. It can be stated that the engineering of the slip ring unit increases uncertainty in product specifications and as well in the production which has affected to variance in the lead time. In addition to this, the supplier has also proven to have some minor challenges in their production planning and control because of missing components during their production process. More detailed study on supplier A untimeliness is executed in Chapter 5.4 in which a pilot supplier development project on delivery reduction is presented.

Supplier B

Supplier B is a good example of a supplier which has improved the delivery performance lately. After they started to control their production by having a necessary safety stock in between the casting phase and machining their delivery performance increased remarkably. Supplier B has experienced major challenges in quality control of the castings by having a large percentage of defective castings which has implicated to delays in the deliveries. Furthermore, ABB has identified that Supplier B has had challenges in the coordination between their castings and machining facilities.

Supplier C

Supplier C is relatively new supplier for ABB and therefore they have experienced challenges in meeting the ABB requirements. In other words, the lack of cumulative learning and process standardization can be considered as the main cause for untimely delivery. However, they have lately shown a good progress in improving their delivery reliability. According to the interviews ABB has requested deliveries from Supplier C earlier than from more experienced suppliers in order to reduce supply risk. Unlike other suppliers in this case, this has led to fact that Supplier C has delivered higher proportion of early deliveries.

Supplier D

The main causes of untimely delivery for Supplier D are long lead times and lack of flexibility in order fulfillment process in combination with the fact that they deliver components from Finland to China. This issue can especially be seen as poor responsiveness to rush orders. ABB has experienced that Supplier C has challenges in their internal planning and coordination and response rate to purchasing orders. In order to reduce supply risk ABB has placed orders to Supplier C with longer buffers.

5.2 Implications of poor supplier delivery performance

The implications of insufficient supplier delivery performance at ABB corresponds often to delays in production. Since the production planning at ABB is scheduled based on the available production slots and promised delivery dates to the customer, earliness in incoming material flow does not lead to any benefits but on the contrary it has disadvantages due to increased inventory levels and capital employed in projects which are harmful for efficient production.

Delayed deliveries from supplier may have an exceeding impact on project lead time roots from production stoppages and re-planning which mean waiting time and/or extra work which often is done in the form of overtime work by extending work days or working on weekends. Additional work leads to increased costs in project execution which makes projects less profitable. Moreover, larger the lead time deviation from the planned lead time, higher the variability in supplier order fulfillment process which emphasizes the importance of controlling the variability. Suppliers' order fulfillment process variability in case of ABB is relatively high and therefore is controlled by internal buffers which are as well sources of additional indirect cost.

As stated above the earliness perspective of poor supplier delivery reliability consist of excess inventory and employed capital in projects. However, the cost impact of supplier delivery earliness is relatively small at ABB because of the low production volume which is typical for ETO companies and project-based purchasing. From financial standpoint, it is nevertheless noticeable that valuable A-class components have somewhat impact on the costs because of their high purchasing value and thereby interest on capital employed in a project. Another challenge associated with early deliveries is the capacity of the warehouse which is relatively limited. Especially, components that require lot of room are a challenges if they are delivered too early. In connection to limited warehouse capacity is limited amount of assembly cells. If a project is postponed under the production phase due to a missing component and therefore replaced by next project in order to avoid total production stoppage, the same storing problem is evident.

The worst case scenario of poor supplier delivery performance is delayed delivery to the customer and possible penalty fees due to delayed delivery. Delayed delivery to the customer has huge impact on customer satisfaction at a market where the number of customers is low and the risks associated with losing a customer are significant. Penalty fees are as well relatively high in ABB's business which may turn so far profitable projects to unprofitable.

5.3 Cost of untimely delivery

This subchapter presents current delivery performances of the four case suppliers. The approach to identify the delivery performance is by aiming to identify the costs which are associated with untimely delivery and how the delivery variance implicates these costs. I.e. each untimely delivery from a supplier implies to additional costs at the buyer and by reducing the delivery variance the expected cost of untimeliness will be reduced as well. The probability and the magnitude of untimeliness is purely statistical and based on historical performance.

There are several sources for the untimeliness cost may occur. These costs may be direct such as excess inventory holding cost for early delivery or production disturbance cost if the delivery is late or indirect costs which result due to planned buffers by the buyer. However, in association with early deliveries, the holding cost is not the only dimension since companies also have to struggle with their operational net working capital and the cash flows involved in everyday business. The cost of capital should be noticed when determining the cost for early deliveries. Therefore, this case study identifies cost of capital and inventory holding as the cost types of early delivery.

In late deliveries the number of different cost sources can be even higher due to the possibility of complex accounting in production costs at the buyer's end. This case study approaches the costs due to late delivery by the fact that waiting results to overtime. The statement "waiting time is overtime" can be considered as an assumption since the real nature of ABB production is highly complex and project-based which means that many uncounted occurrences in the production are unique. However, certain assumptions must be made to be able to model the behavior and implications of untimely deliveries. In case, the internal buffer of ABB covers the damage of late delivery the cost is not overtime, but the cost of buffer. The costs are presented later when explaining the delivery performances of the four case suppliers.

The analysis of the delivery performances starts by illustrating delivery performance histograms with probability density functions of delivery timeliness. The data behind the delivery performance histograms is acquired from the case company ERP data. In order to support the histogram, a set of key values is calculated based on the data. These values are mean, standard deviation and variance which is derived from the standard deviation. Mean value represents the point on the normal distribution curve which is most likely to happen. The Standard deviation, on the other hand, quantifies the variation or dispersion of the data set values by covering 68% of all data set occurrences. Table 5 shows an overview of the case suppliers' delivery performance. All values in this thesis that are in currencies and dates are on normalized with a certain multiplier in order to respect the confidentiality agreement between the author and ABB and yet to be able to show the relations between different suppliers.

Table 5: Overview of case suppliers' delivery performance

Value	Supplier A	Supplier B	Supplier C	Supplier D
Mean	+0,14	+0,97	-0,70	-0,43
ST.DEV.	0,291	0,295	0,152	0,951
Variance	0,847	0,872	0,230	0,904
Observation period	3 years	2 years	1 year	1 year

From the statistical error perspective, it is important to understand that all goods receipt dates in ERP system may not be absolutely correct. This due to the fact that the inventory at the Shanghai plant is not open during weekends and public holidays. Thus, the impact of holidays and weekends must be included when observing possible errors in the calculations. The used value for late receipt of goods due to holidays or weekends is normalized according to the delivery data. However, if the production is clearly behind the planned schedule and there is a possibility that an Azipod® delivery might be delayed to the customer overtime work is extended to weekends. Overtime work during the weekends result to higher labor costs which increase the expected costs of supplier delivery. It is estimated that overtime weekends represent approximately 20% of all overtime work at the Shanghai plant. In the Table 6, it is presented an overview of error margins.

Table 6: Identified errors when calculating expected costs due to untimely delivery

Error type	Margin	Description
Late receipt of goods due to holidays and weekends	0,03	Possible, if there are processing queues in inventory and inspection at the plant.
Early receipt of goods due to holiday and weekends	(0)	Not possible, because goods cannot be received before they have actually arrived.
Share of overtime work during weekends	20% of all overtime	Estimation, if extended workdays are not enough for catching up the production schedule

After the statistical delivery performance in the histogram is established, the expected costs can be calculated by supplier. In calculating these costs in total four cost types are accounted depending on if the delivery was early or late. The cost types are:

- Inventory holding cost
- Cost of capital (9%/year interest rate on the purchase price when the component is in stock)
- Cost of excess capacity in workforce ($/time period, at normal workload)
- Production stoppage cost ($/time period, when overtime must be done in order to catch up the schedule)

As showed in Figure 17 the on-time delivery window of ABB is from 0 days to 7 days late. After the 7th day late, the lateness starts to generate costs. In the sense of actual material requirements, it is noticeable that the components are not necessarily needed in milestone G04 at 0 days. First of all, the production plan or so called slot chart of ABB allows 14 days lateness from the G04. The period between 0 days and 14 days late is a buffer which is applicable for all projects. In addition to this, the assembly order, after the production starts, allows some extra lateness when the actual need at the assembly line is compared to the production start date. Length of the buffer depends on the component and the requirement in the production. This buffer is naturally considered in cost of untimeliness calculations when determining the impact of production stoppages. The delivery distribution with different types of untimeliness is shown in Figure 18 in which c1 = start of on-time delivery window, c2 = end of on-time delivery window and c3 = start of the production stoppage.

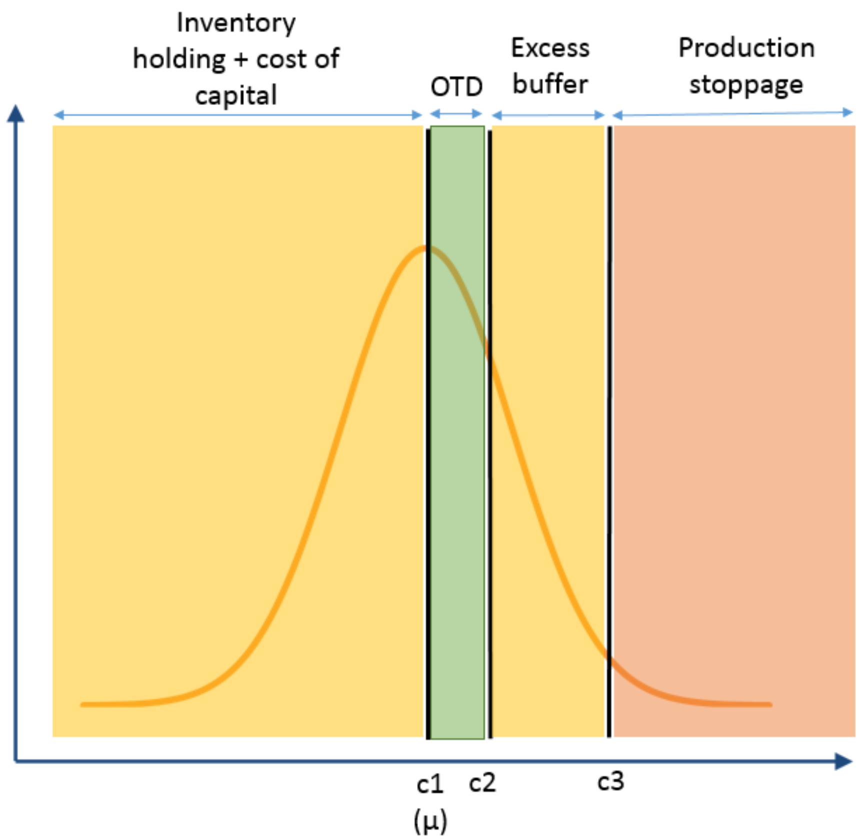

Figure 18: Different areas of the delivery distribution

From the earliness perspective, the inventory holding cost is relatively obvious as it is always identified in modern management philosophies such as JIT. It is calculated based on component's need of space in the stock and the time period the component was stored in the inventory. The second type of earliness costs is cost of capital, which is based on the time value of money thinking. Since the supplier can issue an invoice after they have delivered the component and at the delivery moment the component moves to ABB's books, early deliveries are not desired. Therefore, in this thesis, all deliveries which occur before on-time delivery window are assigned with the inventory holding cost and the cost of capital.

In order to sum up the costs of untimeliness, Equation 1 from Chapter 3.5.2 is used to calculate the total expected cost due to untimely delivery. When revisiting Equation 1 it can be noticed that cost of lateness K and cost of earliness or inventory holding cost QH are required. Since, this thesis includes the cost of capital aspect and the cost of excess capacity, these cost of must be redefined.

First of all, ABB purchases components according to project-based need and suppliers A, B, C produce A-class components which are order in quantity of one, the Q can be assumed as 1. In case of Supplier D it is calculated the average order size and purchase price and its space requirement which are then used as constant and Q remains 1. The inventory holding cost is calculated by component specific square meters in inventory per day. The holding cost is then summed with the cost of capital C which is calculated based on the purchase price of the component or in case of Supplier D the purchase price of an average purchasing order. As explained earlier, the cost of lateness K is divided into two categories: cost of excess capacity or capacity buffer E and cost of production stoppage or overtime cost S. The cost E is assigned to late deliveries in between 7 days late and the actual need of component in the production. After the actual requirement date in the production the cost E disappears and is replaced by cost S which represents the amount of hours to be caught up with overtime work in order to stay in original production plan. In the case of production stoppage the cost E turns around to negative cost since the excess capacity is first exploited before the overtime is needed.

An overview of costs is presented in Table 7. The costs presented in this thesis are not based on actual costs at ABB but imaginary cost determined by the author in order to show the relations between suppliers' performances. Numerical solutions for calculating costs due to untimely delivery at the current delivery performance level of all four case suppliers are presented in Appendix B.

Table 7: Cost types and their descriptions

Cost type	Cost amount	Description
Inventory holding (QH)	0,5\$/m^2 per time period	Daily rent for holding inventory.
Cost of capital (C)	9%*component purchase price	Annual interest due to cost of capital which is based on the component purchase price.
Excess capacity (E)	150 \$/assembly cell per time period	10% excess capacity is calculated on normal workload. Assembly in normal workload is executed in 2 worker teams per assembly phase.
Production stoppage (S)	2250\$/assembly cell per time period (or during the weekends 3000\$/assembly cell per time period)	Overtime working hours cost 150% of the normal man hour cost (overtime during weekend is 200% of normal man hour cost). Calculated in 2 worker assembly teams

Supplier A

In the case of Supplier A, it is clearly noticeable in Figure 19 that they have very high delivery variance and struggled with timeliness of deliveries during the past three years. They have delivered both exceedingly early and late. The mean of Supplier A deliveries is skewed 0,14 late from the zero which indicates that an average delivery arrives clearly late. The values of mean, standard deviation and variance are presented in Table 5. The reason why the observation period is set to three years is that the ordering interval and ordering volume from Supplier D is relatively low.

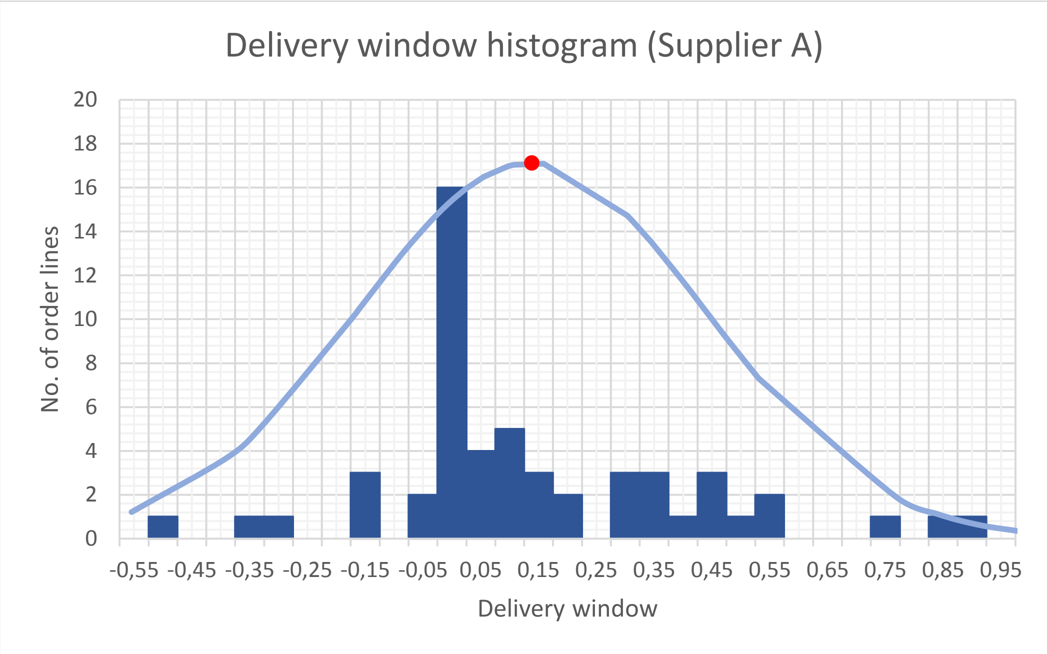

Figure 19: Supplier A delivery window histogram (past 3 fiscal years included)

From the cost perspective Supplier A has evidently highest expected cost per order. As shown in Table 8 at current delivery variance the excepted cost of untimeliness per delivery is 136$, where the largest share of total expected costs comes from production stoppage cost due to significantly positive mean value and high variance. The extended cost graph with different delivery variances is presented in Figure 20 in which the red point indicates the current cost level.

Table 8: Total expected cost due to untimely delivery at current delivery variance for Supplier A

Supplier A	Cost type	Excepted cost at current variance
	Cost of early delivery (QH+C)	1$
	Excess capacity (E)	8$
	Production stoppage (S)	120$
	Total cost	**136$**
	Average purchase price	*50 000$*

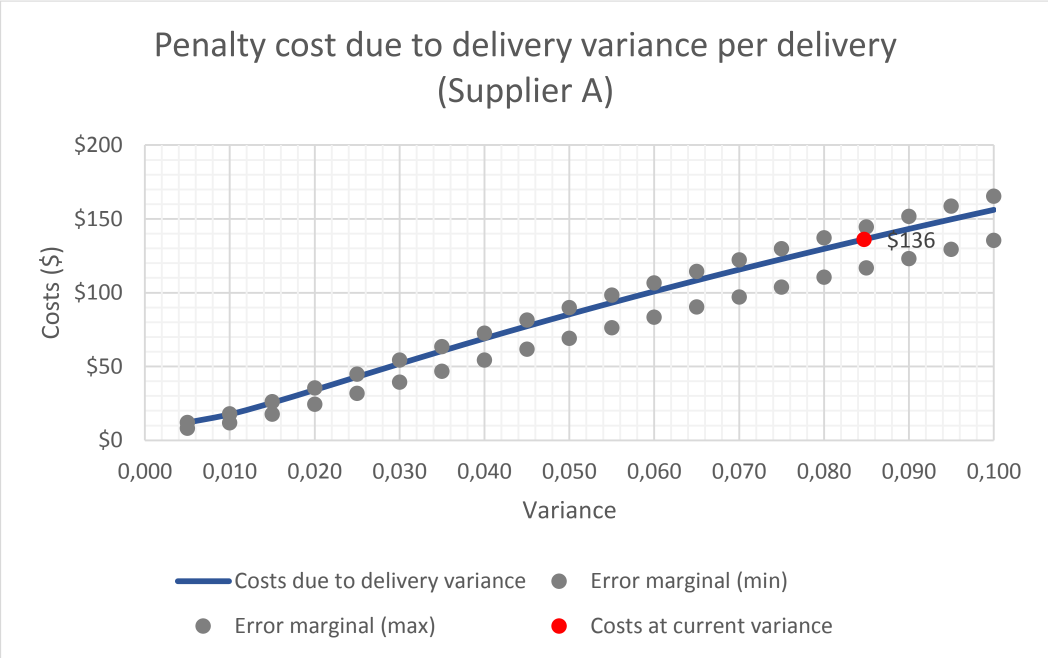

Figure 20: Expected total cost due to untimely delivery for Supplier A

Supplier B

Like Supplier A, Supplier B has also very high delivery variance. However, the mean value of Supplier B deliveries is closer to zero or G04 date at 0,97 days late as shown in Figure 21 which means that an average delivery arrives to the Shanghai plant approximately 10 days late. Therefore, the expected cost for Supplier B due to untimely delivery is lower than for Supplier A. When ordering from Supplier B the expected cost at current variance is 111$, where the largest share is generated from possible production stoppages due to high variance. The observation period of Supplier B is chosen to be two years in order to have more stable and reliable statistics.

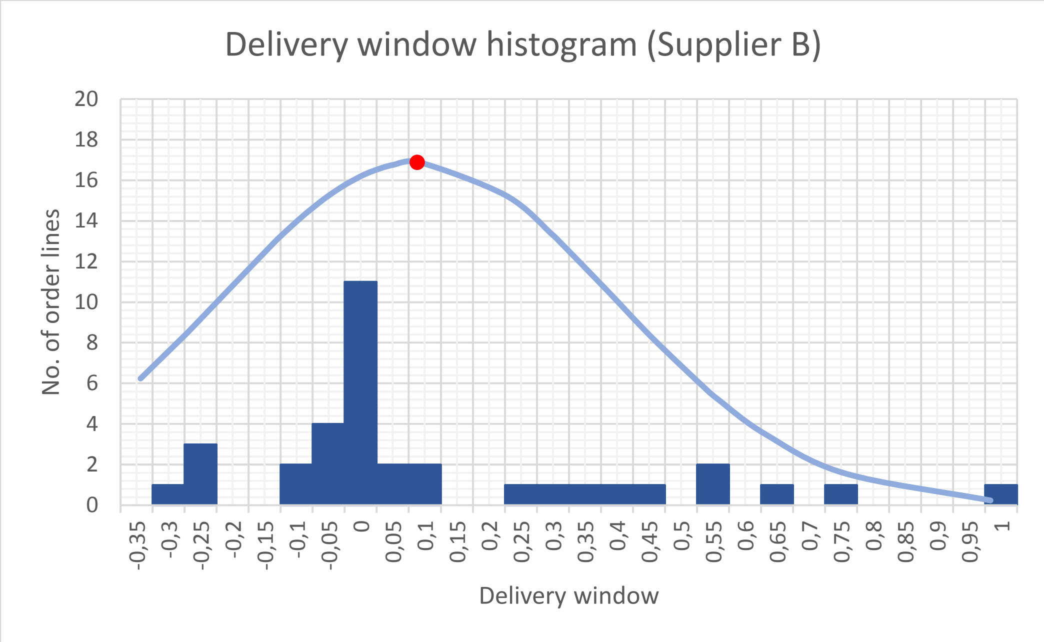

Figure 21: Supplier B delivery window histogram (past 2 fiscal years included)

The expected cost of untimely delivery (per delivery) is presented in Table 9 at current variance. The extended cost curve for Supplier B is presented in Figure 22, in which the red point indicates the current cost level.

Table 9: Total expected cost due to untimely delivery at current delivery variance for Supplier B

Supplier B	Cost type	Excepted cost at current variance
	Cost of early delivery (QH+C)	1$
	Excess capacity (E)	13$
	Production stoppage (S)	97$
	Total cost	**111$**
	Average purchase price	*20 000$*

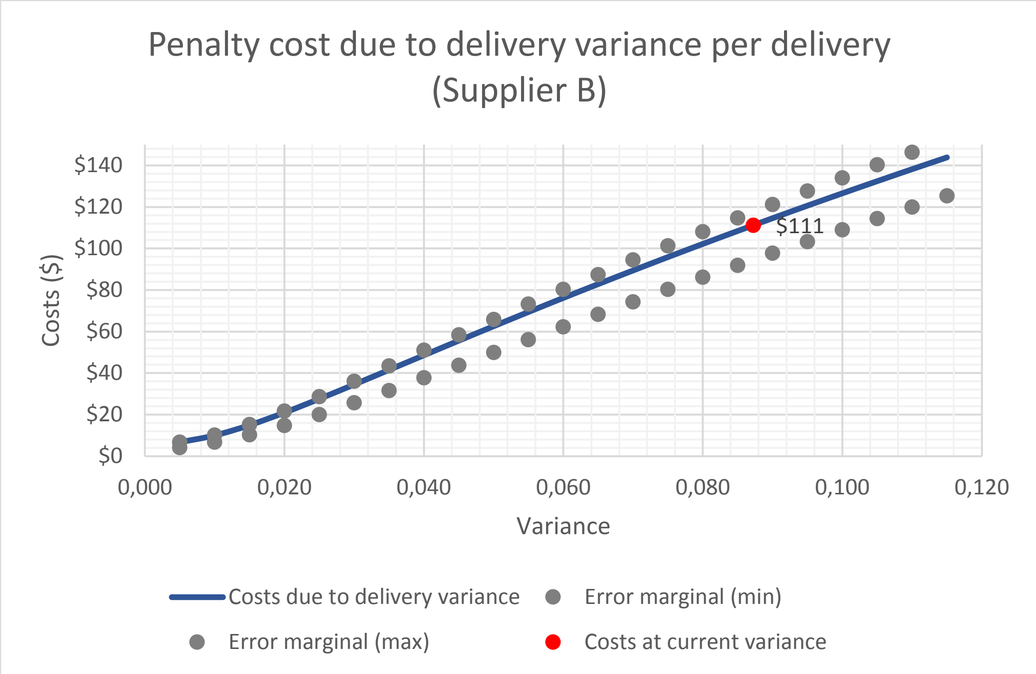

Figure 22: Expected total cost due to untimely delivery for Supplier B

Supplier C

In case of supplier C, the situation is largely different when comparing to Supplier A and B. The delivery variance is significantly lower and consequently the total expected cost is reduced. In addition to reduced variance the mean value of Supplier C deliveries is 0,70 early as shown in Table 5. This means that an average delivered component is stored to ABB's inventory approximately one week before the on-time window. Furthermore, when analyzing Figure 23, it can be clearly seen that Supplier C does not have as clear peak at G04 date in their delivery distribution as Supplier A and B. This phenomenon may be a result of ABB's acceptance of early deliveries when ordering from Supplier C.

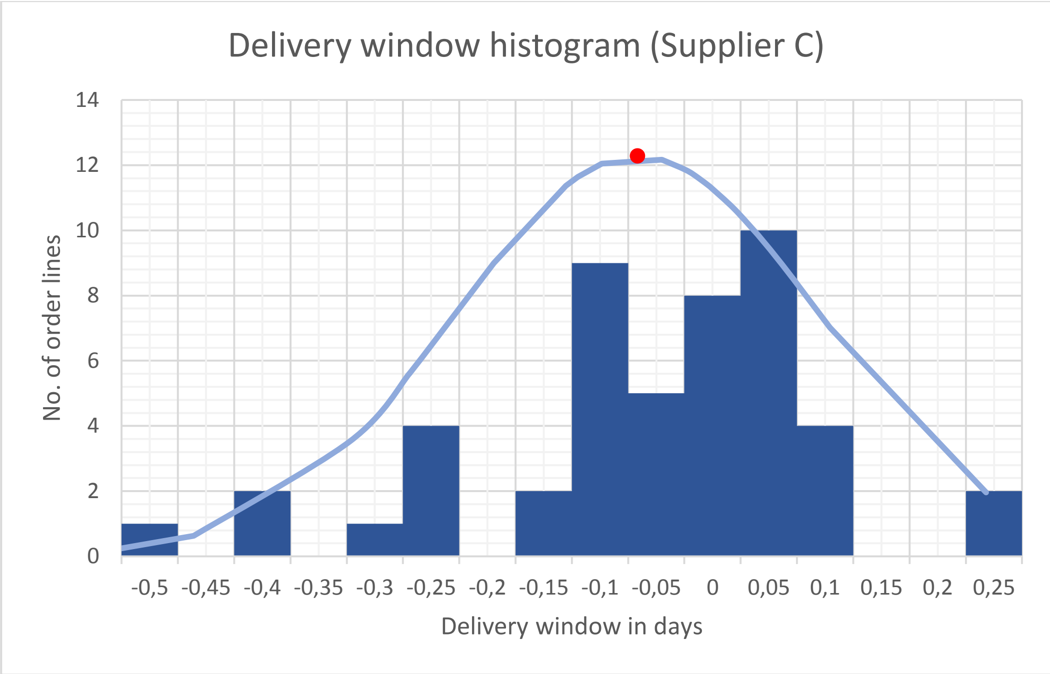

Figure 23: Supplier C delivery window histogram (past 1 fiscal years included)

At the current delivery variance, the expected total cost for Supplier C is 3,24$ where the largest share comes from excess capacity (Table 10 and Figure 24). The reason for this is that the component purchase price is relatively low which reduces the impact of the cost of capital and the delivery variance is adequately low for avoiding the probability of production stoppage. Furthermore, it is notable that the error marginal is higher than in cost calculations for Supplier A and B. This is due to the fact that the delivery variance in relation to error in mean shift is small and the 3 days error has increased impact on the costs (43,1%).

Table 10: Total expected cost due to untimely delivery at current delivery variance for Supplier C

Supplier C	Cost type	Excepted cost at current variance
	Cost of early delivery (QH+C)	0,30$
	Excess capacity (E)	2,12$
	Production stoppage (S)	0,81$
	Total cost	**3,24 $**
	Average purchase price	*4 000$*

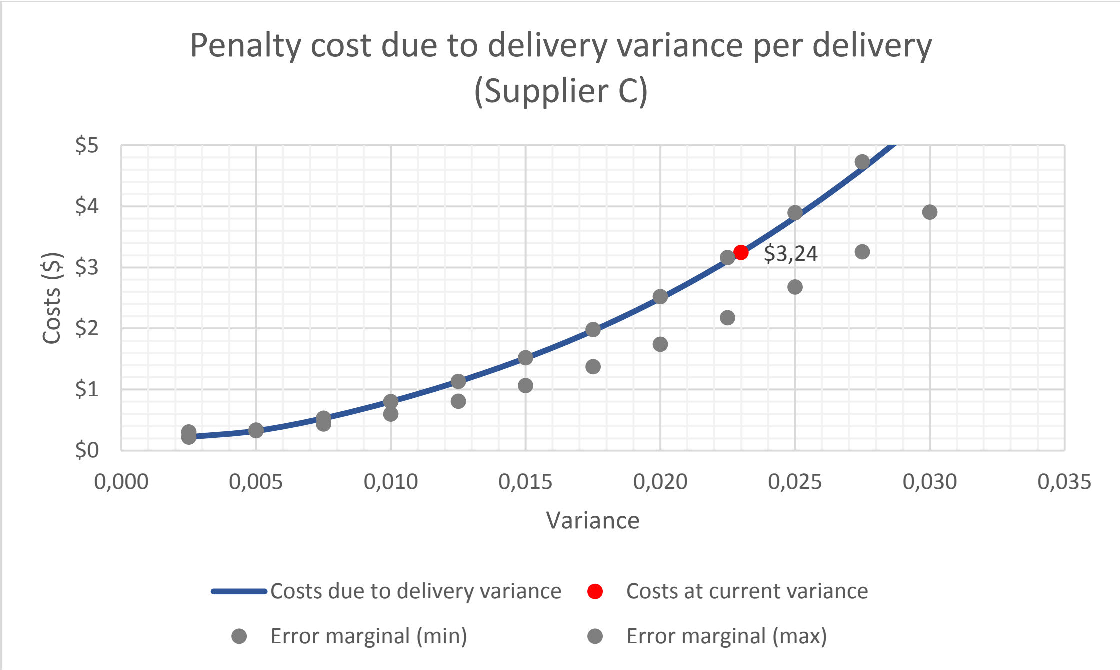

Figure 24: Expected total cost due to untimely delivery for Supplier C

Supplier D

Supplier D has clearly the best delivery performance of all four case suppliers in terms of delivery variance. Like Supplier C, the mean value of Supplier D delivery is almost 0,05 (Figure 25) early which increases inventory holding time when comparing to Supplier A and B. Furthermore, Supplier D has clearer one-peaked delivery distribution. The delivery variance during the year 2016 was 0,009 which approximately ten times less than the variance for Supplier A or B.

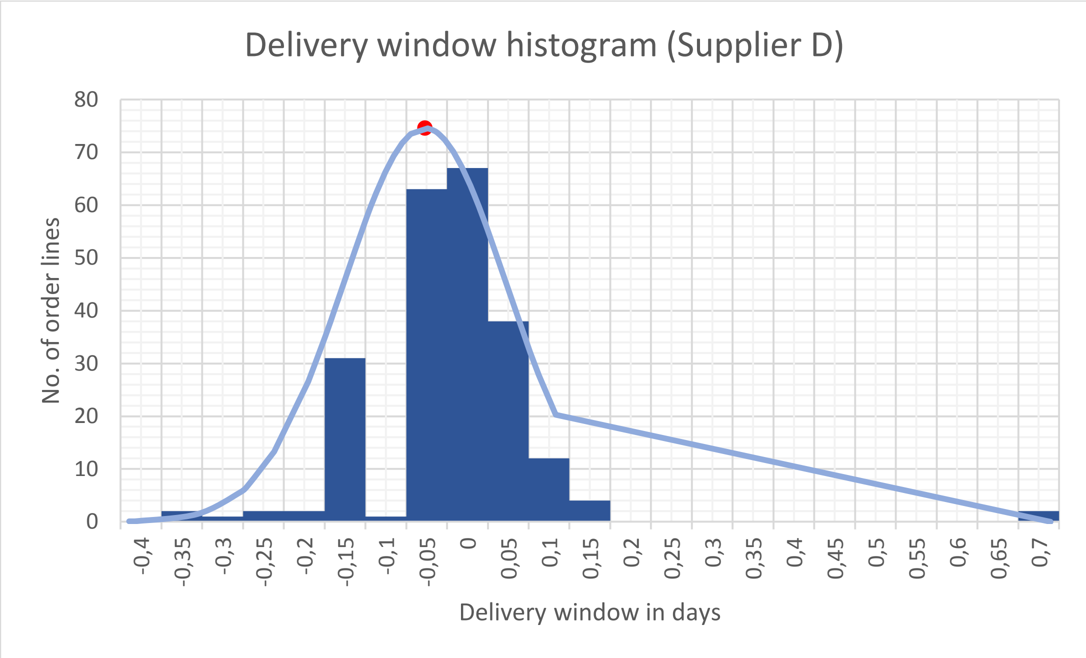

Figure 25: Supplier D delivery window histogram (past 1 fiscal years included)

From the cost standpoint, the largest share of expected costs comes from ABB's excess capacity which is not directly caused by supplier. The excess capacity or buffer, however, is necessary for ABB in order to overcome delivery problems caused by other suppliers, such as Supplier A and B. The expected cost at current delivery variance is 1,18$ which over hundred times less than Supplier A's or B's expected costs (Table 11 and Figure 26). Like Supplier C, Supplier D has also relatively high error margin because of the same mean shift.

Table 11: Total expected cost due to untimely delivery at current delivery variance for Supplier D

Supplier D	Cost type	Excepted cost at current variance
	Cost of early delivery (QH+C)	0,13$
	Excess capacity (E)	0,79$
	Production stoppage (S)	0,25$
	Total cost	**1,18$**
	Average purchase price	200 $

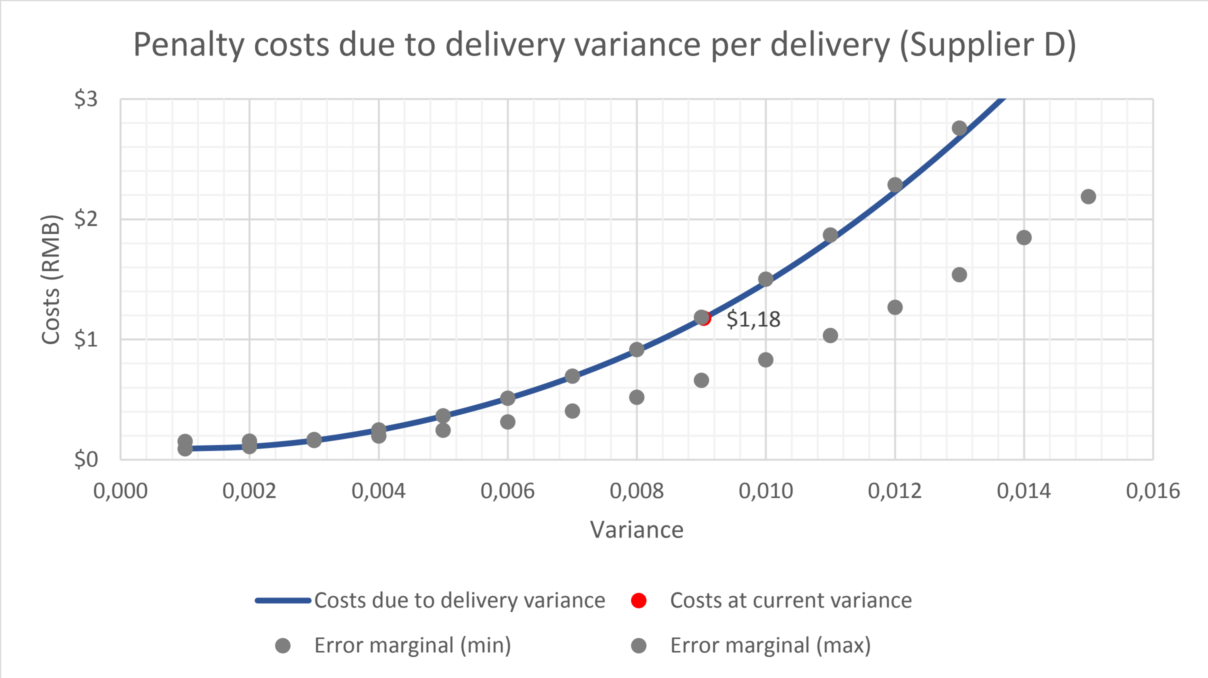

Figure 26: Expected total cost due to untimely delivery for Supplier D

5.4 Case study: Supplier delivery performance improvement project

This chapter provides an analysis on the current challenges in the delivery reliability of Supplier A and how these challenges could be overcome. The main reason for choosing Supplier A as the case supplier is that they have the worst performance of the four case suppliers according to the cost of untimeliness calculations and the delivery window histogram. As discussed in the literature review, supplier development initiatives play an important role in improving supplier's capabilities and the supply chain excellence. Therefore, this chapter approaches delivery performance improvement by conducting a supplier development project on Supplier A.

The project in question is ABB's quality management tool called 4Q project which divides the improvement process in four parts or "Qs". The four Qs are: measure, analyze, improve and sustain which are carried out in cycles from Q1 to Q4. The 4Q project is known and used quality tool in ABB's organization and was therefore selected for this analysis.

The first Q was conducted alone by the thesis author in which the delivery performance measurements were presented and the necessary project introductions made together with project targets. The measurements used in the Q1 were the histogram in Figure 19 and the expected cost due to delivery untimeliness in Figure 20 which illustrate the current situation.

After the measurements, the project was given a deadline or scope and targets that should be reached by the deadline which was set to one year from the project start. Following targets were determined:

1. The mean delivery to be from 0 to 0,05 late in the delivery distribution
2. The delivery variance to be reduced by 20%

The Q2 was conducted in a workshop together with the thesis author and representatives from both ABB and the supplier. The focus of this workshop was first to identify all possible causes for delays that have occurred during the past years. After listing the causes, a root cause analysis with Fishbone method was made in order to find the ultimate reasons for supplier delivery untimeliness. Finally, the causes of delays were set in a matrix in which the untimeliness impact and likelihood were determined. Figure 27 and Figure 28 present impact vs. likelihood matrix and Fishbone-model based on the findings in the workshop.

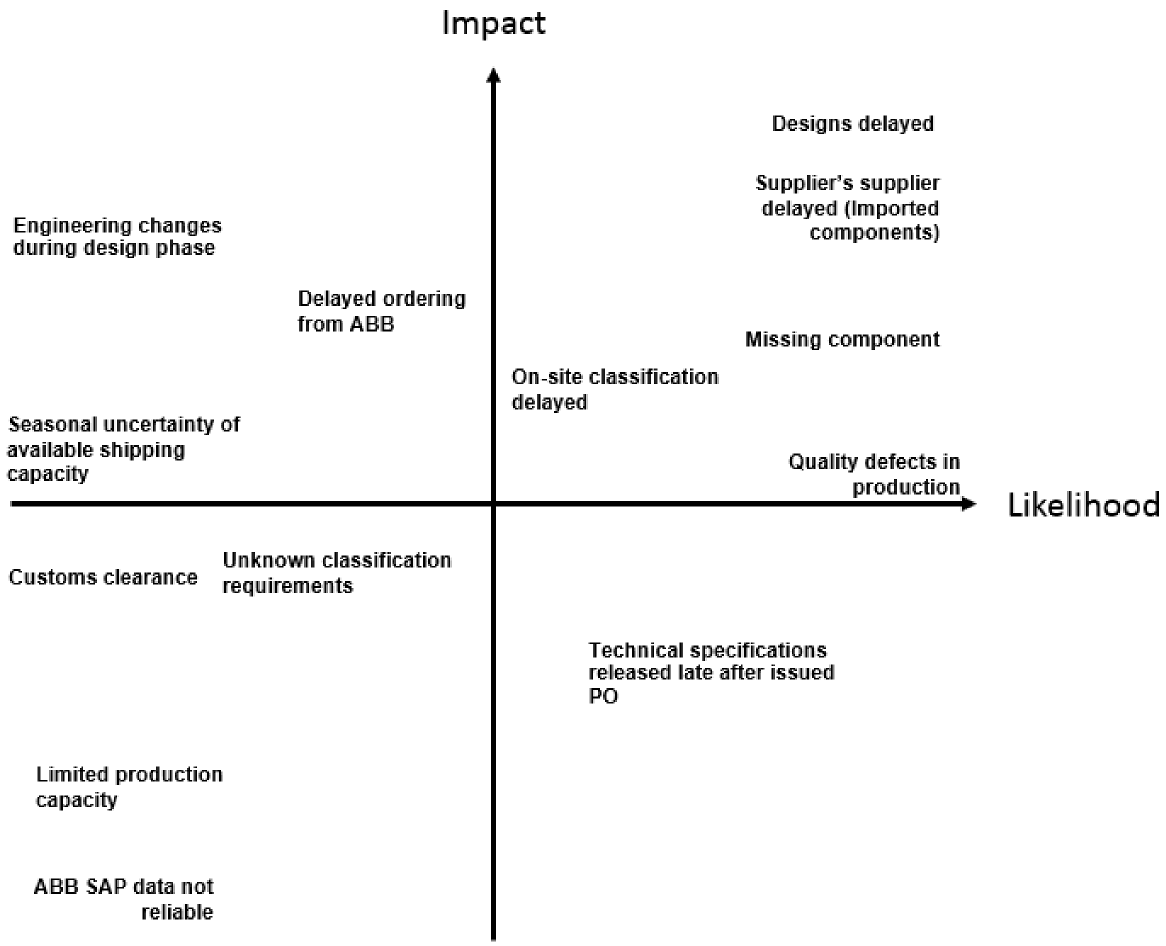

Figure 27: Supplier untimeliness impact and likelihood matrix

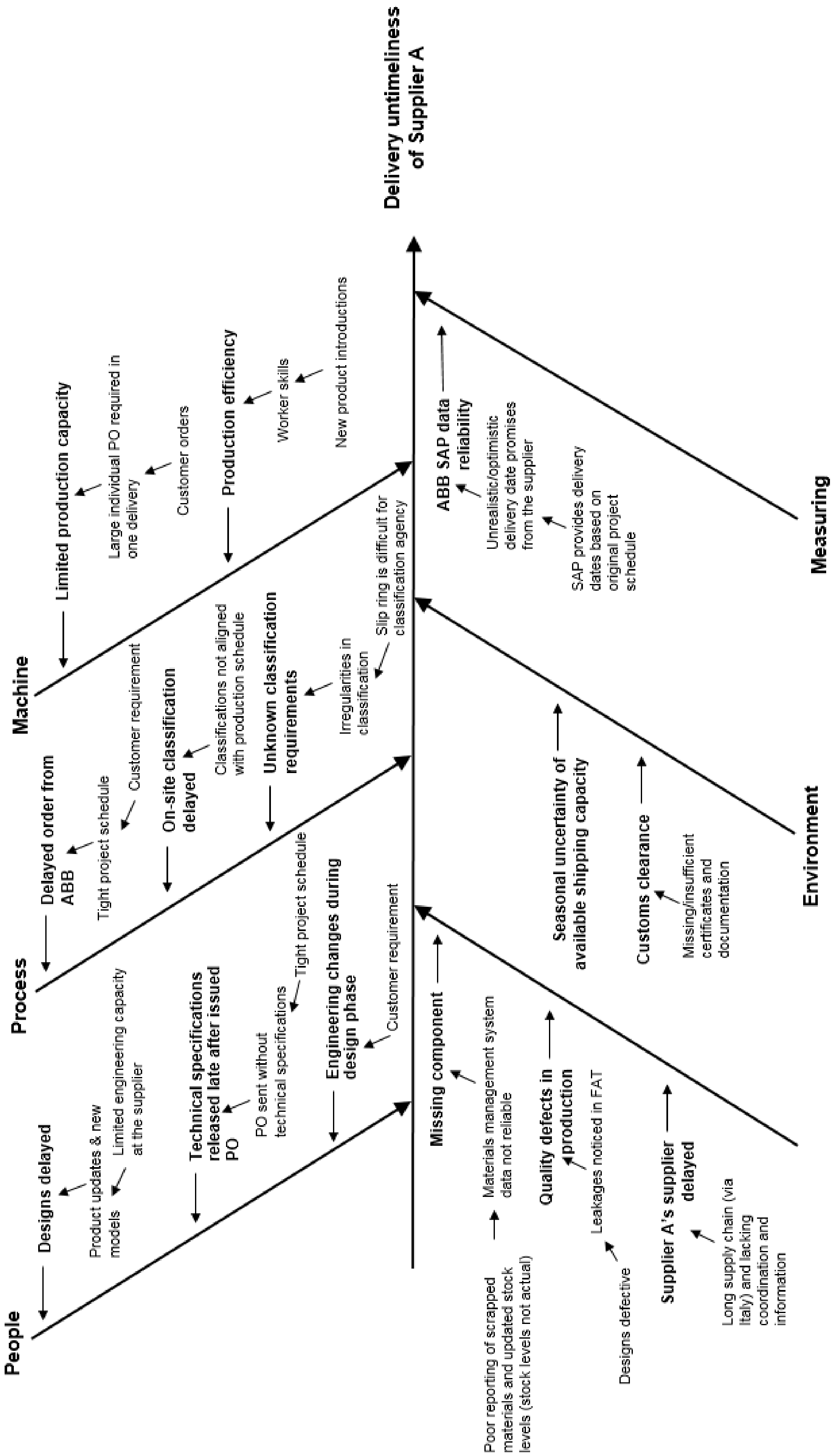

Figure 28: Fishbone model of Supplier A untimeliness

The root cause analysis was followed by another workshop day with same participants in which Q3 - Improve was conducted. The improvements were approached by first proposing possible solutions and then assigning needed action in order to achieve the solutions and eliminate the underlying root causes. Table 12: Found solutions for the causes of Supplier A untimelinessTable 12 and Table 13 summaries the found solutions and actions to be made.

Table 12: Found solutions for the causes of Supplier A untimeliness

Cause of untimeliness	Solutions
Designs delayed	• Earlier warning about product updates to Supplier A • Differentiation in controlling new and existing models (current lead time not enough if major updates) • Coordination plan between engineering in Finland and supplier's project management in China
Technical specifications released late after PO	• Necessary technical specifications for early stages of engineering must be communicated with the supplier before sending the purchasing order
On-site classification delayed	• A coordination plan with classification agency in which tasks, responsibilities and deadlines are shown. Target is to standardize the process.
Unknown classification requirements	• A coordination plan with classification agency in which tasks, responsibilities and deadlines are shown. Target is to standardize the process.
Missing component	• Develop strict procedures on how the stock levels are updated and scrapped material in reported in order for re-ordering.
Defective component	• Designs to be improved (Azipod® C) • More coordination between production and engineering in Europe
Supplier A's supplier delayed	• More coordination and information sharing required in order to track challenges in order fulfillment in Europe
Customs clearance delayed	• Shipping/customs documents sent earlier so that the insufficiencies can be detected • Send purchasing orders to logistics department; so that required documentation is known before hand
Lowered production efficiency	• More qualified worker should be trained • Introduce assembly instructions

Table 13: Action plan for Supplier A improvements

Action		Target date	Complete date
1.	Implement an actual lead time report including each step in the order fulfilment process	5/2017	
2.	Coordination between ABB R&D projects and component orders	9/2017	
3.	Make a class coordination plan to standardize the classification process where responsibilities and deadlines are shown.	5/2017	
4.	Continuous improvement to avoid quality issues (leakages etc.); Root cause analysis/Quality tool	5/2017	
5.	Standardize scrapping procedures (report defects) and cycle count to ensure component availability. Verification in Q4 based on supplier's QC system.	9/2017	
6.	Implement periodical order fulfilment progress reviews from Europe	9/2017	
7.	Train more (2 employees) qualified workers who are specialized in Slip ring unit production.	12/2017	

Because of the fact that the effect of the found solutions require time to be realized, the Q4 is impossible to carry out in the restrictions of this thesis and is thereby outside of the thesis scope. However, together with Q3 workshop it was determined a preliminary follow up plan that verifies if the determined actions actually eliminated the root causes. The final step of the follow up plan is to review the supplier performance and report if the targets were achieved by the deadline. The complete 4Q project can be studied in Appendix C.

5.5 Cost of improvement in supplier delivery performance

Based on interviews with supply chain management employees at ABB, the company has not conducted supplier development projects on delivery performance and delivery variance reduction. Therefore, in the light of this analysis, it is difficult to model the cost for delivery variance reduction by supplier development initiatives. Since the cost for delivery variance can be reduced by investing into supplier development as explained in Chapter 3.5.2, benchmarking data from past improvement projects or continuous improvement programs is needed in order to model the improvement cost curve more accurately. ABB has, however, conducted audits and workshops at their suppliers, but the costs and results of these incentives are not reported adequately for the analysis purposes.

Currently, the supplier development responsibility at ABB is given to four sourcing engineers and supply chain manager who leads the supplier development team. In this light, the annual budget for supplier development could be derived from team's man hour costs because their main objective is to develop the supply base and according to the interviews ABB has not allocated resources to a specific supplier development budget. However, this approach is only applicable at the aggregate level for whole supply base and it is impractical to allocate improvement resources for an individual supplier. Therefore, this chapter applies targets and cost reporting of the case study in Chapter 5.4 and aims to illustrate an experimental cost curve for the delivery variance reduction for Supplier A. Table 14 shows an overview of cost variables and values used in the improvement project.

Table 14: Overview of the improvement cost variables and values

Variable	Variable value	Description
Estimated cost of reducing delivery variance (λ)	100$	Working hours used for improvement
Variance reduction target (h)	20%	The target of 4Q project in delivery variance reduction (%)
Current delivery variance (v_0)	0,085	The current delivery variance based on Supplier A delivery performance (Table 5)
Target delivery variance (v)	0,068	The target delivery variance of the 4Q project

Based on the case study in Chapter 5.4 summarizes the variables and values is used in calculating the cost for the delivery variance reduction. When revisiting Equation 1: The formula for the expected cost for untimely delivery at a certain delivery variance, it can be calculated the target delivery variance if the case study targets are to be realized. In Equation 3 which is derived from Equation 2 the estimated cost of reducing delivery variance λ equals to the total improvement cost C(v), and therefore they cancel out each other.

$$Based\ on\ \text{Equation 2: } C(v) * \ln\left(\frac{1}{1-h}\right) = \lambda * (\ln(v_0) - \ln(v))$$

$$\ln(v) = \ln(v_0) - \ln\left(\frac{1}{1-h}\right) \rightarrow v = v_0 - \left(\frac{1}{1-h}\right) \quad (3)$$

Equation 3: Achieved delivery variance by investing into supplier development

When solving Equation 3 with Table 14 values the improved delivery variance v is 0,068. The extended cost curve for Supplier A improvement with the cost of untimeliness is presented in Figure 29.

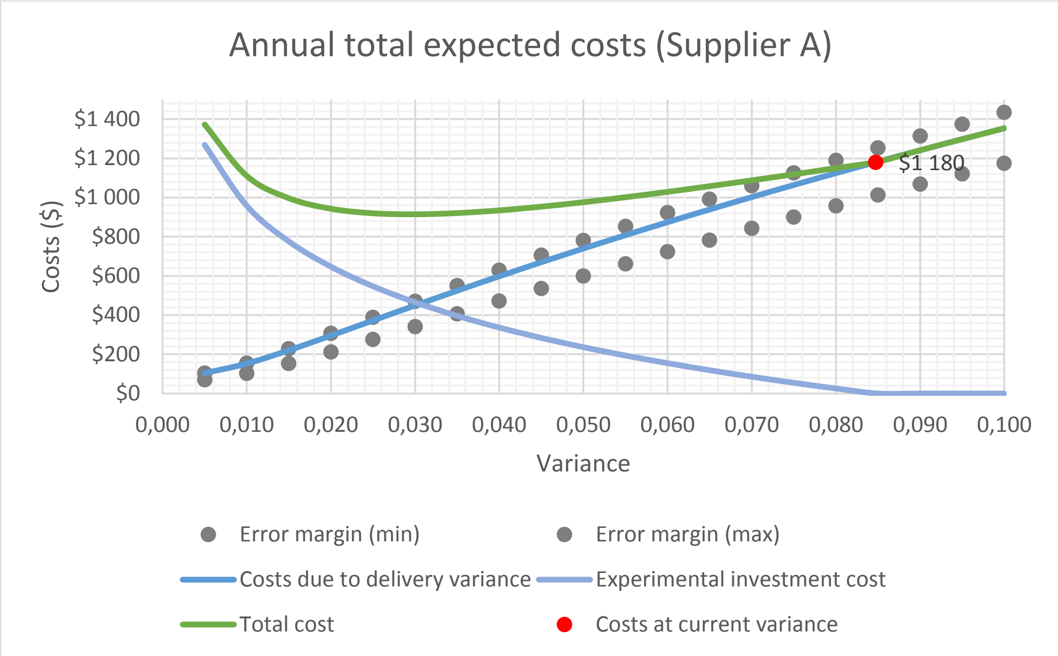

Figure 29: Annual total expected cost of Supplier A due to delivery untimeliness

When analyzing the improvement and total cost curves in Figure 29, it can be clearly seen that the current delivery performance level is far away from the optimal variance. In this case study, the conducted supplier development project is assumed to be the only development initiative for Supplier A and budgeted to spend 100$. The targets of the case study, which were presented in Chapter 5.4, are as well assumed to be realized in one year.

The limitation of this approach to include improvement costs, however, is that the results of the improvement project are not known before reviewing them when the project is over. Furthermore, the illustrated improvement curve is not constant and should be reviewed case by case. I.e. the development potential of a supplier may be drastically increased for instance by new technologies or internal learning which may change the curve behavior. Finally, possible adjustments in the mean value of the delivery distribution which can be achieved by better timing of placing purchase orders may result that the benefit of the improvement is decrease. The effect of mean shift is discussed in Chapter 6.1.1.

6 Improvements in managing supplier delivery performance

In this part, it is discussed the results of the analysis conducted in Chapter 5 by suggesting improvements to current supplier performances and supply chain management practices. Thereby this part can be considered as TO-BE approach which is divided into two subchapters: supplier delivery window optimization and managerial suggestions for supply chain processes. The delivery window optimization focuses on how the supplier performance could be improved in terms of delivery window and the cost-based data analysis which is based on the delivery window distribution. This subchapter suggests two improvement methods, average delivery shift or mean shift and delivery variance reduction, which are based on the 4Q project and cost calculations in Chapter 5.3. The second subchapter, managerial supply chain process improvement approaches the theme in question from three angles. These angles are improved supplier delivery performance metrics which were used in analysis part of this thesis, ordering and supplier order fulfillment process and supplier development and management. In other words the first improvement area concerns how the suppliers are measured, the second how the procurement is executed and finally and thirdly managerial level approach to supplier management and development practices.

6.1 Optimizing supplier delivery window

This chapter suggests improvements based on the outcome of the data analysis conducted in Chapter 5.3. The chapter consists of two part in which the two main variables which have an impact on the expected cost are discussed. These variables are the mean value and the delivery variance. By adjusting the mean value a more desirable delivery distribution can be achieved, which reduces the likelihood of extremities in the delivery window. The delivery variance reduction, on the other hand, leads to reduced variability and increased punctuality in the supplier's order fulfillment process. By reducing overall delivery variance of the supply base may ultimately result to reduced buffer in between purchasing and production.

The emphasis in this chapter is on Supplier A and B since they cause the largest share of the expected costs due to untimely delivery. Because of the ABB's internal buffer in between purchasing and the production start and good performance suppliers C and D, the expected cost of these suppliers cannot be significantly improved by developing them. The largest share of the costs are generated due to the buffer while major lateness is very unlikely and inventory holding and the cost of capital does not have critical impact on the total cost due to low purchase value.

6.1.1 Adjusting the delivery window

Based on the conducted analysis on delivery distribution and expected costs of the four case suppliers it can be clearly seen that mean values (average delivery) of Supplier A (+0,14) and B (+0,10) are late and thereby have an expectancy to cause production stoppages which are the most major cost type of supplier untimeliness. Since in the case of Supplier A and B most of the expected costs are generated due to production stoppages, shifting the mean could reduce the share of major lateness and probability of the stoppages. Therefore, by adjusting the mean to on-time delivery date the expected costs could be significantly reduced. This is highly recommended because overtime days (production stoppage) are over times 10 times more expensive than inventory holding or the buffer cost.

The mean shift of Supplier A's or B's delivery distribution do not necessarily require any process development actions such as supplier development. By simply ordering earlier and thereby giving the supplier more time, the mean can be shifted backwards at the delivery window timeline. This could be beneficial especially in case of new models which require more engineering and the standard lead time is shown to be difficult to reach. Therefore it is suggested that the slip ring unit orders would be differentiated accordingly. Figure 30 and Figure 31 and illustrate the effect of the mean shift without considering changes in the delivery variance.

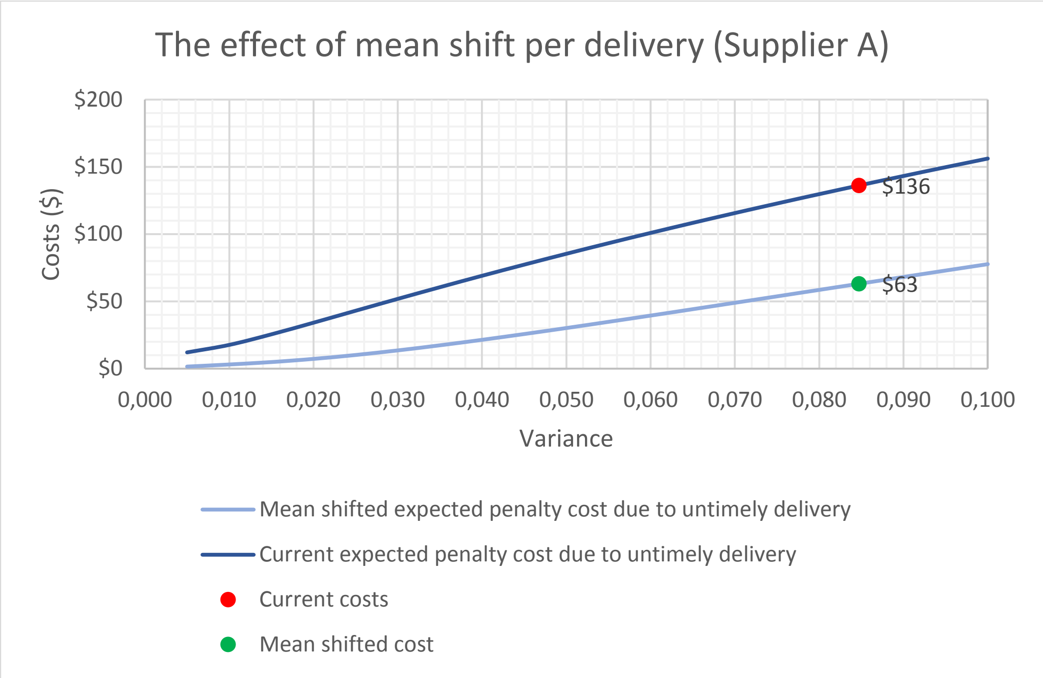

Figure 30: The effect of mean shift for Supplier A

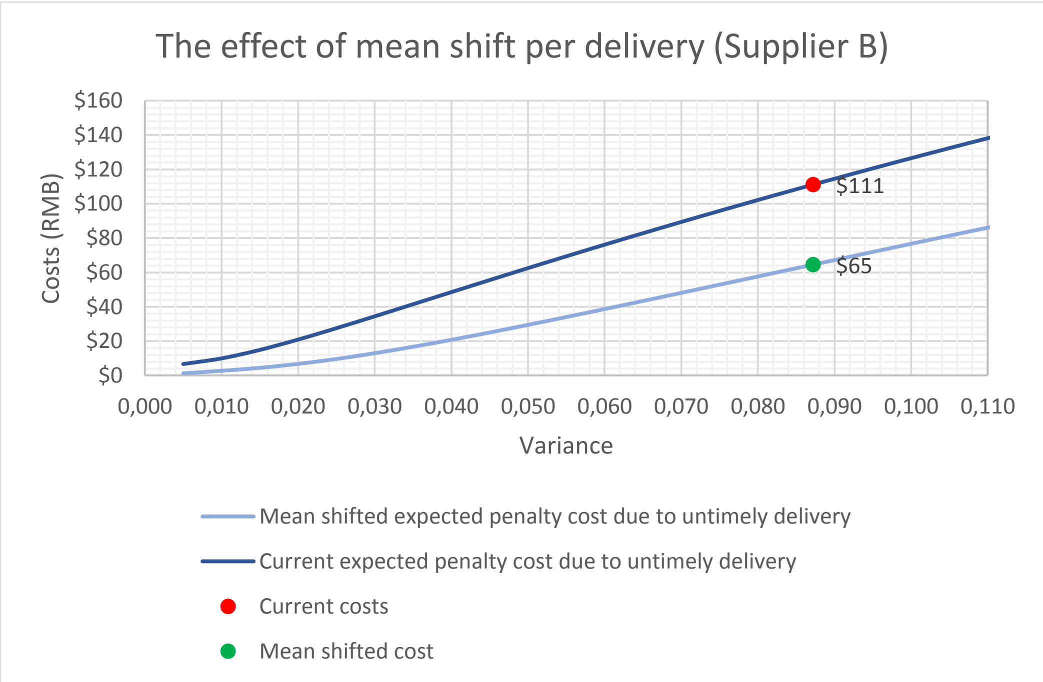

Figure 31: The effect of mean shift for Supplier B

As seen in the figures above, the mean shift has a major impact on the expected cost of untimeliness. In percentages, Supplier A expected cost is reduced by 54% and Supplier B by 42%. To emphasize the mean shift effect even more, the cost reduction is achieved purely by adjusting the mean values not the delivery variance which is kept constant from the analysis chapter.

However, the limitation of lays in the fact that the data of Supplier A is collected over the past 3 years and Supplier B over the past 2 years which means that their one-year mean values may be better than what Chapter 5.3 analysis indicates. On the other hand this problem is applicable for all data-driven analyses with constant time periods.

Even though Supplier C (-0,07) and D (-0,04) have their mean values inside the on-time window, it is beneficiary to focus on them as well. Since both suppliers clearly deliver too early, the supply chain management team at ABB could intervene their current delivery policies and refuse to receive early deliveries. According to the conducted interviews, the first actions in order to control early delivery are already taken place. The impact of these actions, however, can be seen in near future when the delivery performance of Supplier C and D are reviewed.

6.1.2 Delivery variance reduction

The data analysis in Chapter 5.3 shows clearly that Supplier A and B have significantly high delivery variance. High supplier delivery variance is a crucial issue for ABB project management and production since it increases uncertainty and built-in buffers in the order fulfillment process. By reducing delivery variance ABB may deliver projects faster to the customer and reduce costs in the order fulfillment process. However, to reduce the delivery variance a comprehensive study on the main issues and root causes must be conducted in order to eliminate causes that generate process variability and drive the improvement. Therefore, this subchapter refers to Chapter 5.4 Case study: Supplier delivery performance improvement project in order to discuss how the delivery variance may be reduced.

According to the findings of the 4Q project the main challenges are fourfold. Based on the four types of delivery variance reduction, all challenges are somewhat related to tighter control over process flow times and improved communication between different parties. The first challenge is coordination between Supplier A's project management in China and main component procurement and production in Europe. Currently, the plant in China sends purchase order which includes all main components to Europe and receives an order acknowledgment with promised delivery date. When the order is ready to be delivered the plant in China is informed and asked to arrange transport for the goods. However, any other information except some occasional inquiries because of late deliveries is not passed during the order fulfillment process. Thereby, it is extremely hard to identify where the variability in process times is sourced and what is the root cause behind the delivery variance from Europe.

The second challenge is coordination and information flow between engineering teams and project management in China. According to the conducted root cause analysis, the supplier is lacking resources in engineering which have led to delays. This issue is evident especially when ABB orders new models which require more designing. Furthermore, ABB’s R&D team is continuously working together with Supplier A in their product development projects which means that work orders to Supplier A engineering department are sent from multiple sources. Therefore, it can be argued that in addition to limited engineering capacity at Supplier A, the work flow of engineering tasks needs to be more coordinated and prioritized better between the work orders from ABB Finland R&D and supplier’s plant in China in order to avoid bottlenecks and momentary overloads. In general, the engineering phase is considered to spend remarkably large share of the total lead time of 180 days and is identified to have potential in standardizing work procedures, tracking lead time phase by phase and thereby reducing unnecessary process variance.

The third finding is lack of internal process control in material management and quality at supplier’s plant in China. During the observation period in the data-analysis, the supplier has experienced missing materials in the production phase due to not matching stock levels. Furthermore, when a material is found to be missing, they have simply reordered particular material without reporting the nonconformity properly by finding the root cause and eliminating the issue for good. In other words, the supplier has focused on firefighting when quality issues have appeared instead of developing quality management processes to become more sustainable.

Finally, the classification process of slip ring units is considered uncertain which has occasionally caused delays. The problematic issue is timing the third party classification together with the production and FAT at the plant in China. According to the discussions in root cause workshop, the supplier finds it difficult to plan classification agency appointments without delaying order fulfillment process. In addition to the timing issue, the classification agency requirements are often not clear for any of the parties due to high component complexity. In order to achieve reductions in process variance and thereby in the delivery variance, a new standardized guideline is proposed on how both ABB and the supplier cooperate together with the classification agencies. The guideline includes tasks, deadlines and responsibilities with a target of process standardization.

6.2 Managerial suggestions for supplier chain processes

During the data analysis and delivery performance improvement project on Supplier A it was found several improvement areas that are not direct outcomes of these analyses as in Chapter 6.1 but on the contrary more general findings on ABB's supplier management. These findings consider themes such as supplier development, performance indicators, coordination and communication with suppliers. This chapter is divided into three parts by starting from the improvement on supplier delivery performance measuring in which already introduced delivery histograms and expected cost per supplier delivery are proposed as supplier management foundation when assessing suppliers. The second part focuses on suppliers' order fulfillment processes on operational level and suggests two new aspects to be adopted in everyday ordering. Finally, the managerial aspects of improvement are discussed by focusing on supplier development and how supplier's performance level should be communicated with them.

6.2.1 Delivery performance measuring

The cost-based method to supplier delivery untimeliness and supplier delivery performance measurement can be considered as one of the focal points of this thesis. The method applied in this thesis regards the expected cost of delivery untimeliness for each component or supplier based on a statistical delivery data set. Even though this method is more advanced than the current OTD percentage of all orders which is in use at ABB and as well widely adopted in the industry, there are still some limitations and extensions which should be comprehended when applying the method proposed in this thesis. This chapter discusses about the advantages and disadvantages of the cost-based model which was used in Chapter 5.3.

First of all, before proceeding to the expected cost model, this thesis suggests that ABB should implement delivery distribution histograms for each supplier which work as foundations for further cost calculations. Based on the data analysis conducted in Chapter 5 delivery distributions are effective and visual way to realize supplier's delivery performance internally and communicate it to the supplier. The delivery distribution shows many important factors such as distribution width (or standard deviation), mean delivery and if the deliveries are evenly distributed or there are deliveries outside the even distribution.

As shown in the analysis part delivery distribution data can be analyzed further in terms of expected cost of supplier delivery untimeliness which aims to unveil the cost which is somewhat hidden in the procurement process. As stated in the literature review the delivery performance should be measured financially which the first and foremost advantage of the expected cost method. Currently ABB is not able to measure financially the implication of supplier untimeliness which is a significant factor when assessing supplier delivery performance. Furthermore, the fact that the expected cost method is based on a data set over a time period, it eliminates or reduces the impact of possible pure exceptions which would distortedly influence the delivery performance. Finally, the expected cost method includes an advantage of adjusting given lead times and analyzing the delivery variability in more detail when comparing to pure OTD calculations.

However, the advantage of reduced impact of exceptions in the performance score can be seen as disadvantage as well because the changes in trends can be more easily hidden in the data set and shifts in the performance indicator may take long time to change due to relatively long observation periods. This issue can be present in all data-driven approaches. E.g. if Supplier A halves their delivery variance during one year, the indicator still shows higher expected cost due to poor performance before the improvement period started. The second disadvantages is that calculating the expected cost requires more complicated mathematics than current delivery performance KPI of OTD percentage at ABB. More complicated calculations equal often to difficulties in understanding how the KPI is calculated and its further applicability may suffer because formulas behind the expected cost indicator are complex.

As a conclusion, despite the disadvantages, this thesis suggests ABB to consider the expected cost of supplier delivery untimeliness since it is firmly linked to the delivery distribution approach. Moreover, based on the interviews, ABB is currently not able to identify or estimate the cost associated with supplier untimeliness which is highly recommended in the literature. In addition, the expected cost of untimeliness indicator enables ABB to use it as decision-making support when assessing and comparing suppliers to determine if supplier is to be developed or switched.

6.2.2 Ordering and supplier order fulfillment process

This chapter suggests two improvement areas that deal with the supplier order fulfillment process at operational level. The first suggestion aims to improve the level of supplier coordination and the information flow between ABB and the supplier which were found insufficient and as the main challenges during the 4Q project and the target of reduced variability in the supplier order fulfillments. Conducted interviews also emphasized that ABB lacks knowledge on suppliers' processes. The second improvement area is improved communication to the supplier. By communicating accepted delivery window instead of one deadline date or required date increases the level of transparency in buyer-supplier relationships and gives the supplier more flexibility in fulfilling ABB's orders. Currently, ABB is using the delivery window approach in internal supplier performance measuring but does not communicate it clearly with their suppliers.

As it was noticed in the 4Q project, ABB does not necessarily know suppliers' actual process times. This is especially important when ordering long lead time and strategic components because otherwise it is difficult to identify where the improvement potential is hidden in supplier's overall lead time. Even supplier's actual lead time tracking is very challenging based on available data at this moment since ABB orders usually many order lines on same order which have different requested dates. As a consequence of this, when the overall lead time is calculated, ABB may rely only on the order lines that are required first to the factory. The lead time of later deliveries in the same order is thereby unknown because the supplier may start the order fulfillment simultaneously with the first order lines or postpone the start by a certain time period. Therefore, this thesis suggests that ABB should introduce process time tracking in supplier's order fulfillment process simply as an additional requirement for the supplier in order to map step by step actual lead times. Based on the interviews, ABB does not currently require supplier to report actual process times.

When supplier's actual process times are known, it is easy to identify the process variability and the sources of delivery variance. From the buyer's standpoint, reported process times help ABB to maintain their focus on the most problematic steps in supplier's order fulfillment process. Thereby, it is clearer for ABB to target their supplier development initiatives to issues that actually create process uncertainty or spend significantly standard lead time agreed with the supplier. Table 15 clarifies the advantages of supplier's process time tracking by an imaginary example based on Supplier A standard lead time and main processes. Based on Table 15, it can be seen that the processes that include most variability and as well as spend most of the standard lead time are technical specifications from ABB (80,24), Design/engineering (286) and procurement (46,24) which in this case should receive most attention when developing the supplier.

Table 15: Process flow times of supplier

Process name	Standard process time	Project 1	Project 2	Project 3	Project 4	Project 5	Average	Standard deviation	Variance
Technical specs by ABB	30 days	40 days	27 days	35 days	20 days	45 days	33,4 days	8,96	80,24
Engineering	40 days	50 days	25 days	45 days	10 days	55 days	37 days	16,91	286
BOM release	14 days	10 days	16 days	15 days	17 days	12 days	14 days	2,61	6,8
Planning	7 days	6 days	8 days	7 days	7 days	7 days	7 days	0,63	0,4
Purchasing	60 days	59 days	63 days	75 days	60 days	55 days	62,4 days	6,80	46,24
Material handling	7 days	4 days	7 days	6 days	8 days	6 days	6,2 days	1,33	1,76
Production	14 days	12 days	14 days	17 days	15 days	13 days	14,2 days	1,72	2,96
FAT	3 days	10 days	5 days	3 days	7 days	13 days	7,6 days	3,56	12,64
Delivery	5 days	5 days	5 days	5 days	5 days	5 days	5 days	0,00	0,00
TOTAL	**180 days**	**196 days**	**170 days**	**208 days**	**149 days**	**211 days**	**186,8 days**	**23,79**	**566,16**

The 4Q project showed clearly that the supplier had difficulties to identify actual root causes and had very little comprehension on their current challenges and performance. Therefore, it can be summarized that in order to reduce the delivery variance, the process times should be measured and reported so that the improvement action could be more precise. Reported process times have also positive impact on the level of transparency between the supplier and buyer.

In addition to the process times reporting and overall lack of supplier coordination and mutually agreed procedures, ABB could introduce delivery windows on their orders so that the accepted delivery periods are visible for suppliers. The fact that there is not only latest accepted date or requested delivery date, but also earliest accepted date would give the supplier more flexibility in planning and executing their order fulfillment schedules. Most of ABB suppliers have several customers which means that they have to balance with many different customer requirements and take care that all orders are delivered on time. ABB is internally using delivery window approach from 14 days early to 7 days late in their OTD calculations but this information is not directly communicated with suppliers. Furthermore, by providing the supplier with earliest accepted date they would increase the level of transparency in how ABB determines the limits of sufficient performance. The implementation of this suggestion however requires customization in ERP system so that the system automatically calculates delivery windows based on the project schedule and the delivery window is shown on the purchase order which is generated for the supplier.

6.2.3 Supplier development and management

This subchapter discusses improvements that are related to managerial level in ABB's supplier management supply chain management and supplier development. While Chapter 6.2.2 concentrated in ordering procedures and the buyer-supplier cooperation under supplier order fulfillment this subchapter focuses on performance-based and consequence-driven supplier management by introducing more clear reward programs and penalty fee claims linked to supplier development in delivery performance. The proposed improvements are threefold by having an emphasis on supplier development initiatives.

Based on the interviews with ABB's supply chain management employees, it was found that ABB does not systematically claim supplier due to their poor delivery performance. They do not either reward suppliers that are continuously exceeding the performance targets. The fact that ABB does not show suppliers any systematical consequences due to supplier performance, is not generally recommended among the researchers. By introducing penalty fees it is not meant that ABB could receive significant amounts of money to compensate the extra costs that have occurred due to poor supplier performance but to manage and motivate suppliers to improve their performance levels. For instance by penalizing underperforming suppliers will give a direct signal to the supplier which tells the current performance is not good enough. On the other hand well-performing suppliers could as well be distinguished from the supply base. Therefore, this thesis strongly encourages ABB to introduce penalty fee policy that is clear and understood by suppliers and to study the possibility of rewarding well-performing suppliers.

As argued in the literature review and as well found very useful in the 4Q project on Supplier A, supplier development plays a major role in the overall supply chain performance. However, ABB has not conducted supplier development projects on their delivery performance and hence have not realized the potential in such projects as it was stated in the beginning of Chapter 5.5. Therefore, this thesis will emphasize the role of supplier development when aiming at improvement in procurement processes and supplier performance. Apart from the literature, the benefits of supplier development focusing on delivery variance and performance has already been shown in the 4Q project. According to the 4Q workshops both ABB and supplier found this kind of supplier development project beneficial for reaching higher performance levels. On aggregate level the achieved improvement in delivery performance by supplier development projects may even enable ABB to reduce their built-in project buffers. This implicates positively to the overall project lead time, project execution capability and customer satisfaction. However, based on the interviews, ABB might have some capacity constraints in their supply chain management if they are willing to pursue more aggressive supplier development program. Therefore, it is suggested to evaluate resource allocation in supply chain management and decide if more capacity is required. When a typical CoGS of ETO companies, which argued to represent up to 80% of contract values, is considered and compared to the current size of ABB's supply chain management team the capacity is presumably the restrictive factor for more aggressive supplier development initiatives. I.e. the resources allocated for supplier development are not sufficient and aligned with the size of the supply chain.

A reason for why ABB has not conducted supplier development projects before is the lack of employee knowledge and preparedness for such projects. This issue was evident during the 4Q project on Supplier A since both ABB supply chain team members and the supplier representatives were not experienced with similar projects. Therefore, in addition to more aggressive supplier development, this thesis recommends that ABB trains their supply chain team members to execute quality projects such as Six Sigma or 4Q.

This thesis suggests that more active supplier development could be achieved by implementing a supplier development program which aims to improve so called *focus suppliers'* performances. The focus suppliers are selected based on predefined set of criteria that may include following criteria: strategic importance, lead time length, delivery variance, number of quality notifications and OTD percentage. After selecting the suppliers, appropriate improvement targets and projects are assigned for them like in the 4Q pilot project on Supplier A delivery variance. By concentrating in smaller group of focus suppliers which have large impact on the overall supply chain performance would be a reasonable approach keeping in mind that supply chain management resources are limited.

7 Conclusion

As it is widely argued in the literature and found in the thesis case study it is beneficial for a company to measure their suppliers' delivery performance both financially and non-financially. In case of ABB, the non-financial delivery performance measurement is covered in their performance indicators in terms of on-time delivery, but they are currently lacking an indicator that considers the financial impact of supplier's untimely deliveries and as well as the variability in their order fulfillment process. Therefore, this thesis suggests ABB to adopt the cost of supplier untimeliness model as an indicator that aims to identify those suppliers which high delivery variance, which translates directly to additional costs in buyer's operations. Furthermore, the model can be used to find out the type of untimeliness, early or late, which is based on the statistical average over a chosen time period. Thus, the company can see if the agreed lead time is enough for the supplier to fulfill their orders.

In order to study how the delivery variance can be reduced a case study (4Q project) was executed on Supplier A. Based on the delivery histogram and the cost associated with untimely delivery it became clear that major delays occur relatively often and they may have a critical impact on ABB's ability to deliver on-time. The most significant causes for delays in case of Supplier A were identified to root from poor communication and coordination with cooperating parties and insufficient control over the supplier process times which are also recognized as main causes for delivery variance in the literature. Even though the study group identified several root causes due to poor work practices, the first and foremost problem was actually lack of practices. This problem roots from the fact that ABB nor Supplier A do not collect information on actual process times at the supplier which makes it extremely difficult to find actual sources for the variability. Therefore, the main outcome of the case study suggests that ABB should require actual process times or order fulfillment project times from supplier, especially when ordering long lead time components.

Another critical challenge when reducing delivery variance is poor coordination between other parties involved in the order fulfillment such as classification agencies and Supplier A's Italian operations that include engineering office, main component production and their procurement. The root cause analysis shows clearly that there is a very little information flow between these third parties. For instance, component classifications have been sometimes delayed due to delayed booking of on-site classifications or unclear classification requirements for new designs that have led to failed FATs or extra processing time at the classification agency. Further, since supplier's engineering department in Europe receives work orders both via ABB's component orders and R&D projects the coordination should be improved in order to overloads in engineering which found out to be a critical bottleneck in supplier's order fulfillment process. In addition to ABB, enhanced coordination is beneficial for supplier's Chinese organization that orders main components from Europe has very little control or knowledge over their project progress. Thus, the 4Q project actions strongly encourage for deepened coordination and standardization in working procedures between all the parties so that the unnecessary variability can be eliminated.

Based on the interviews, communication with supplier has also improvement potential in ordering. Therefore, this thesis suggests that ABB would introduce delivery windows in their purchase orders that would provide suppliers more flexibility in planning their own production and transparency about ABB's operations in general. Thus the set targets for supplier delivery accuracy in an on-time delivery timeline can be clearly communicated to the supplier. In addition to clearer communication, ABB should claim penalty fees due to untimely delivery from suppliers systematically based on the given on-time delivery window requirements so that suppliers know the requirements and are more motivated to improve their performance. The point with penalty fees in first instance is not to compensate costs due to lost production or excess inventory costs but to manage their performance and motivate for future. In contrary, ABB could as well study the possibility of rewarding suppliers which continuously exceed the delivery performance requirements.

In order to improve suppliers' delivery performance and reduce the delivery variance it is generally recommended to develop suppliers. The supplier development is found especially important with strategically important suppliers such as supplier A and B in case of ABB. Based on the conducted interviews and the 4Q project supplier development initiatives are not well emphasized in supply chain operations at ABB which means that there exists a significant potential to be exploited. In case, current resources in supply chain management are not insufficient for more aggressive supplier development, the suggestion is to reallocate the resource use or increase resources. Nevertheless, it is not profitable to invest resources in all suppliers since ABB has a large supply base including largely different suppliers and relatively small supply chain management team with restricted budgets. Therefore, it is suggested to start cost efficient supplier development by selecting a group of so called "focus suppliers" that consist of strategically important and poorly performing suppliers. More aggressive supplier development, however, requires employees who are qualified in such programs or projects which means that appropriate training must be carried out before implementation of supplier development.

7.1 Limitations

This empirical study has also its limitations that should be considered when assessing the results and the credibility of the thesis. The limitations were mainly found in the 4Q project case study on Supplier A on which the delivery variance reduction discussion is based. Since it was a single case study its results may be somewhat exceptional and not to be repeated in other similar projects with different suppliers. However, if the results indeed are strongly supplier depended the requirement for more cooperation and development with different suppliers is evident as suggested in this thesis. Another limitation is the lack of actual process times at the supplier which makes it more difficult to identify the causes for variability in order fulfillment processes. Currently, ABB is aware of the total supplier order fulfillment process in terms of the difference between promised date and actual delivery date.

The suggested new KPI which considers the cost associated with supplier untimeliness has also its limitation. Since the KPI is based on relatively complicated mathematical formula it can be challenging to implement in performance measurement practices. Therefore, it is very important that the calculations behind the KPI are truly understood and the calculations are automated on adequate level in order to avoid mistakes in results before the implementation. However, the cost impact of untimely delivery is widely recognized as a key measurement area in supply chain delivery performance which is the underlying reason for its emphasis in this thesis.

7.2 Further research

This thesis could be taken for further research by studying two areas. The first research area is extension of the suggested cost associated with untimely supplier delivery model by estimating the impact of delayed deliveries to the end customer and flexibility in production plans when multiple projects simultaneously in assembly. Since the penalty fees from ABB's customers due to delayed delivery are significant yet delays occur rarely, it would be useful to study the actual impact of supplier untimeliness in delayed deliveries to the customer. On the other hand, production plans at ABB allow sometimes delays in component deliveries for individual projects inside a production slot because of the buffers and that there are typically several projects simultaneously in assembly which means that full production stoppage occurs rarely. In this thesis it is considered that there is only one project on the factory floor which stops the production if components are late.

The second area for further research would be a study on the implications of the conducted 4Q project. Since the last stage of this project is excluded due to restricted timeframe, it would be beneficial to analyze the results of the project and suggest improvements for further supplier development. At this moment there are very little available information on suppliers' order fulfillment processes and improvement rates due to supplier development initiatives. This leads to difficulties in budgeting appropriate resources for supplier development and argumentation for more emphasized supplier development.

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Appendix A: Interview questions

Date and place: 6.-10.2.2017, Lingang, Shanghai, China

Interviewees: Wilson-Taiping Nie (Supply Chain Manager), David-JiaWei Gu (Supplier Quality Engineer), Ro-WenChao Zhang (Purchasing Engineer) and Candy-MeiHong Tang (Purchasing Engineer)

Theme 1: Causes for untimely delivery

1. What are the main reasons or supplier's explanations of untimely delivery? (For each case supplier)
2. Why supplier delivers early?
3. How often is order sent late due to internal project delay?

Theme 2: Implications of untimely delivery

4. What are the implications of supplier delivery untimeliness?
5. How early or late can supplier deliver without causing major damage for ABB delivery project?
6. Has ABB penalized or rewarded suppliers based on their performance?

Theme 3: Supplier development

7. What are the strategic goals of supplier delivery performance?
8. How is suppliers' delivery performance managed currently?
    a. How is delivery performance measured?
    b. What kind of practices do ABB use in case of insufficient supplier delivery performance?
9. Has ABB conducted improvement project on supplier delivery performance?

Appendix B: Cost calculations

Supplier A cost calculations:

Distribution variables			Cost variables		
Untimely delivery variables			**Cost categories**		
Quantity	1	PC	Overtime cost, extension	2250	$ (2 workers per time period)
c1	0		Overtime cost, weekend	3000	$ (2 workers per time period)
c2	0,07		Excess labour cost	150	100$/h (2 workers *0,1)
c3 (stoppage)	0,3		Holding cost	8	$ (3$ per m2)
Variance	0,085		Purchasing price	50 000	$ (Average)
Mean	0,14				
Min	-0,53		**Delay categories**		
Max	0,96		Production stoppage	2250	$ per time period (Equals to overtime, customer penalty costs are excluded)
ST.DEV	0,291		Production buffer	150	$ per time period (Excess capacity per project against ideal working hours)
No. Orders	26		Inventory holding cost	8	$ per time period
			Cost of capital	12	$ per time period
(X-Mean)/SQRT(v)					
(c1-Mean)/SQRT(v)	-0,481		**Investment variables**		
(c2-Mean)/SQRT(v)	-0,240		v_0	0,085	
(c3-Mean)/SQRT(v)	0,550		v_m	0,06	
			Cost of investment per h	100	$
phii (propability)			Reduction in variance	20 %	Based on 4Q project
phii_c1	0,355				
phii_c2	0,388		**4Q project**		
phii_c3	0,343		Achieved variance (v)	0,068	Based on investment variables
Phii (cumulative)			**Others**		
Phii_c1	0,315		Cost	0	$
Phii_c2	0,405				
Phii_c3	0,709				

Penalty cost calculations			Error observation		
Expected penalty costs			**Error margins**		
Production stoppage	120	$	Queue in material recept	0,03	
Production buffer	15	$	Overtime weekend	20 %	of all overtime work
Inventory holding	1	$	Error corrected, material receipt	0,11	mean shift
			Error corrected overtime cost	2400	$
Total expected penalty cost			Error percentage, min	16,9 %	

Per delivery	136	$	Erro percentage, max	5,5 %
Annually	1180	$		

Improvement cost		
Example at current variance	*155*	*$*

Error margins		
Min total expected costs	117	$
Max total expected costs	144	$

Supplier A numerical solutions for graphs:

Numerical solutions

Cost due to delivery untimeliness

ST.DEV.	Variance	Expected penalty cost per delivery	Expected annual penalty cost	Improvement cost per variance	Total annual cost per variance
0,316	0,100	156	1353	0	**1353**
0,308	0,095	150	1298	0	**1298**
0,300	0,090	143	1241	0	**1241**
0,292	0,085	137	1183	0	**1183**
0,283	0,080	130	1124	26	**1150**
0,274	0,075	123	1064	55	**1119**
0,265	0,070	116	1002	86	**1088**
0,255	0,065	108	939	119	**1058**
0,245	0,060	101	874	155	**1029**
0,235	0,055	93	808	194	**1002**
0,224	0,050	85	740	236	**976**
0,212	0,045	77	670	284	**953**
0,200	0,040	69	598	336	**934**
0,187	0,035	61	525	396	**921**
0,173	0,030	52	449	465	**915**
0,158	0,025	43	373	547	**920**
0,141	0,020	34	296	647	**943**
0,122	0,015	25	221	776	**997**
0,100	0,010	18	153	958	**1110**
0,071	0,005	12	104	1268	**1372**

Error margins

Total costs min	Total cost max	%-min	%-max	Annual min	Annual max
136	165	15,2 %	5,6 %	1175	1434
129	159	15,7 %	5,6 %	1122	1375

123	152	16,2 %	5,6 %	1068	1314
117	145	16,8 %	5,5 %	1013	1253
110	137	17,5 %	5,5 %	957	1190
104	130	18,2 %	5,5 %	900	1126
97	122	19,0 %	5,4 %	842	1060
90	115	19,9 %	5,4 %	783	992
83	107	20,9 %	5,3 %	723	924
76	98	22,1 %	5,3 %	662	853
69	90	23,4 %	5,2 %	599	780
62	81	25,0 %	5,1 %	536	706
54	73	26,9 %	5,0 %	471	629
47	64	29,1 %	4,8 %	406	551
39	54	31,9 %	4,6 %	341	471
32	45	35,3 %	4,3 %	276	389
24	35	39,4 %	3,9 %	212	308
18	26	44,1 %	3,1 %	153	228
12	18	47,7 %	1,9 %	103	156
8	12	48,5 %	0,4 %	70	105

Supplier A mean value shift:

Mean shift		
New variables		
Mean	0	
Cost impact		
Production stoppage	51	$
Production buffer	9	$
Inventory holding	2	$
New total costs		
Per delivery	63	$
Annually	546	$
Numerical solutions		
Costs per delivery	Annual costs	
78	673	$
73	632	$
68	590	$
63	549	$
59	507	$
54	466	$
49	424	$

44	383	$
39	342	$
35	301	$
30	261	$
26	223	$
21	185	$
17	150	$
14	117	$
10	88	$
7	62	$
5	42	$
3	26	$
1	13	$
Effect		
Percentage	-54 %	

Supplier B cost calculations:

Distribution variables			Cost variables		
Untimely delivery variables			**Cost categories**		
Quantity	1	PC	Overtime cost, extension	2250	$ (2 workers per time period)
c1	0		Overtime cost, weekend	3000	$ (2 workers per time period)
c2	0,07		Excess labour cost	150	100$/h (2 workers *0,1)
c3 (stoppage)	0,3		Holding cost	8	$ (3$ per m2)
Variance	0,087		Purchasing price	20 000	$ (Average)
Mean	0,097				
Min	-0,32		**Delay categories**		
Max	0,96		Production stoppage	2250	$ per time period (Equals to overtime, customer penalty costs are excluded)
ST.DEV	0,295		Production buffer	150	$ per time period (Excess capacity per project against ideal working hours)
No. Orders	22	2 years	Inventory holding cost	8	$ per time period
			Cost of capital	5	$ per time period
(X-Mean)/SQRT(v)					
(c1-Mean)/SQRT(v)	-0,328		**Investment variables**		
(c2-Mean)/SQRT(v)	-0,091		v_0	0,09	
(c3-Mean)/SQRT(v)	0,688		v_m	0,06	
			Cost of investment per h	100	$
phii (propability)			Reduction in variance	20 %	
phii_c1	0,378				
phii_c2	0,397		**4Q project**		
phii_c3	0,315		Achieved variance (v)	0,070	Based on investment variables

Phii (cumulative)			**Others**		
Phii_c1	0,371		Casting cost	10 000	$
Phii_c2	0,464				
Phii_c3	0,754				

Penalty cost calculations

Error observation

Expected penalty costs			**Error marginals**		
Production stoppage	97	$	Queue in material recept	0,03	
Production buffer	13	$	Overtime weekend	20 %	of all overtime work
Inventory holding	1	$	Error corrected, material receipt	0,07	mean shift
			Error corrected overtime cost	2400	$
Total expected penalty cost			Error percentage, min	17,6 %	
Per delivery	111	$	Erro percentage, max	5,5 %	
Annually	1223	$			
Improvement cost					
Example at current variance	*168*	*$*			
Error margins					
Min total expected costs	95	$			
Max total expected costs	118	$			

Supplier B numerical solutions for graphs:

Numerical solutions

Cost due to delivery untimeliness

ST.DEV.	Variance	Expected penalty cost per delivery	Expected annual penalty cost	Improvement cost per variance	Total annual cost per variance
0,3	0,115	144	1583	0	1583
0,3	0,110	138	1520	0	1520
0,3	0,105	132	1457	0	1457
0,3	0,100	127	1392	0	1392
0,3	0,095	121	1327	0	1327
0,3	0,090	115	1260	0	1260
0,3	0,085	108	1193	12	1205
0,3	0,080	102	1124	39	1163
0,3	0,075	96	1055	68	1122
0,3	0,070	89	984	99	1082
0,3	0,065	83	911	132	1043
0,2	0,060	76	838	168	1006

0,2	0,055	69	764	207	970
0,2	0,050	63	688	249	938
0,2	0,045	56	612	297	908
0,2	0,040	49	534	349	884
0,2	0,035	42	457	409	866
0,2	0,030	34	379	478	858
0,2	0,025	28	303	560	863
0,1	0,020	21	230	660	890
0,1	0,015	15	164	789	953
0,1	0,010	10	110	971	1080
0,1	0,005	7	73	1281	1355

Error marginals for graph

Total costs min	Total cost max	%-min	%-max	Annual min	Annual max
125	152	14,8 %	5,6 %	1379	1677
120	146	15,2 %	5,6 %	1319	1611
114	140	15,7 %	5,6 %	1259	1543
109	134	16,2 %	5,6 %	1199	1474
103	128	16,7 %	5,5 %	1137	1405
98	121	17,3 %	5,5 %	1075	1334
92	115	17,9 %	5,5 %	1012	1262
86	108	18,6 %	5,4 %	948	1189
80	101	19,4 %	5,4 %	883	1115
74	94	20,3 %	5,3 %	818	1039
68	87	21,3 %	5,3 %	751	962
62	80	22,4 %	5,2 %	685	884
56	73	23,7 %	5,1 %	617	805
50	66	25,2 %	5,0 %	550	725
44	58	26,9 %	4,9 %	482	643
38	51	29,0 %	4,8 %	414	561
32	43	31,4 %	4,6 %	347	478
26	36	34,4 %	4,3 %	282	396
20	29	37,9 %	3,9 %	220	315
15	22	41,9 %	3,3 %	162	238
10	15	46,1 %	2,4 %	112	168
7	10	49,9 %	1,2 %	73	111
4	7	62,6 %	0,1 %	45	73

Supplier B mean value shift:

Mean shift		
New variables		
Mean	0	
Cost impact		
Production stoppage	54	$
Production buffer	9	$
Inventory holding	2	$
New total costs		
Per delivery	65	$
Annually	474	$
Numerical solutions		
Costs per delivery	Annual costs	
91	666	$
86	632	$
81	597	$
77	563	$
72	528	$
67	493	$
62	458	$
58	423	$
53	388	$
48	353	$
43	318	$
39	284	$
34	250	$
29	216	$
25	184	$
21	152	$
17	123	$
13	95	$
10	71	$
7	50	$
4	33	$
3	20	$
1	9	$
Effect		
Percentage	-42 %	

Supplier C cost calculations:

Distribution variables

Untimely delivery variables		
Quantity	1	PC
c1	0	
c2	0,07	
c3 (stoppage)	0,3	
Variance	0,02	
Mean	-0,07	
Min	-0,32	
Max	0,96	
ST.DEV	0,15	
No. Orders	48	1 year
(X-Mean)/SQRT(v)		
(c1-Mean)/SQRT(v)	0,464	
(c2-Mean)/SQRT(v)	0,926	
(c3-Mean)/SQRT(v)	2,443	
phii (propability)		
phii_c1	0,358	
phii_c2	0,260	
phii_c3	0,020	
Phii (cumulative)		
Phii_c1	0,679	
Phii_c2	0,823	
Phii_c3	0,993	

Cost variables

Cost categories		
Overtime cost, extension	2250	$ (2 workers per time period)
Overtime cost, weekend	3000	$ (2 workers per time period)
Excess labour cost	150	100$/h (2 workers *0,1)
Holding cost	2	$ (3$ per m2)
Purchasing price	4 000	$ (Average)
Delay categories		
Production stoppage	2250	$ per time period (Equals to overtime, customer penalty costs are excluded)
Minor production disturbance	150	$ per time period (Excess capacity per project against ideal working hours)
No impact on production	2	$ per time period
Interest on NWC	1	$ per time period
Investment variables		
v_0	0,023	
v_m	0,020	
Cost of investment per h	100	$
Reduction in variance	20 %	
4Q project		
Achieved variance (v)	0,018	Based on investment variables
Others		
Welding cost	2000	$

Penalty cost calculations

Expected penalty costs		
Production stoppage	0,81	$
Production buffer	2,12	$
Inventory holding	0,30	$
Total expected penalty cost		
Per delivery	3,24	$
Annually	156	$

Error observation

Error margins		
Queue in material recept	0,03	
Overtime weekend	20 %	of all overtime work
Error corrected, material receipt	-0,10	
Error corrected overtime cost	2400	$
Error percentage, min	43,1 %	
Erro percentage, max	1,6 %	

Improvement cost
Example at current variance

Error margins

Min total expected costs	2	$
Max total expected costs	3	$

Supplier C numerical solutions for graphs:

Numerical solutions

Cost due to delivery untimeliness

ST.DEV.	Variance	Expected penalty cost per delivery	Expected annual penalty cost	Improvement cost per variance	Total annual cost per variance
0,173	0,030	6	264	0	264
0,166	0,028	5	222	0	222
0,158	0,025	4	183	0	183
0,150	0,023	3	149	10	159
0,141	0,020	2	120	62	182
0,132	0,018	2	94	122	217
0,122	0,015	2	73	191	264
0,112	0,013	1	54	273	327
0,100	0,010	1	39	373	412
0,087	0,008	1	25	502	527
0,071	0,005	0	15	684	699
0,050	0,003	0	11	994	1005

Error margins for graph

Total costs min	Total cost max	%-min	%-max	Annual min	Annual max
4	6	40,9 %	2,7 %	188	272
3	5	41,9 %	2,3 %	156	227
3	4	42,6 %	2,0 %	128	187
2	3	43,2 %	1,6 %	104	152
2	3	43,3 %	1,2 %	84	121
1	2	43,0 %	0,8 %	66	95
1	2	42,1 %	0,4 %	51	73
1	1	39,8 %	0,2 %	39	54
1	1	34,4 %	0,0 %	29	39
0	1	21,1 %	0,0 %	21	25
0	0	-4,1 %	0,0 %	16	15
0	0	-26,7 %	0,0 %	14	11

Supplier D cost calculations:

Distribution variables			Cost variables		
Other variables			**Cost categories**		
Quantity	1	PC	Overtime cost, extension	2250	$ (2 workers per time period)
c1	0		Overtime cost, weekend	3000	$ (2 workers per time period)
c2	0,07		Excess labour cost	150	100$/h (2 workers *0,1)
c3 (stoppage)	0,21		Holding cost	2	$ (3$ per m2)
Variance	0,009		Purchasing price	200	$ (Average)
Mean	-0,043				
Min	-0,39		**Delay categories**		
Max	0,69		Production stoppage	2250	$ per time period (Equals to overtime, customer penalty costs are excluded)
ST.DEV	0,095		Minor production disturbance	150	$ per time period (Excess capacity per project against ideal working hours)
No. Orders	29		No impact on production	2	$ per time period
			Cost of capital	0,05	$ per time period
(X-Mean)/SQRT(v)					
(c1-Mean)/SQRT(v)	0,457		**Investment variables**		
(c2-Mean)/SQRT(v)	1,193		v_0	0,01	
(c3-Mean)/SQRT(v)	2,666		v_m	0,007	
			Cost of investment per h	100	$
phii (propability)			Reduction in variance	20 %	
phii_c1	0,359				
phii_c2	0,196		**4Q project**		
phii_c3	0,011		Achieved variance (v)	0,01	Based on investment variables
Phii (cumulative)			**Others**		
Phii_c1	0,676		Other manufcaturing cost	0	
Phii_c2	0,884				
Phii_c3	0,996				

Penalty cost calculations			Error observation		
Expected penalty costs			**Error marginals**		
Production stoppage	0,25	$	Queue in material recept	0,03	
Production buffer	0,79	$	Overtime weekend	20 %	of all overtime work
Inventory holding	0,13	$	Error corrected, material receipt	-0,07	
			Error corrected overtime cost	2400	$
Total expected penalty cost			Error percentage, min	76,8 %	
Per delivery	1,18	$	Erro percentage, max	1,4 %	
Annually	34	$			

Improvement cost		
Example at current variance	114,46	$
Error margins		
Min total expected costs	0,67	$
Max total expected costs	1,19	$

Supplier D numerical solutions for graphs:

Numerical solutions

Cost due to delivery untimeliness

ST.DEV.	Variance	Expected penalty cost per delivery	Expected annual penalty cost	Improvement cost per variance	Total annual cost per variance
0,122	0,015	4	108	0	108
0,118	0,014	3	92	0	92
0,114	0,013	3	78	0	78
0,110	0,012	2	65	0	65
0,105	0,011	2	53	0	53
0,100	0,01	1	43	0	43
0,095	0,009	1	34	2	36
0,089	0,008	1	26	55	81
0,084	0,007	1	20	114	134
0,077	0,006	1	15	184	198
0,071	0,005	0	11	265	276
0,063	0,004	0	7	365	372
0,055	0,003	0	5	494	499
0,045	0,002	0	3	676	679
0,032	0,001	0	3	987	989

Error margins for graph

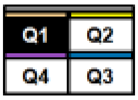
Total costs min	Total cost max	%-min	%-max	Annual min	Annual max
2	4	-69,9 %	-3,4 %	63	112
2	3	-72,1 %	-3,1 %	54	95
2	3	-74,1 %	-2,8 %	45	80
1	2	75,8 %	-2,5 %	37	66
1	2	77,0 %	2,2 %	30	54
1	2	77,5 %	1,8 %	24	44
1	1	76,8 %	1,4 %	19	34
1	1	74,5 %	1,0 %	15	27
0	1	69,8 %	0,6 %	12	20
0	1	61,5 %	0,3 %	9	15

0	0	47,5 %	0,1 %	7	11
0	0	25,4 %	0,0 %	6	7
0	0	-3,8 %	0,0 %	5	5
0	0	-29,0 %	0,0 %	4	3
0	0	-39,1 %	0,0 %	4	3

Appendix C: 4Q Project on Supplier A

Issue:	Delivery performance development and delivery variance reduction
Issue Owner:	Tuomo Salmi
Customer:	SCM team in Lingang, Shanghai

Current Status

Status Replace **O** with **X** to indicate that the project is complete for that quadrant.	**X**	**Q1 Measure**	 Any necessary containment done, project set up and data collected. The current state investigated and understood	 Root Cause Analysis (RCA) complete and verified
	X	**Q2 Analyze**		
	X	**Q3 Improve**	 New work methods and processes standardized. Issue closed.	 Long Term Solution developed, piloted and implemented that eliminates the root causes.
	O	**Q4 Sustain**		

Q1 Measure

Q1a.	*Containment / Short term actions*

Action	Owner	Target Date	Complete Date
1. Delivery data acquired from SAP	Tuomo Salmi		2/2017
2. Delivery performance histogram	Tuomo Salmi		2/2017
3. Cost-based delivery performance analysis conducted	Tuomo Salmi		3/2017

Q1b.	Project description

Supplier delivery performance has a major impact on Azipod delivery process. If a supplier cannot meet the delivery performance requirements of ABB, i.e. a supplier delivers outside the on-time delivery window, additional costs are occurred. ABB has strong incentives to improve supplier performance by developing suppliers. This 4Q project is part of a master's thesis on supplier delivery performance management and simultaneously a pilot project on how 4Q analysis can be used as a tool in improving supplier delivery performance.

The main focus of this 4Q project is to reduce supplier's order fulfilment process variability. By identifying root causes in supplier delivery untimeliness, a set of actions can be made which aim to improve supplier's process robustness and ability to deliver on-time. The delivery performance data and parameters behind this project are based on a new KPI proposal which considers the cost associated with untimely delivery for ABB. Before, the main KPI of supplier delivery performance has been OTD percentage which indicates the share of deliveries delivered on-time. However, the OTD percentage does not take account into the consequences of untimely delivery which is modelled in this new KPI proposal.

The scope of this project is set on the engineering and production phases of the slip ring unit order fulfilment process.

<table>
<tr><td>What is happening?

Supplier A supplies slip ring units to Azipod plant in Lingang, Shanghai. Slip ring unit is a key component (A-class) and interface to a ship in Azipod steering module. The delivery performance of Supplier A is shown in Q1c.</td><td>Why this is a problem?

The delivery performance in terms of delivery variance and OTD is currently significantly low. Supplier A untimeliness causes usually excess inventory and more employed capital in projects and waiting time in the production. In worst case, slip ring unit delivery may cause critical production delays at Lingang plant by risking Azipod on-time delivery to the customer.</td></tr>
<tr><td>When does/did the problem happen?The problem may occur during every order fulfillment process of Supplier A.</td><td>Who is involved with the problem?

Supplier A and its suppliers, production and SCM at the Lingang plant, ABB project engineering.</td></tr>
<tr><td>Where does/did the problem happen?

In order fulfillment process of Supplier A.</td><td>How do we know we have a problem?

ABB measures OTD which is not at the required level. In addition, based on a new model, the expected cost associated with supplier untimeliness is significantly high. The model results are shown in Q1c.</td></tr>
<tr><td colspan="2">Organizations needed for the investigation?

ABB: SCM and production at Lingang plant in Shanghai, project engineering in Helsinki, Finland

Supplier: Supplier A</td></tr>
<tr><td colspan="2">Project target and major assumptions

The target is to improve Supplier A’s delivery performance by reducing delivery variance and the expected cost due to untimeliness. In addition, a project target is set to shift the mean delivery closer to OTD window. By focusing on the major root causes and their elimination and making Supplier A’s order fulfillment more robust, the delivery performance should be improved. The objective of this 4Q project is to achieve following targets:

Targets (to be achieved by 5/2018)

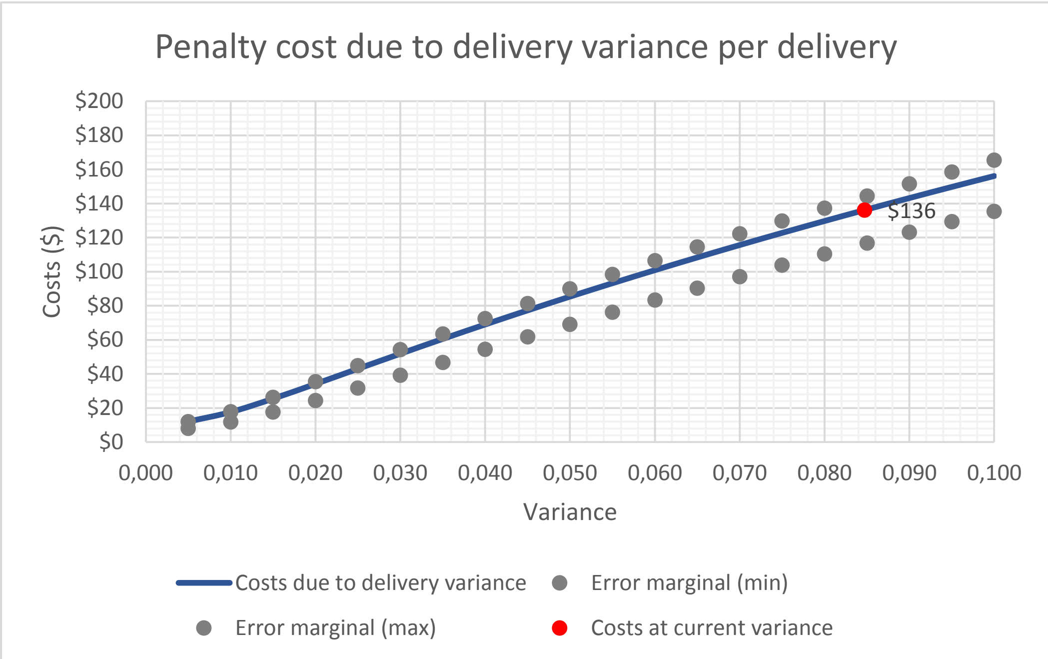
Delivery distribution mean: between 0-5 days late

Delivery variance: reduced by 20%</td></tr>
</table>

Q1c.	Data collection / Process mapping

Size of Problem

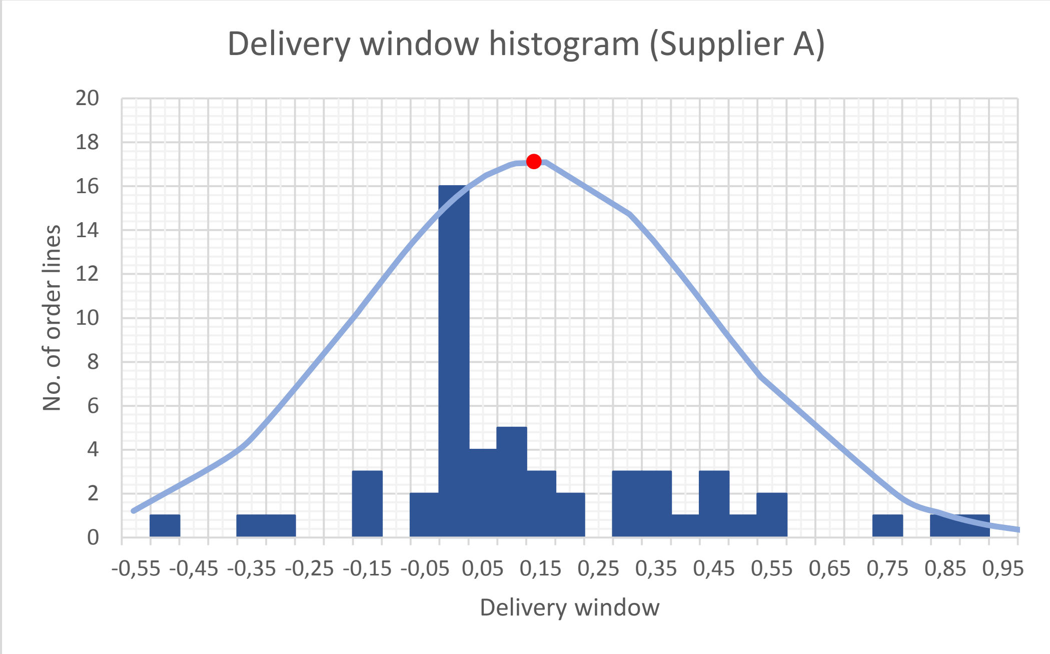
The expected cost of delivery untimeliness by delivery variance is following:



The expected cost is calculated by assigning costs per time period for early and late deliveries. The share and magnitude of early and late deliveries is presented in a delivery window histogram from which the average delivery, standard deviation and variance of the delivery distribution derived. The delivery variance is defined as how far does the deliveries spread out from the mean value. The red point indicates the current expected cost of untimely delivery. The formula behind the cost calculations considers the probability of all events in the delivery distribution and assigns a cost for each event. The OTD window is between 0 days early and 7 days late. Rest of the events cause costs.

Data/evidence

The expected cost is derived from following histogram which shows the delivery performance of last three years (2014-2016):



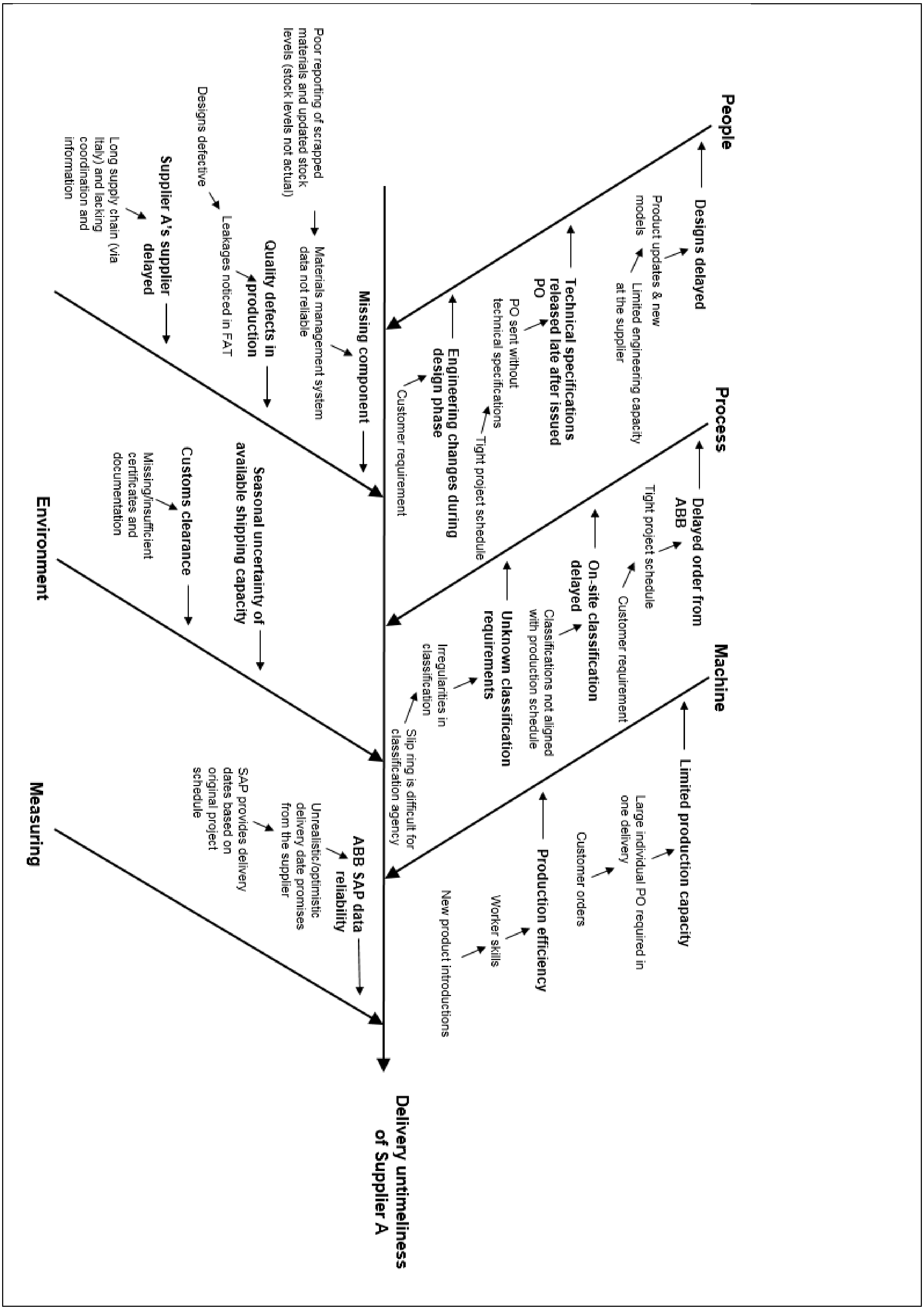
In the histogram, negative are early and positive are late deliveries. The red point indicates the mean value (+0,14) of deliveries during the time period (3 years). The histogram data is based on ABB purchase order data in ERP system.

Q2 Analyze

Q2.	Root Cause Analysis (RCA)

All Possible causes

Since the major problem with Supplier A deliveries is delayed deliveries instead of earliness, the focus in this root cause analysis is set on delays. The causes that have led to delivery delays were found by analyzing orders individually in cooperation with the supplier in a workshop. The workshop session was arrange so that both ABB and Supplier A were able to discuss together about possible reasons for delays caused by both sides. First, it was identified the major issues that have led to delays. Second, these major issues were dug deeper according to Fishbone model so that the root cause was found. In some cases the root cause was not found since the supply chain of slip ring units includes Supplier A in Europe and ABB in Finland and the cause was rooted to these locations. In this sense, the RCA was found difficult and limited to operations in China. In the following figure it is presented Fishbone of Supplier A delivery untimeliness:


People
Designs delayed
Product updates & new models
Limited engineering capacity at the supplier
Technical specifications released late after issued PO
PO sent without technical specifications
Engineering changes during design phase
Customer requirement
Tight project schedule
Missing component
Materials management system data not reliable
Poor reporting of scrapped materials and updated stock levels (stock levels not actual)
Quality defects in production
Leakages noticed in FAT
Designs defective
Supplier A's supplier delayed
Long supply chain (via Italy) and lacking coordination and information
Process
Delayed order from ABB
Tight project schedule
Customer requirement
On-site classification delayed
Classifications not aligned with production schedule
Unknown classification requirements
Irregularities in classification
Slip ring is difficult for classification agency
Seasonal uncertainty of available shipping capacity
Customs clearance
Missing/insufficient certificates and documentation
Environment
Machine
Limited production capacity
Large individual PO required in one delivery
Customer orders
Production efficiency
Worker skills
New product introductions
ABB SAP data reliability
Unrealistic/optimistic delivery date promises from the supplier
SAP provides delivery dates based on original project schedule
Measuring
Delivery untimeliness of Supplier A

Most likely root cause(s)

Following list of root cause was made based on the fishbone approach.

RC1: Limited capacity at Supplier A Engineering

RC2: Lacking coordination between work orders from ABB R&D FI and slip ring unit orders, workload peaks at Supplier A engineering

RC3: On-site classification difficult to book precisely beforehand (or difficult to predict the right timing)

RC4: Slip ring unit and its requirements unfamiliar to classification agencies

RC5: Picking and scraping procedures (stock levels) disrespected

RC6: Leakage issues during assembly and FAT

RC7: Supplier A European suppliers' delivery reliability low. Lack of information on delayed deliveries and coordination with suppliers

RC8: Missing/insufficient documentation in customs clearance

RC9: Insufficient worker skills

Verified root cause(s)

Root causes were verified in a meeting where both Supplier A's European and Chinese representatives were present together with ABB's representatives

Q3 Improve

Q3.	Pilot and implement solution

All Possible solutions

RC1:

- Earlier warning about product updates to Supplier A
- Differentiation in controlling new and existing models; 180 lead time not enough if major updates
- Coordination between engineering in Finland and supplier's project management in China

RC2:

- Necessary technical specifications for early stages of engineering must be communicated with the supplier before sending the purchasing order

RC3:

- A coordination plan with classification agency in which tasks, responsibilities and deadlines are shown. Target is to standardize the process.

RC4:

- Look at RC3.

RC5:

- Develop strict procedures on how the stock levels are updated and scrapped material in reported in order for re-ordering

RC6:

- Designs are defective (Particularly in C-pod)
- More coordination between production and engineering in Europe

RC7:

- More coordination and information sharing required in order to track challenges in order fulfillment in Europe

RC8:

- Shipping/customs documents sent earlier so that the insuffiencies can be detected
- Send POs to logistics department; so that required documentation is known before hand

RC9:

- More qualified worker should be trained
- Introduce assembly instructions

Action	Target Date	Complete Date
8. Implement an actual lead time report including each step in the order fulfilment process	5/2017	
1. Coordination plan between ABB orders and R&D projects	9/2017	
2. Make a class coordination plan to standardize the classification process where responsibilities and deadlines are shown.	5/2017	
3. Continuous improvement to avoid quality issues (leakages etc.); Root cause analysis/Quality tool	5/2017	
4. Standardize scrapping procedures (report defects) and cycle count to ensure component availability. Verification in Q4 based on Supplier A's QC system.	9/2017	
5. Implement periodical order fulfilment progress reviews from Europe	9/2017	
6. Train more (2 employees) qualified workers who are specialized in Slip ring unit production.	12/2017	

Q4 Sustain

Q4a.	Permanent solution

Action	Target date	Complete date
1.		
2.		
3.		
4.		

Q4b.	Issue closed, knowledge captured and distributed