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ANALYZING THE DISTURBANCES IN A MANUFACTURING COMPANY

Analyzing the change in disturbances for the Order to Delivery process from pre-pandemic until present year.

Master's thesis in Quality & Operations Management

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Optimizing the Order to Delivery Process in Manufacturing: Identifying Disturbances and Optimizing Flow

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An analysis on the OTD Process at an established manufacturing company. Focusing on the identifying key contributors to an unstable OTD process.

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SUMMARY

The Order to Delivery (OTD) process plays a critical role in manufacturing, directly impacting lead times, production efficiency, and customer satisfaction. Since the COVID-19 pandemic, the studied company, an established manufacturer, has struggled to restore pre pandemic OTD performance levels. The number of products deviating from the Standard Activity Process (SAP) has more than doubled since 2019, primarily due to an increase in post-production adjustments, reworks, and component shortages.

This thesis aims to identify the most frequent and impactful disturbances within the OTD process by analyzing both qualitative and quantitative data collected from internal databases and interviews with key stakeholders. Structured around the three main OTD phases: Order, Industrial, and Market. The study applies a data-driven case study approach supported by theoretical frameworks including Lean Manufacturing and Six Sigma's DMAIC methodology.

The thesis does not seek to determine root causes but instead maps and quantifies the disturbances that consistently challenge OTD stability. Additionally, it visualizes what an "optimal flow" could look like if the process operated without disruptions. The findings provide the company with clear guidance on where to focus future improvement efforts to enhance responsiveness, reduce non-value-adding activities, and approach ideal performance standards.

Keywords: OTD Process, Manufacturing, LEAN, Order process, Industrial Process, Delivery Process, Optimal flow, Production disturbances, Quality Management, Operational Management

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1. Introduction

This chapter introduces the background and problem descriptions with current challenges of the OTD process. Also it presents the purpose of the study: to identify the most common disturbances in each phase and illustrate what the optimal flow could look like.

1.1 Background

During the COVID -19 pandemic the company, like all manufacturing companies in the industry, experienced major disruptions. Global supply chain bottlenecks and semiconductor shortages led to severe delays in sourcing critical components for the production. To handle the disruptions, the company implemented temporary solutions. However, this often led to post-production adjustments, reworking the products by replacing components, updating software or installing missing parts. This led to the significant consequence of a prolonged increase in the total lead time for the Order to Delivery process (OTD). Despite a return to more stable conditions in 2024, the system has not fully recovered, and lead times remain elevated. This suggests that underlying inefficiencies persist beyond the initial pandemic impact.

1.2 Problem description

The OTD process today is unstable. The company tracks Key Performance Indicators (KPIs) that measure how many items deviate from the Standard Activity Process (SAP). Any instance where additional resources are required to complete a product is categorized as "not following the Standard Activity Process." This issue has become increasingly frequent in recent years. To illustrate the scale of the problem, in 2019, 25% of items did not follow the SAP, but by 2024, this number had risen to 55%. These deviations require post-assembly adjustments, such as manual reworks, additional quality inspections and modifications to the finished product. These adjustments are leading to non-value-adding activities that significantly increase costs, time, and resource consumption for the company. The growing need for adjustments suggests underlying inefficiencies in the OTD process that prevent a return to pre-pandemic (2019) performance levels. It has even gone to the extent that sometimes the items are delivered to the customer with a missing part that is not crucial for the function of the product or that implies any safety concerns, but it is however something that has decreased the quality aspect of their process.

Given this shift, stakeholders are interested in investigating whether this cultural transition has become a contributing factor to inefficiencies in the OTD process. Understanding how pandemic-era work habits continue to influence production could provide valuable insights into post-production adjustments and help shape strategies for process improvement.

Another key challenge is that the company wants to make more data-driven decisions and use that approach to problem-solving. While managers have hypotheses about why the deviations are increasing, these insights are largely based on experience rather than factual data. They recognize the importance of making decisions based on evidence rather than intuition, yet the company's current approach can be described as "firefighting"-reactively addressing issues rather than eliminating their root causes. As a result, problems that were thought to be resolved in the past have resurfaced, indicating that previous solutions were not effective in the long term.

The increasing frequency of deviations suggests underlying inefficiencies within the OTD process. Without identifying and addressing these deviations, the company risks further instability, increased operational costs, and decreased product quality.

1.3 Purpose

As the company seeks to return to pre-pandemic production stability, there is a need to understand why post-production adjustments have increased and what factors are driving these inefficiencies. The purpose is to find the most common disturbances for each phase of the OTD process. Additionally, the purpose is also to show what the optimal flow can look like for the OTD Process if everything was perfect. By combining data analysis and literature research the hope is to provide the stakeholders with recommendations on what areas to focus on when improving the process.

In order to return to pre-pandemic stability, it seems necessary to first identify what key factors are continuously causing disturbances to the different phases of the OTD process. As per request of the stakeholders, they also want to know what the optimal flow would look like and that is done by identifying the excepted level of performance. The following research questions will be investigated:

- What are the key factors continuously causing disturbances in the OTD Process?
- What can the optimal flow look like in the OTD process?

1.4 Clarification of key concepts

To ensure a clear understanding of the key concepts within the research questions, they will be defined below.

The OTD process is essentially three phases: Order, Industrial and Market. In terms of what makes a disturbance a key factor is based on several criteria. One of them is the frequency of the disturbance, how often, when, where etcetera. Secondly, the volume of the disturbances. Because of the wide variety of problems that exist some sort of prioritization has to be done and therefore volume is an important consideration. Thirdly, the magnitude of the disturbance, meaning how critical is this issue.

Furthermore, clarifying "optimal flow" in the OTD Process. The optimal flow is defined as, if everything worked perfectly, no material flow, production, quality issues could happen, what would the flow look like? An extended clarification of the optimal flow and the OTD process is stated in Current State Analysis.

Performance in the OTD process can be measured using multiple parameters, depending on different operational priorities. To clarify what defines as expected performance in this study, a list of the most relevant parameters and Key Performance Indicators (KPI) is listed below. Also, other key concepts are listed below that are used in this thesis.

Number of adjustments: The number of adjustments refers to the number of corrections and modifications of the products after it has passed the standard production process.

In the adjustment phase, reparation and replacement of different parts that can be missing from the assembly line is corrected, to meet the required quality standards and customer requirements. The adjustment phase is a non-standard assembly process, and a high number of adjustments indicates inefficiencies in the production process.

Number of missing parts: This describes the number of occurrences when a product is missing one or more components. The consequences of having high number of missing parts can be extra logistics costs, customer dissatisfaction and extra rework at the adjustment phase. However, missing parts may not always impact the safety or functionality of the product, it depends on the criticality of the part.

Production efficiency: Production efficiency evaluates how effectively the different lines and stations operate. A key metric for this indicator is the First Time Through (FTT). FTT measures the percentage of all the products that pass through the specific line or station without requiring any rework or adjustment. A high number of FTT point to a high-quality production process.

Open points: Open points refer to all types of irregularities in the production process that is not resolved before the end of production line, hence the word "open". Some of the open points needs to go through the adjustment process to be repaired before being cleared as ended of the production phase. Different kinds of open points can be missing parts, wrongly assembled or not assembled parts. The open points data also shows on what type of product the fault is concerning, problem owner of the fault and reporting area.

Remark: a Remark is comment of an issue that has happened in the production line and is solved in the production line. For example, if a screw is loose and an operator finds it, he reports it as a remark and tighten the screw. If he would not tighten the screw, it would be an open point.

Problem owner: A problem owner is the station, person, line or place where a problem has occurred. It is the problem owner's responsibility to see through that the root cause of the fault will be found and solved.

Planned production start (PPS)/actual production start (APS): PPS is the date when the vehicle is planned to start in the production phase. APS is the actual date. Often the two are the same date and time, however, it can be some issues that delay the start of the production process.

Planned production end (PPE)/Actual production end (APE): PPE and APE is the planned versus actual production end. Just like PPS and APS, PPE and APE can be delayed due to issues in the process.

Planned delivery date (PDD)/Confirmed delivery date (CDD)/ Actual delivery date (ADD): PPD is the date the customer receives when he orders the vehicle, and CDD is the confirmed date, when the product is ended in the industrial phase and is on the transport to the customer. ADD, however, is the actual date the product arrives to the customer.

Campaign: Campaign is when a fault on the product, usually from the production phase, is found on a large number of products and needs to be adjusted, either internal if the products are located in the factory still, or external if it has reached the customer.

1.5 Delimitations

The thesis will not include connected processes outside Order to Delivery process.
The thesis will only include the main assembly plants in Europe and the corresponding supply chain. Meaning the thesis will only investigate two factories which are referred to as factory 1 and factory 2.

Due to company restrictions the limitation of confidential data and other relevant information regarding the company will be restricted. When presenting relevant data and information regarding the OTD process, an unknown factor X will be added to the data to hide the actual data. Some of the internal data from the company was difficult to find due to the complexity of being a large international company and relevant data cannot be presented to the authors due to limited access to the internal databases. The issue of having two different factories to analyze within the OTD process makes location a limitation factor, since one of the factories is in another country and travel restrictions at the company make the investigation of the certain factory more difficult. Since the OTD process involves two factories, a limitation of different kinds of databases of the two factories to find relevant data, together with language difficulties make it difficult to find relevant data.

Additionally, because the OTD -process is so comprehensive and due to time constraints of the project, the market phase will not be investigated as well as the inhouse manufacturing part of the Industrial phase.

2. Methodology

The study will utilize a data-driven approach, incorporating historical production data, process mapping, and available research literature and stakeholder interviews to identify disturbances. By pinpointing the primary inefficiencies, this research aims to provide actionable insights that can help optimize production flow, minimize non-value-adding activities, and improve overall OTD efficiency at the company.

2.1 Research design and approach

This study investigates the Order to Delivery (OTD) process at the company through a structured research approach with both theoretical and empirical data. A mixed method approach is used by applying both quantitative and qualitative data. The study also follows a case study approach, described by Yin (2009). The case study approach is particularly suitable for examining existing processes within their real-world context and when the topic of the thesis is complex and broad (Yin, 2009), in this case the real-world context is the objective from the company’s OTD process. The research moreover touches on a deductive approach, meaning that it studied beforehand in established theories within quality and operations management to test different hypotheses with the data collected (Yin, 2009). The deductive approach is mainly used when looking at the optimal flow. However, the study was mainly based on an inductive approach through the qualitative analysis of interview responses, as empirical responses emerging patterns and themes. This allows for both exploratory and explanatory insights and with case studies as a method it can integrate multiple sources of evidence (Yin, 2009). An illustration of the research design is shown in *figure 1* below. A combination of deductive and inductive approaches furthermore allows both hypothesis testing and theory and makes the research findings more robust (Bell & Bryman, 2019).

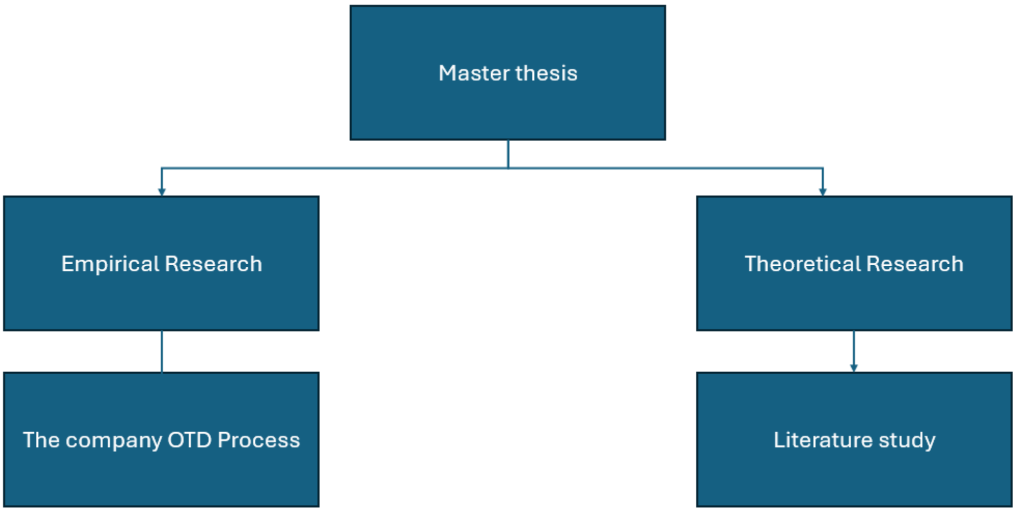

Figure 1:A tree structure of the Master thesis project

2.2 Integration of Six Sigma DMAIC approach

To analyze and improve the OTD process, this study uses the Six Sigma DMAIC approach (Define, Measure, Analyze, Improve, Control). The DMAIC approach ensures that inefficiencies are identified, measured and addressed in an evidence-based way (Pyzdek & Keller, 2014). While DMAIC wasn't followed in full as a formal research model in the thesis, it was a helpful guide in practical project work that was conducted during the study. The framework helped structure the thinking, planning and identifying data, but not all steps were applied in a strict or detailed way in the thesis itself. The most focus for the thesis lies on the Define, Measure (Data collection) and Analyze phase (Data analyze), but the Improve and Control phases are only addressed, as the study is more exploratory and analytical. Some examples of when using the DMAIC framework are that the scope of the problem was defined with Six Sigma tools such as SIPOC and focused on bottlenecks in the production and logistic phase of the OTD process.

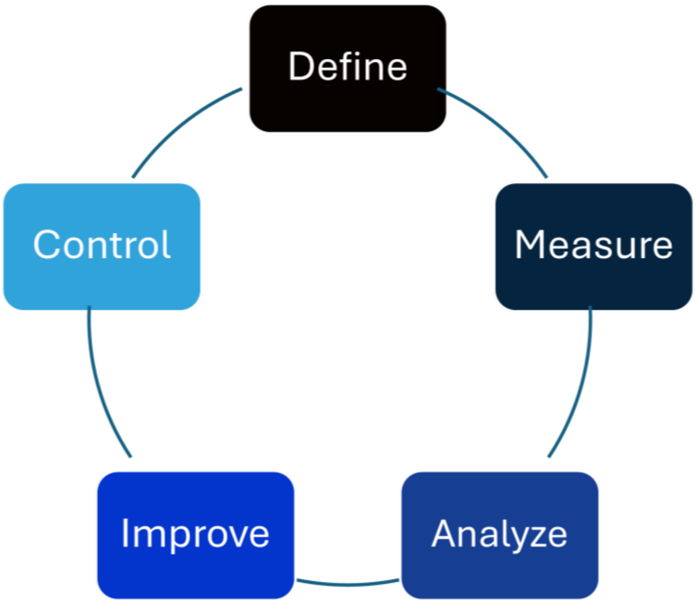

Figure 2 DMAIC STRUCTURE

2.3 Literature review

A literature study was conducted to establish a theoretical foundation for the study within the optimal flow of the OTD process. The literature review should be focused and relevant, and aligned with the research questions (Bell & Bryman, 2019). The purpose of doing a literature review is to contextualize with existing knowledge of literature within the subject (Bell & Bryman, 2019), in this case, the OTD process. According to Machi and McEvoy (2016) there are several key points regarding finding sources. The first one is what type of sources to use. This study uses mostly primary and secondary sources, such as academic journals, industry reports and relevant other books and texts that were researched to find the most relevant data of the subject. The next step is to evaluate the sources by looking at the author, is the author credible, and is the source up to date. As outlined by Machi and McEvoy (2016), perhaps the most relevant key point when looking at the sources is the relevance. Does the source directly relate to the topic the thesis is about or not. Furthermore, to find relevant sources, academic portals such as Google Scholar and Chalmers Library were the main literature collection portals for this study. Some literature was also found with the help of the supervisor at Chalmers and other relevant researchers at Chalmers. The sources was books, industry reports, doctoral thesis and peer-reviewed journal articles. Relevant literature of competitors OTD process was particularly difficult to find due to many of the companies' processes are classified. However, some were found although some of the articles wasn't a clear competitor.

To find the right sources, the criteria were that the articles should be from the year 2000 and forward to ensure relevance and aligning with current technologies and methods. But as some Theoretical frameworks were described in earlier papers, some articles may be from before the year 2000 as well. Also, the authors should have relevant knowledge about the subject, so a search of mostly professors and doctorands in the fields of subject was looked at. Some of the articles where from Sweden due to the authors of this paper is Swedish, hence easier to find Swedish articles, but the majority of the articles where English. Another thing was that the articles needed to be unlocked for reading, therefore there were plenty of articles that were removed from the filter because they weren't accessible. Relevant search words in the academic portals were

OTD process, Optimal flow, Production flexibility, supply chain flexibility, Six Sigma methodology, Just in time, 4V, sourcing, Lean manufacturing, Pareto principle, Bullwhip effect, production process, Manufacturing, supply chain disruptions, Production Bottlenecks, Quality Assurance, automotive, Delivery process, covid-19, Methodology. As a lot of articles pop up when searching for only one of the search words, a combination of the search words where applied. A literature is not only a summary but more a form of argument, and it can demonstrate how existing literature informs and justifies the study (Bell & Bryman, 2019).

2.4 Data collection

The data collection presents how the data was collected within the company, both for the quantitative and qualitative data. The subchapter further presents what types of internal data are used and what types of interviews with stakeholders were conducted.

2.4.1 Internal database quantitative data collection

Quantitative data was gathered from the company internal database, based on historical OTD performance, production and logistics data. Several different databases were used to retain the relevant data. By investigating and analyzing differences in the OTD process before and after the Covid -19 pandemic, the data gathered were extensive. The time frame of the data spans from the year 2018 to 2025. The type of data gathered was the number of open points within assembly in the factory 1, where the data could be sorted out in different stations of the assembly, and what type of fault the open point was about. This data was from 2021 until 2024 and are from a system called Tool A. A large number of data similar to the open points was also gathered from factory 2. This data was not as detailed, but the data spanned from 2018 until 2024. There was an internal database program referred to as Tool B that was interesting to the thesis due to it had information about the product from order phase and reached to delivery phase, the entire OTD process was managed in Tool B. When an order was started it also started in Tool B and followed the product when it entered specific phases in the process. In Tool B showed when the product was planned to start, and actual start, and actual end. People working in the phases could also delay the product in the program and change dates of when estimated delivery should happen. This data was one of the most important ones due to the fact that you could see where and for how long it had been delayed in the process. In Tool B the data from all products produced could be seen, what time the products had entered and finished a phase and also what the planned time was. So, in that database you could find in which phase the product was delayed, and how many products that were delayed. The data also showed if the products had entered the adjustment phase, and if it had missing parts, needed workshop or had a campaign. However, it didn't have much detailed information, only on a high level. Other data collected was data from a source where all the people from the factories, both blue collar and white collar, had been resigned, either voluntarily or not. Other data looked at was from relevant Power-Bi sources within the company's internal portal. All data collected was extensive, and also due to company restrictions it needed to be multiplied with an unknown factor to present it in the thesis.

2.4.2 Qualitative data collection

Semi structured interviews were held with key stakeholders at the company, who worked or were involved in the OTD process at the company. This approach allowed for both consistency within interviews and flexibility to explore in more depth, depending on the stakeholder's experience (Bell & Bryman, 2019). The plan for the interviews was to investigate every phase of the OTD process. To do that at least one person from each phase of the OTD process was interviewed. For every phase of the OTD process, relevant questions were asked related to the stakeholder's area of expertise. But all the interviews were held to find qualitative insights into challenges, inefficiencies and optimization efforts for the OTD process within the company. There were different types of roles the stakeholders had, such as Production leaders, Data scientists, Operators, Quality engineers, forecast managers, Regional Managers, team leaders, logistic engineers and Product Managers. The total number of interviews held was seven, and the duration of the interviews was approximately 40-120 minutes, depending on the complexity of the role and the interview. The interview protocol was designed similarly for each interview, and had the same core theme, such as views on process disruptions, bottlenecks and flow optimization. But the questions were also tailored around the stakeholders area, so all relevant information should be gathered for each phase. According to Bell & Bryman (2019), semi structured interviews are particularly suitable when the aim is to understand the stakeholders perspectives while also comparing the answers. In addition to the interviews, other relevant qualitative data was also gathered at informal discussions and internal meetings with relevant company representatives. Regarding the information about the company, such as background, factory comparison, the company OTD process, it is from interviews, regular meetings, emails and discussions with relevant people within the organization. The stakeholders remain anonymous throughout the thesis, due to company restrictions and agreements.

2.5 Data analysis

The data analysis presents both quantitative and qualitative data analysis for the thesis, how the analysis is conducted, and furthermore how the statistical validity is analyzed.

2.5.1 Quantitative analysis

The use of quantitative data allows to analyze the relationships, patterns and variations of the data over time (Bell & Bryman, 2019). The data from internal databases were analyzed with statistical and data visualization technique programs such as Excel and Power Bi. The data was then presented in PowerPoint. The data involved relevant information about the different phases in the OTD process, mostly from the production, logistics and adjustment phase. Data such as type of remark, problem owner, open points, type of product, missing parts, delivery dates and reporting owner, over a period from 2019 to 2024 was investigated and analyzed to see trends over time and in performance. Other tools such as different matrixes were also used. To determine which types of supply chain flexibility are most critical for OTD performance, we applied a structured pairwise comparison method inspired by the Pugh Matrix. Drawing from the flexibility dimensions proposed by Merschmann & Thonemann (2011), each factor was systematically compared against every other factor. For each comparison, the factor perceived to contribute more significantly to delivery performance was marked as preferred. The total number of “wins” per factor was then tallied, providing a ranked list of flexibility dimensions. The five factors with the highest comparative advantage were selected for further analysis.

2.5.2 Statistical Validity Using Chi-Squared & Cramér’s V test:

To evaluate if there was any statistical significance between different categories related to the OTD process, both a Chi-squared test and a Cramér’s V test were performed. More specifically the categories compared were the following:

- Missing Parts

- Adjustments
- Workshop
- Campaign

To keep consistency, one category was kept constant, namely adjustments. There were several reasons for that. Adjustments are the most relevant to the research questions, but also a very frequent occurrence in the OTD process.

The chi-squared test determines whether the observed distribution of values, differs significantly from what would be expected if the variables were independent. (Greenwood & Nikulin, 1996). Also given the large sample size the test is appropriate.

The chi-squared test was calculated by using the following equations:

Equation 1 Formula for chi-squared test

$$X_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

$$c = Degrees\ of\ freedoom$$
$$O = Observed\ Value(s)$$
$$E = Epected\ Value(s)$$

Equation 2 Expected value formula

$$Where\ E_{r,c} = \frac{n(r) \cdot c(r)}{n}$$

$$r = row\ in\ question$$
$$c = Column\ in\ question$$
$$n = corresponding\ total$$

After this process was completed, the Cramer's V test was performed.

Equation 3 Cramer's formula

$$Cramér's\ V = \sqrt{\frac{X_c^2}{n(k-1)}}$$

$$Where\ X_c^2 = Chi\text{-}Squared\ Value$$

$$n = total\ sample\ size$$

$$k\ is\ the\ smallest\ of\ (rows, column)$$

According to Cramér, (1999), Cramér's V gives you the strength association between two chosen variables:

- 0.1 or less is considered weak association.
- 0.3-0.5 is considered moderate association.
- 0.5 or more is considered strong association.

2.5.3 Qualitative analysis

The qualitative data gathered from interviews was analyzed using thematic analysis. This method is suitable to find recurring themes and to identify patterns or themes to structure the qualitative insights (*Bell & Bryman*, 2019). This approach helps researchers to structure and analyze data by organizing insights into recurring categories, and enhances the validity, clarity and the depth of the findings according to *Bell & Bryman* (2019). A thematic analysis was chosen due to the effectiveness and flexibility of capturing detailed and relevant information from the stakeholders interviewed from the different phases of the OTD process.

The data collected from the literature review of the optimal flow within the OTD process was then evaluated and compared in a Pugh Matrix. Stuart Pugh developed the Pugh matrix, a tool used to evaluate and compare the performance of multiple options or alternatives (Quigley, 2023). A Pugh matrix consists of a table with rows representing different alternatives and columns representing evaluation criteria or performance characteristics. Each cell in the table contains a rating or score that reflects the relative performance of the option being evaluated on the corresponding criterion. The ratings can be based on objective data or subjective judgment. Once all of the options have been rated, the scores are summed up and the option with the highest total score is identified as the preferred option. The Pugh matrix can be used to compare multiple options in a structured, systematic and to identify the strengths and weaknesses of each option. It is often used in conjunction with other tools and techniques, such as brainstorming and prototyping, to support the decision-making process (Quigley, 2023).

2.6 Reliability

There are some things that need to take into consideration, Reliability and Validity. Reliability is an important consideration in research and refers to how reliable the process is and how consistent and repeatable the research findings are (Björklund & Paulsson,2003).

There are three main aspects of reliability according to Bell & Bryman (2019), those are stability, internal reliability and consistency. Stability is when the measure is stable over time. The next aspect is internal reliability, if the items correlate with each other, and the last is consistency, when there are more than one observer in observations of the data, do the observers agree (Bell & Bryman, 2019).

To ensure a high level of reliability, the study had mixed model methods, through quantitative and qualitative research designs. For the qualitative part, the interviews were semi structured with core questions similar to each other for each stakeholder interview. The responses were transcribed and analyzed manually using a common structure to minimize biases. For the quantitative data a standardized database queries were used to find relevant information and relationships in the data sources. Some filtering criteria such as time frames were applied and used in the data base, that reduced the risk of variation in the data handling. Using consistent data extraction techniques and documenting them clearly enhances the reliability (Björklund & Paulsson, 2003).

2.7 Validity

Validity refers to the research accurately measures and captures what it is intended to be measured and how the findings reflect on other phenomenon being studied (Pyzdek, 2003). There are different kinds of validity according to Bell & Bryman (2019), and the thesis analyzes measurement validity by establishing the study with theories from relevant literature, and internal validity by looking at the relationship between variables (Bell & Bryman, 2019). A literature review was conducted to ensure that the frameworks were aligned with the existing knowledge. By defining key concepts based on academic sources, the study ensured that it targeted the right elements it aimed to examine. For internal validity, one thing to consider was how the qualitative data from interviews were collected and handled. Because a possible threat to validity in interviews is the response biases from the stakeholders, where they say desirable answers for them or respond in a way that only align within company expectations. To reduce this, the anonymity of the stakeholders was applied, and confidentiality was assured to all participants interviewed. Another thing was that neutral and not leading questions were asked to the stakeholders to minimize bias. To further strengthen the validity, a cross verification was made between the interviews and literature.

The selection of who to interview also supported validity. The stakeholders were particularly chosen to cover and represent the major phases of the OTD process, such as Order, Industrial and Delivery phase. This approach of finding and interviewing multiple stakeholders from different phases ensured that multiple perspectives were included, and that ensured that the study captured the full complexity of the company's OTD process.

2.8 Ethical Considerations

Several ethical considerations were considered for the thesis. One concern is confidential data, how confidential and sensitive data is presented, by not exposing too much of the company data, and how it is handled. This was of great importance for the thesis and the company, and no exposing of sensitive information was shown. There was a balance of how much of the data that was presented in the thesis, and due to the confidentiality, all numbers are hidden or multiplied by an unknown number. Anonymity was assured to all stakeholders interviewed and personal identifiers were removed during transcription. As this is a Master thesis, the work of the thesis is concluded solely by the authors, and not by AI. However, since AI is a good assistance for translating and find other words, help has been gained by AI.

3. Theoretical Framework

This chapter will cover the theoretical framework that will act as the research foundation for the thesis project by highlighting and explaining key concepts, theories and frameworks that help with analyzing the problem.

3.1 Order to Delivery Process

This chapter will explore the various stages of the Order to Delivery (OTD). It will investigate existing research as this involves using different models, established theories and methodologies to define these stages and highlight their significance. Additionally, it will examine The company's perspective on the OTD process, identifying the key steps the company considers essential and how its approach differs from established research.

The order to delivery process is an important aspect in a lot of manufacturing companies, particularly in this industry. The goal of the theoretical framework is to establish reference framework to continue analyzing causes for postproduction adjustments. Why are certain products getting all these additional reworks after being finished on the production line. This thesis integrate concepts like lean manufacturing, Six Sigma Black Belt theories and other important analysis tools.

According to Viswanadham (2000), Krajewski and Ritzman (2005), and Jonsson and Mattson (2016), the OTD process for a product can be divided into the following key stages:

1. Order Processing & Scheduling, which refers to the process of a customer placing an order and the subsequent scheduling of production.
2. Finishing of ordered goods, which involves assembling and producing according to specifications.
3. Internal transportation of goods.
4. Distribution and transportation.
5. Billing.

3.2Theoretical Perspectives on OTD Optimization

This subchapter presents the existing research of the OTD process base on literature, and a visualization based on different categories of factors that are connected to the OTD process.

3.2.1 Existing Research on OTD Challenges and Post-Production Adjustments

Several studies have examined inefficiencies in OTD processes. For instance, Narasimhan (2018) highlights the impact of delays and inefficiencies on production quality through Makigami Analysis. Industry reports emphasize that post-production adjustments often stem from process synchronization gaps between design, supply chain, and assembly operations. Alternative sources discussing process synchronization and OTD variability include Smith & Brown (2018) and Johnson (2020). Additionally, empirical studies on Lean and Six Sigma applications reinforce the argument that structured defect prevention is more cost-effective than corrective actions (Pyzdek & Keller, 2014).

3.2.2 Optimal flow visualization

Today, most companies want to have a flexible and quickly responsive supply chain. But having a flexible supply chain is expensive (Merschmann & Thonemann, 2011). Therefore, the right balance between the supply chains flexibility and the supply chains uncertainty needs to be reached to find the optimal flow for the company and OTD process (Merschmann & Thonemann, 2011).

Supplier relationships also play an important role in the manufacturing industry, and their corresponding production efficiency. Lim et. Al (2014) mentions that a close and robust relationship between suppliers and manufacturers is of great importance when a change in customer order occurs. According to Liker and Choi (2004), they suggest six steps to have and maintain a good relationship with the suppliers after analyzing American automotive companies:

- Understand supplier's practices
- Lead suppliers to compete against each other
- Directly supervise suppliers
- Enlarge suppliers' technology

- Send information to selected suppliers
- Improve practices with suppliers.

By following these steps the automotive companies can be more robust against quick changes, both from the customer but also from the market perspective, when a large fluctuation in the market happens (Liker and Choi, 2004).

3.2.3 Identified KPI's for a responsive stable OTD-Process

To find the optimal flow for the company's OTD process, the optimal flow factors were outlined based on Merschmann & Thonemann (2011) and Rokicki, T., & Szebérenyi, A. (2024). The following factors within the supply chain flow are presented in Table 1 below and explained further below the table:

Table 1: Optimal flow categories and corresponding factors

Categories	Various types of factors				
Production Process complexity:	Impact of pre process output on post process performance	Impact of pre process changes on post process output	Delivery Delays	Increased Operational Costs	Extent of on time delivery
Product variation	Frequency of redesigns of products	Number of items changed per redesign			
Sourcing complexity	Frequency of delays for critical material	The quality of critical material	Frequency of changes for critical material		

Product complexity:	degree of modularization				
Demand variation	Predictability of demand patterns	Extent of sharing demand forecasts with suppliers/customers			
Order process variation	Frequency of order content changes by customers	Frequency of short-term Adjustments			
Customer-oriented flexibility	Improvement of responsiveness to changing market needs	Improvement of level of customer service	Improvement of delivery reliability		
Internal flexibility	Level of customization	Ability to adjust internal production capacity	Prolonged Lead Times		
Supply chain flexibility	Adjustment of worldwide delivery capacity/ capability	Supply Market Scope			

Production Process complexity:

This factor is evaluating how connected the production process is across stages. If the production process has a high complexity, any change within one stage can have major impact on the following stages in the production process. Delivery delays and high operational costs often come from poorly synchronized production stages.

Product variation

Product variation shows how frequently a product undergoes design changes and modifications. The more changes of the product, product variation requires a more flexible supply chain and the supply system and corresponding production needs to be highly adaptable to changes.

Sourcing complexity

This factor measures the complexity of sourcing, how to handle critical material. The OTD process is very dependent on external suppliers and how they need to deliver at the right quality and quantity. The uncertainties within sourcing need to be in control to reach an optimal flow, as companies with high sourcing complexity are mor vulnerable.

Product complexity:

A simple product requires less handling of material. More standardization of product, and a higher degree of modularization is more optimal both for the supply chain but also for the production due to faster assembly and easier quality controls.

Demand variation

A good relationship between the company and the customer is of great importance. The more flexible the company is in sharing the demand forecasts for the customers and suppliers, the more flexibility the supplier can have, and the company becomes more trustworthy, enabling better alignment across the value chain. This transparent communication helps all parties to be prepared for fluctuations.

Order process variation

The frequency of order changes at the last minute can have a large impact on the production and the corresponding supply chain within the company. It is therefore important to have a good relationship with the customer. Furthermore, to have a good knowledge of the market and how fast a market can fluctuate.

Customer-oriented flexibility

This is connected to order process variation. How to deal with a changing market demand, and how to handle customer service and how to improve the reliability of the delivery process. A high responsiveness means being able to change priorities and adjust delivery times without impacting on the quality of the product.

Internal flexibility

Internal flexibility is how flexible production can be. The more customization, the more variants and material within the factory. This is connected to product development lead time, the more customization the more time in product development. Internal flexibility can also measure how fast and by how much the factory can adjust its capacity.

Supply chain flexibility

Due to changing markets and worldwide problems, a flexible supply chain is of great importance for the company. To have the right basis within the supply chain, and a robust network is important when more and more worldwide problems arise and occur these days. Having diversified and local suppliers and a flexible logistic capability can enhance the supply chain flexibility when changing market and worldwide problems occur.

3.2.4 Optimal flow visualization within production processes

For the production phase, there are two stages where you can divide disturbances within the optimal flow. There are input disturbances that occur before or outside the production process but can disturb the flow. Input disturbances often originate from suppliers or the upstream supply chain. There are also process disturbances, what is happening inside the production facility itself and disturbing the flow. Process disturbances are often related to machinery, material handling or internal processes. According to Golinska et. Al (2011) the most important disturbance for production is stated below:

Input disturbances:

Non-standard delivery lead times: Variations in supplier delivery times can lead to material shortages. If material is delivered earlier or later it disrupts the production planning and can lead to production stops and pushing delivery dates forward.

Poor quality of supplied components: Defective parts require rework or replacement, causing delays, as the product needs to have increased inspection time, adjustment time and waiting time, and can cause customer dissatisfaction if not handled in time.

Lack of needed components: Inventory shortages disrupt the production flow and can occur when there is supplier failure, inaccurate forecasting and transport issues. When the material isn't in the right place at the right time it can lead to the production line stopping.

Invalid Bill of Materials (BOM): As BOM can act as the instruction of the assembly process, and can lead to assembly errors and delays when the BOM is Outdated or incorrect. Delays can be caused by assembling the wrong part as the BOM is not updated, and can cause confusion on the assembly line. Extra work in adjustment phase needs to be done (Golinska et. Al, 2011)

Process disturbances:

Machine breakdowns: Equipment failures halt production lines due to lack of maintenance, overload of capacity, old machines. This creates bottlenecks in the OTD flow and disrupts production planning and may lead to overtime work.

Non-standard material requirements: Customers requires sometimes special requests of customizations that require special handling in production as it can complicate scheduling and resource allocation, and also disturb regular production line. When adding more material, and special variants of something you never or almost never built before, it introduces more room for errors in the production.

Non-standard supply lead times: Unpredictable and unsynchronized internal flow within production can create longer lead times, leading to uncertainties in downstream processes.

Poor quality in processes: Internal defects such as assembly faults, incorrect installations or no quality inspections, can lead to increased rework, impacting throughput as it increasing lead dime and delivery reliability (Golinska et. Al, 2011).

Key Contributions to Digitalization:

Dranov et. Al (2024) discusses the possibility of digitalization of manufacturing systems. According to the article, to achieve the optimal flow of a manufacturing process, three contributions can be made. The three contributions within digitalization are listed below:

Digital Integration: The toolchain combines design, planning, and production stages through digital means, facilitating seamless transitions and reducing manual interventions.

Enhanced Flexibility: By leveraging digital tools, manufacturers can quickly adjust to new product designs or changes in production volume, addressing the need for customization and responsiveness.

Improved Efficiency: The integration of digital processes leads to better resource management, minimizing waste and optimizing production schedules.
This approach aligns with Industry 4.0 principles, emphasizing the importance of digitalization in modern manufacturing environments.

Another factor in reaching optimal flow within the OTD process is to look at the different markets and see if there is a need to adapt to different markets. Brabazon & MacCarthy (2017) discusses market specific OTD configurations and emphasizes that different markets have unique customer expectations regarding product customization and delivery times. According to the study manufacturers should adapt their OTD process to align more with the specific market requirements. The study also stated that manufacturers need to decide whether to concentrate on upstream factors (such as order processing and production planning) or downstream factors (like logistics and distribution) based on the characteristics of each market (Brabazon & MacCarthy 2017). They mention that a European market might prioritize flexibility and customization, which suits better with upstream factors to focus on. While an emerging market with fewer options and longer transport distances may need a robust distribution network, meaning they need to focus on downstream factors.

3.3 OTD Research within other companies

As part of this thesis, research will be conducted to analyze how competitors approach the OTD process and what differentiates their methods. According to Staeblein, T & Aoki, K. (2015) the OTD process for two companies, one German and one Japanese company showcased that in the order, planning and scheduling phase were quite similar. However, the biggest difference was in the production, manufacturing, and product variety.

Moreover, Staeblien & Aoki (2015) also analyzed different customer requirements based on geographical markets like the European and American. They concluded that the European customers had no problem waiting several weeks or even months for their product if they were able to customize their order to their specific needs, whereas the US customers generally wanted their order within two weeks. This highlights the need for a different OTD process since the European market is more based on Order-to-Make whereas the US tends to be more Make-to-stock. Because of the short amount of time the American customers expect to receive their product the ability to provide highly customizable options diminishes. However, for the European market where the customers do not have the same expectations on the short lead time. the ability to offer customizable experiences is higher. The downside by offering highly customizable products is that it increases the complexity of the production which in the current case could be one of the reasons for the number of faults occurring in production.

In the order phase, the company's customers have the chance to change, remove or hold the order specification up to six weeks before planned production start (PPS). A freeze point three weeks before PPS is also added, after that point there can be no changes of the specification, and the build order are sent to the factories. The customers have some flexibility if they want to change their specifications. A comparison can be made with another large product manufacturer, Toyota. According to Tomino et. Al (2009), Toyota allows the customers to change up to 10 percent of the original specification. This system enables Toyota to manage customization demands efficiently without disturbing their Just in Time production system (Tomino et. Al, 2009). Renault follows a relatively similar approach, as they limit the extent to which customers can change their specifications within a certain timeframe before production (Brabazon & MacCarthy, 2017).

Leading automakers have invested in better risk monitoring and early warning systems. For example, Toyota took lessons from the earthquake in 2011 that impacted Japan. By mapping out their suppliers and creating a system that flags suppliers or parts that were most vulnerable in the early stages of a crisis Matsuo, H. (2015). One significant practice identified in strong manufacturer-supplier relationships is collaboration when problems occur. Toyota, for instance, approaches supplier challenges as joint issues rather than isolated supplier failures. According to Bonini (2015), the president of the Toyota Production System Support Center, Toyota's supplier relationships emphasize trust and collaboration rather than penalties:

"Our supplier partners open the door for us and say, 'Look, we know you're not going to penalize us for some mistake we made, and you're here to help, you're part of the team (.'" Shih, W. C. 2022)

This statement shows Toyota's commitment and strategy of building long-term supplier relationships which are founded on trust and openness, where issues are openly communicated rather than concealed out of fear. Such an approach enables continuous improvement and aligns closely with Lean principles, particularly in terms of transparency, collaboration, and problem-solving. This type of supplier to manufacturer collaboration highlights key attributes for an optimized OTD process, emphasizing proactive problem-solving and collaboration between organizations, which can be leveraged to address similar supplier challenges within other manufacturing contexts.

3.4 Theoretical Tools & Frameworks

This subsection aims to introduce the different frameworks and methods used in the thesis. It also aims to explain the different frameworks used and how they are relevant for the thesis.

3.4.1 Lean Manufacturing & Waste Reduction

The Toyota Production System (TPS) emphasizes eliminating inefficiencies through principles such as Jidoka, Just-in-Time scheduling, and Kaizen Liker, J. (2021). Jidoka ensures that defects are detected in early production stages rather than post-production, which is not exactly what the company is currently doing. If a product requires adjustment it is fixed after the product has gone through the production line which again is very different to one of the key principles of TPS "Building quality into the process" rather than fixing defect later. Furthermore, stopping the production forces the action of finding the root cause because stopping production is very expensive which could be a useful lens for the company to look through and to analyze why defects are allowed to continue through production without stopping or correcting the mistakes.

Just-in-Time (JIT) scheduling minimizes inventory and lead time but increases the need for accurate defect Halim, A. H., & Ohta, H. (1994). In the case of the company this makes their planning even more crucial and sensitive to changes or delays of critical materials or deliveries from suppliers. Within the context of the Order-to-Delivery (OTD) process, this means that each production activity, from parts procurement to final assembly, should ideally be triggered by actual customer demand rather than forecasts or batch scheduling. The JIT principle is effective when things are working as planned but leaves very little room for disturbances, especially in a large complex OTD process. For example, sensitivity to planning and disruptions. JIT requires near perfect coordination across the entire supply chain. Even minor disruptions such as delayed shipment of critical parts can halt the production line. In the case of the company such issues often require post production adjustments.

Because of the sensitivity in JIT, it also requires strong forecasts and high accuracy. The JIT wants to reduce inventory and to avoid buffers or backlog in inventory this puts pressure on the sales, order, forecast teams. The JIT lacks traditional safety stock usage which again highlights the pressure of accurate forecasts and planning. As explained, the room for error is so small in a JIT system having adjustments after production is finished goes fundamentally against the JIT system's foundations.

When JIT is implemented in an effective manner it also highlights the flaws and gaps quite clearly which is crucial for continuous improvement, a cornerstone of both lean manufacturing and Six Sigma methodology. This visibility helps with identifying problems quick.

Kaizen, which focuses on continuous improvement, helps reduce recurring post-production adjustments. Lean manufacturing highlights that post-production rework is a non-value-adding activity and should be prevented rather than corrected at the end of the process.

3.4.2 Six Sigma Methodology

Six Sigma refers to a business philosophy. It is an improvement methodology and performance metric. The Six Sigma business philosophy is an initiative that enables world-class quality and continuous improvement to achieve the highest level of customer satisfaction. The Six Sigma methodology utilizes data and statistical tools within a phased approach to improve process performance. The Six Sigma metric establishes a solid performance level that helps align an organization's strategic goals and values to its customers' needs and expectations. Sigma is a measure of the variability of a process with respect to specification limits. In the case of the thesis, this is a great way of measuring variation and variability in the OTD- process.

Six Sigma, particularly the DMAIC (Define, Measure, Analyze, Improve, Control) methodology, provides a structured approach to identifying and reducing process variability (Pyzdek & Keller, 2014). For the define phase. The SIPOC framework

(Suppliers, Inputs, Process, Outputs, Customers) is a high-level process mapping tool that is especially helpful at the early stages of a project. It helps to capture the key elements of a business process in a structured way and clarify scope, stakeholders, and deliverables. After a high level tools has been used it is easier to map out the process using a more traditional Value Stream Mapping (VSM) tool or any process mapping using flow charts is very common to map out the process more visually rather than stating everything in a table like its done in SIPOC. Moreover, the Six Sigma methodologies are a great way of following and structuring projects. Sticking to the principles of defining the problem in a clear way without jumping to conclusions too early or even considering results is important when following the DMAIC structure. This will be important for overall structure of the thesis and help the endeavour or finding key disturbances in the OTD process while additionally, contributing to finding the optimal flow, because the optimal flow is related to a process with little to almost no disturbances.

Additional Six Sigma methodologies are process mapping or Value Stream Mapping (VSM), excellent tools to map out the process and apply the limitations of the project. This way a clear way of mapping inputs and outputs is easier to finish. Combining tools like SIPOC and Process mapping is a great way to start and understand the project's boundaries and the goal.

3.4.3 The Pareto Principle (80/20 Rule)

The Pareto Principle, also known as the 80/20 rule, is a widely used concept in quality and operations management that suggests a large proportion of outcomes often result from a small proportion of causes. In manufacturing contexts, it is common to find that around 80% of problems stem from 20% of root causes (George, 2002). This heuristic is not a strict statistical rule, but it provides valuable lens for prioritizing improvement efforts where they will have the greatest effect.

In Lean and Six Sigma methodologies, Pareto analysis is commonly used to identify the "vital few" issues that contribute most significantly to defects, delays, or inefficiencies

(Brassard & Ritter, 2010). By focusing on these key drivers, organizations can optimize their use of resources and achieve meaningful results faster.

In this thesis, which aims to improve the Order to Delivery (OTD) process by identifying the reasons for post-production adjustments, the Pareto Principle will be applied to categorize and analyze these issues. The goal is to determine whether a limited number of recurring problems are responsible for the majority of adjustments. If so, targeted interventions-such as adjustments in planning, supplier communication, or quality checks-can be prioritized to reduce rework and increase overall process efficiency.

3.4.4 The 4 Dimensions of Operations

The 4V Model, originally developed within service operations, is a conceptual framework used to describe the key characteristics of an operation. While it was first applied to services, authors (Slack et al., 2004) extended its applications, as it is increasingly relevant for manufacturing as well, especially in complex industries such as automotive.

The model identifies four dimensions: Volume, Variety, Variation, and Visibility, influence how operations are designed and managed.

1. **Volume** refers to the quantity or scale of production. In manufacturing, high volume typically allows for standardized processes, automation, and lower unit costs. However, it also requires significant coordination and efficiency to avoid disruptions.
2. **Variety** describes the range of different products or configurations offered. In the manufacturing industry, this includes different models, subproduct types, trim levels, and customization options. High variety increases complexity in both planning and production.
3. **Variation in demand** captures how much and how often customer demand changes. For manufacturing, this could mean seasonal fluctuations, sales campaigns, or last-minute order changes, each of which affects scheduling and resource allocation.

4. **Visibility** reflects how much of the production process is experienced or monitored by the customer. While less visible than in services, manufacturing customers may still track order progress, expect transparency, or react to delays, making visibility a factor in perceived quality and satisfaction.

The 4V Model helps organizations understand the operational challenges tied to their specific context (Slack et al., 2004). In this thesis, the model is used to evaluate how characteristics like product variety or demand variation impact production flow and the need for post-production adjustments, particularly in relation to the order-to-delivery process.

3.4.5 The Bullwhip Effect

The Bullwhip Effect refers to the phenomenon where small fluctuations in customer demand cause increasingly larger variations in the supply chain. This effect is particularly relevant in complex supply chains. Large OEM's or any company for that matter, when trying to secure their own operations and deliveries to the customers has a significant consequence further down the supply chain. As demand information travels upstream, from dealerships to manufacturers to suppliers, sub suppliers, each party of the supply chain tries to secure their own operations. Leading to overreactions in orders from suppliers, or sub suppliers and the "whip" is started. This results to issues like excess inventory, less efficient capacity utilization which puts pressure on the other parties that together create the supply chain your company is dependent on. (Paik & Bagchi, 2007).

In the case of the thesis this shows that the bullwhip effect is important when analyzing how inaccurate forecasting, demand uncertainty and long lead times can contribute to instability in the OTD process and how much securing your own operations can cause a multitude of problems in the future and for other organizations that collaborate. Understanding these dynamics helps highlight the importance of better information sharing and how factors like inventory planning, safety stocks, and batch size can improve. An unstable supply chain like the world has seen over the last 5-7 years with the pandemic, Suez canal crisis, semi-conductor shortage showcases the effect of the "whip" and can be illustrated as in Figure 3 below.

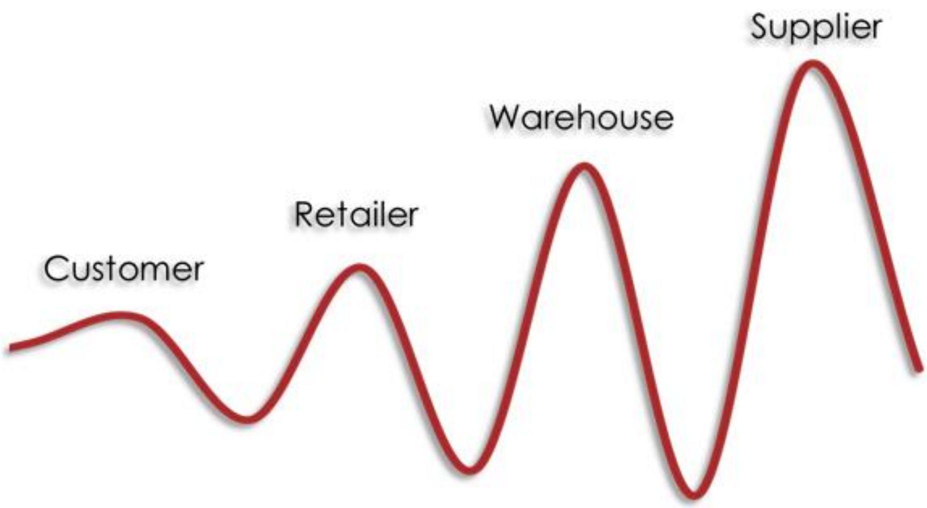

Figure 3 The bullwhip effect, illustrating the variation in demands consequences in the supply chain, F. Broek: Supply Chain Junction

4. Current State Analysis

This chapter aims to give a brief background to the company, its strategic focus and its core operations. The goal is to clearly explain the OTD process so the reader understands what the OTD process is, its different phases and what each phase entails and is collected from the interviews. Furthermore, the goal is also to explain how the OTD process today is different than before the pandemic struck the world.

4.1 Company background

The company is committed to driving sustainable innovation in the transportation and industrial sectors. The company operates manufacturing facilities worldwide, implementing advanced production methods aligned with Lean manufacturing principles and Industry 4.0. The Company Production System ensures continuous improvement, quality assurance, and operational efficiency. Automation, robotics, and digital transformation play a key role in optimizing production processes, enhancing sustainability, and reducing waste. With its strong heritage, commitment to innovation, and focus on sustainability, the Company continues to shape the future within its area.

4.2 Evaluating the Strategic Position Across Four Dimensions

The framework used is called “The 4V’s” and is explained under the Theoretical Framework but the point is to visualize an overview of four important metrics in business operations. The analysis shows the difference between where the company was prior to the pandemic compared to today. The evaluation is based on the information from the interviews but also from the data given.

The key points are the following:

- Variety has increased
- Volume has increased
- Variation in demand has changed quite a lot.
- Visibility, almost the same.

What's most interesting is that variety has increased while at the same time the volume has increased. 2023 was a record-breaking year in the volume produced and the numbers are shown in Table 3 & Table *4.* Pushing high volumes while increasing the variety of customization of products is tricky, generally and what lean theories says is that it is a larger variation of products leads to a larger variation of problems (George, 2002). The variety has increased also because of the demand from the customers, the company are well equipped to take on such challenges, but it is highly difficult to do when running at almost full production capacity as they did 2022 and 2023.

The variation in demand has increased, which is not surprising given the geopolitical instability and global disruptions that have occurred since approximately 2017, which also contributed to the difficulty in predicting the demand which in return makes it more difficult to plan production and supplier material requests.

As for the visibility, this metric has changed the least out of the four factors. The company does not bring the customer through the process more than they did earlier. They are, however, a little bit better since they have increased their adaptability and ability to change and customize their products more so in that sense it has increased. However, the visibility is considered medium to low. For example, something regarded as high visibility would be someone like a private chef that takes the customer through the entire process of their creations, this company does not do that.

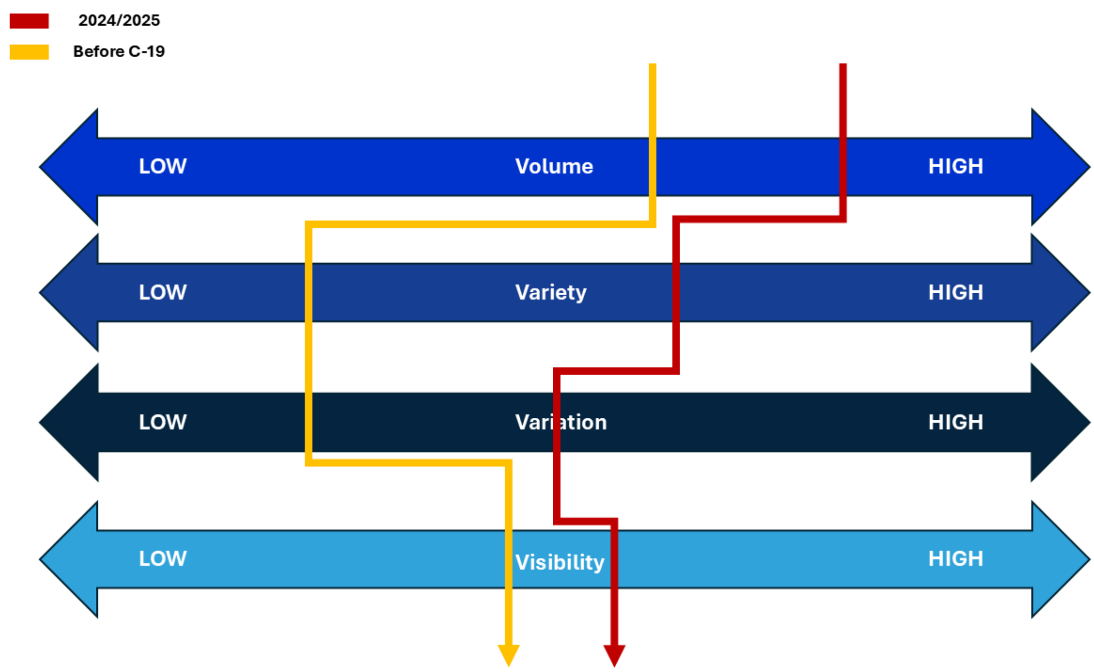

Figure 4 Pre pandemic vs today comparison by using the 4 dimensions of operations performance

4.3 Factory Context and Production Setup

Since the company is global and divided into different divisions, a limitation of which factories to further analyze was conducted. The two factories chosen are sister factories, where they have production of complete products and belonging supply chain. The factories cooperate in several fields including supporting divisions such as quality and logistics. Factory 1 have one production line where they produce products to many markets, and have many variants and different models produced at the same production line. In factory 1 they also have production of knocked down products. They produce a part of the product and then “knock it down”, pack the part and ship it to another factory overseas. This Knocked down process is a part of in-house manufacturing, and the company has several factories around the world that can produce these products. Factory 1 has several projects of products running through the line and produces several different categories of products that each represent different technological at the same factory line. Factory 2 is the larger factory by produced products, since it has two production lines. One of the lines only produces standard products, and the other line produces different variants and models, including a mixture of the categories of products. Since factory 2 has two lines including the faster standard line, it produces two thirds of the total production for the two factories, and factory 1 one third.

While the factories are very similar to each other, there are some factors that differ. For example, the cultural differences in the factories. The factories are located in different countries, where they have other laws and rules within production. In factory 1 a major work within ergonomics in production has taken place during the last five years. For factory 2 ergonomics is not a major factor, so the operators in the production can stand at the same part of the line for a longer period, when in factory 1 there is more rotation of operators.

4.4 OTD process explanation

This chapter provides an overview of the company's OTD process and examines how it compares to theoretical best practices found in the literature. The purpose is to establish a clear understanding of how the process is structured in practice and where deviations from existing frameworks occur. To achieve this, the OTD process will be described and defined, highlighting key characteristics that shape its execution. Additionally, this chapter supports answering the research questions by providing a clear definition of the OTD process, which serves as a foundation for analyzing its different phases and identifying potential disturbances but also provides a foundation for later discussions on the implementation of LEAN principles and the identification of non-value-adding activities.

The current OTD process is on a high-level three phases:

1. Order
2. Industrial
3. Market

Where industrial can be divided into sublevels of Inhouse manufacturing, production and delivery phase. The production phase can also be divided into sublevels, as Figure 5 shows.

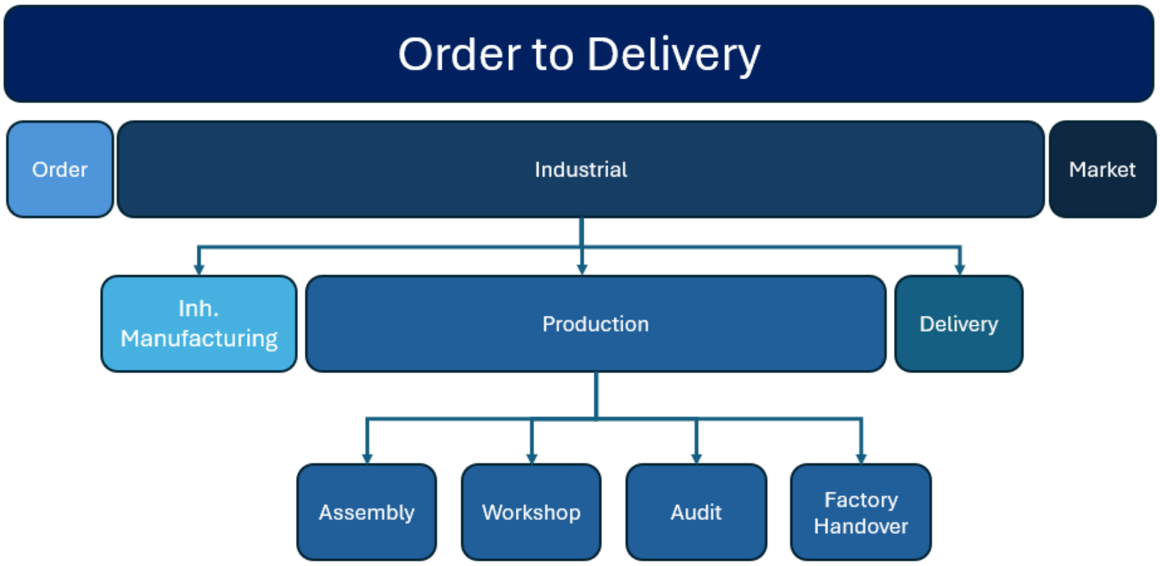

Figure 5: The OTD process breakdown, each phase and its subphases

4.4.1 Order phase

The order phase begins with a program of demand and supply planning process cycle. In the program cycle inputs from all sales markets are collected and looked at with a bottom-up demand, how many products the different market needs per month. The sales areas take the temperature on the different markets and collect as much information as possible so the forecast will be reliable and relatively correct. However, due to different circumstances in the world such as pandemics, wars, inflation, political elections, tolls etcetera, the cycles can change from month to month.

After the planning program is finished, it is sent out to the factories so they can inspect and approve it. The factories look at their time and staff schedule to see if they can meet the requirements of the planning program. The planning program is also sent to the suppliers, so the suppliers know how much the company will buy from them. In the file the suppliers see a proposal for a 12-month timeline. For the nearest time it is more exact in the planning day to day with a full order book, but the more months ahead the more high-level planning and forecasting.

Since the covid-19 pandemic it has been an increase in number of changes of the planning program due to the global disruptions. In 2023 it was a volume record in number of products built, and that was an increased need after the pandemic and all the other crisis in the world. But then the suppliers had difficulty meeting the demand. The company historically had at least 2 different suppliers per article, but after the covid-19 pandemic it is now more common to have 1 supplier per article due to costs. But the supply chain is more sensitive and unsecure now.

Within 3 days of the first program realse the factories, suppliers and purchasing have approved the program plan and then the order planners select which products will be built at the certain factories. After that, the upper management team needs to approve the plan and have the chance to make a priority if they feel that some markets are more important than others. It is rare, but it can happen that the management can change the plan.

Since factory 1 produces all products in one line, factory 2 has two lines, different models and variants go to the different factories. The order-planners look at what types of products are ordered and plan, so each factory has the most optimal flow. In total, factory 1 produces approximately one third of the total products and factory 2 produces two thirds. There is a freeze point about 3 to 6 weeks before production, until then the customers can change the specification of the order. This flexibility allows the customers to change and adapt to their needs. After the freeze point a building frequence are handed out, so the right articles are to the right product in the production phase.

After the order phase is completed, the industrial process is initiated and that is the largest phase and the most complicated one because of the advanced production but also because there are so many different flows that can impact production.

4.4.2 Industrial phase

The industrial phase is divided into three main phases, the Inhouse manufacturing phase, production phase and delivery phase. Industrial phase is the largest phase for the OTD process and therefore the most complex. The subphases are explained in the following subchapters.

4.4.2.1 Inhouse manufacturing phase

Inhouse manufacturing is a part of the industrial process and includes manufacturing process the company performs within the company that is a sub-production.
Within in-house manufacturing there are production processes such as engine manufacturing, gearbox manufacturing, cab manufacturing etcetera. These processes are produced in other factories around the world and then shipped to the complete product manufacturing plant. The factories have a close connection to each other and need to cooperate in the planning, so the right parts arrive in the right order for the correct products.

4.4.2.2 Production phase

Under production there are the following subprocesses:

Assembly. The largest phase and the most complex one. The assembly phase is the heart of the production and where several flows intertwine. For example, incoming material from hundreds of different suppliers. The assembly phase consists of several stations. First, you have the standard assembly line. Here, the product is built in a moving assembly line, and the parts are prepared for each product on the side of the lines, in so called kitting stations, where operators place out the right part for the right products. In order to make this work, instructions for each product and part are shown for the operators. Within the lines there are also quality stations, where educated operators do a quality check. If the operators find a fault, it is either fixed directly if possible or reported in the system to be fixed at the adjustment phase. When the product is at the end of the line, there is test stations where they check the durability, quality, dynamics, and emissions of the product. The last station is a final evaluation of the product, to complete the assembly process. If everything is OK, then it can go to the next phase. If it is not, then the product is moved to the adjustment area. In the adjustment area, reparation of the product is done, both mechanical, electrical and paint repairs. The adjustment process is not calculated as a standard process.

The assembly process is very complex and for the assemblers it can consist of heavy labor work that is both stressful and physically demanding. Additionally, the assemblers need to learn several combinations of the different products, since the company has many different variants of the products. Because this is such a crucial part of the organization a lot of focus and resources is put here. This is also where the real value is created, which is why it is paramount that the assembly process is seamless and has a continuous flow. However, that is easier said than done. The assembly process is where most errors occur due to the complexity of production but also because it is very dependent on so many other flows like incoming material but also because it is assembled by humans which inevitably causes errors.

Workshop. This phase primarily focuses on customization requests from customers, such as paint jobs, as well as repairs for damages incurred during the assembly process. The workshop process is divided into two parts, internal and external workshops. The internal part of the workshop handles the standard customizations, while the external part of the workshop deals with the more special customizations and is then shipped to other companies outside the factory area. This is included in the OTD process and therefore a standard process. However, only a certain amount of time is prepared for this process, and if the external or internal workshop is delayed, the OTD process will be delayed.

Audit. The Audit department do different kinds of tests on the products after the assembly to see if the products are customer ready. Different kinds of tests are performed, such as product audits, where a secret percentage of all products built should be checked, but also project audits and sample audits. In the audit department conformity of production is performed as well, where the auditors make sure and make a verification that the products meet regulatory and quality standards within production. When an auditor finds a problem in an audit, the auditor informs the relevant department within the assembly and depending on the degree of severity a number of points is set, and then the affected department needs to deal with this problem together with the quality department. The Audit process is a standard process in the OTD process and therefore not relevant in finding nonstandard activities for this thesis.

Factory Handover. This is when the production is completed, and the operators transfer the products from the production area to the distribution yard. When the product is parked it is the end of the factory handover and end of production phase. If a product is delayed, a correction is added to the production process, the customer will be informed on the delay and a new estimated time of arrival will be planned. When the factory handover is done the product is clear to enter the next phase of the OTD process.

4.4.2.3 Delivery phase

Within the industrial part of the OTD process, delivery is the final step. Delivery is divided into two parts, Delivery stock and Transport. In delivery stock the products are often placed at the distribution yard, waiting for the transport to be ready. If the product stands at the distribution yard for more than six weeks, it needs to have an extra maintenance check and possible repair. In some cases, the products can enter the delivery yard without being Green OK (GOK), meaning the products are finished and ready to enter the next phase. If there are some material shortages, or other stops within production, the products can go through the line and it will then be repaired afterwards. An extra activity will then be planned, and the product might be delayed to the customers. The next step is the transport of products. It is the last step of industrial, and the products are transported to the market, either directly to the customer or through a dealer, depending on where the customer is located.

4.4.3 Market phase

The market is the last step of the OTD process. Here, the dealers and market companies take action and receive the products, take contact with the customers, do a possible extra customer requests on the product and after that, hand them over to the customer. The Market phase is out of scope for this thesis and therefore will not be researched on more than to this point of view.

5. Results from qualitative findings and data analysis

This chapter presents the key findings from both quantitative and qualitative and qualitative phases of the study. The chapter is divided into two main chapters, where the first part covers the qualitative findings from the interviews collected, and the second part covers the quantitative data findings from the tools investigated. The purpose of this chapter is to address the research questions:

- What are the key factors continuously causing disturbances in the OTD Process?
- What can the optimal flow look like in the OTD process?

5.1 Qualitative OTD process findings

Initially, this part of the chapter presents the most important findings from the interviews with key stakeholders in the OTD process. The interviews provide valuable qualitative insights into the different phases which are further supported by the data analysis which includes data related to OTD process.

The findings will be structured to first present the most important insight from interviews. The structure of the interview follows the OTD process (Order, Industrial, Market). Then followed by a detailed analysis linking the findings to the research questions.

5.1.1 Order phase: Supplier strategies and the effects of global instability

To gain a clearer understanding of the order phase and its impact on various departments, an interview was conducted with a Forecasting Manager. The primary responsibility of the Forecasting Manager is to distribute the forecasted demand and create predictions for the expected production volume for the upcoming year. These predictions are based on input from the sales department and historical data, which are then communicated to a wide range of suppliers who rely on these forecasts to adjust their production plans accordingly.

The order phase is a critical component of the overall OTD process. This phase lays the foundation for production planning by determining the volume each factory needs to produce. As a result, it significantly influences the production speed that factories must maintain to meet production targets.

According to the forecasting manager, the company's strategy has been to focus on building long-term relationships with a select group of suppliers, rather than relying on a broad network. This approach aims to improve collaboration and reliability. Single sourcing offers the advantage of easier utilization of economies of scale (Gupta & Sharma, 2017). However, this strategy also makes the company more vulnerable to disruptions if a supplier fails to deliver. 5.2 Performance Insights from Data Analysis of the OTD Process supports this concern, showing that supplier-related disruptions have been a key issue over the past few years.

Furthermore, the order phase includes ongoing supplier communication, where suppliers are informed about the estimated quantities of specific materials or parts needed. However, since suppliers only receive forecasts rather than confirmed orders, they may encounter difficulties meeting demand if there are sudden shifts in requirements or challenges in maintaining quality standards.

5.1.2 The industrial phase: Production related challenges and improvements

To understand what contributing factors there could be for the increase in products needing post-production adjustments and not following the standard activity process, a Quality Manager was interviewed.

When asked about their thoughts on the rise of products deviating from the standard production process needing adjustments. The Quality Manager explained that there has been a high demand for products. Especially in 2023, which was a record breaking year for the company, which affected the factories by operating at nearly maximum capacity for long extended periods. This leaves very little room for production and maintenance adjustments and places tremendous pressure on the entire organization. When suppliers cannot meet demand, the risk of major disruptions to production increases.

Additionally, the introduction of new products launches and updates to existing models has complicated production according to the Quality Manager. These updates often involve significant changes, such as requiring new suppliers, altering production flow, and adjusting planning.

The Quality Manager also noted that production has become more thorough in documenting faults. Previously, if a worker identified a recognizable issue they could fix, they often did so without documenting the issue. While these fixes were simple, they were still deviations from the intended process. However, there seems to be a gap in instructions. Operators are encouraged to fix issues on the line, when possible, but this approach risks those faults going undocumented. As a result, there may be an unknown number of undetected cases that remain unrecorded. The increase in documented faults could partially be attributed to the improved documentation process, revealing previously unrecorded issues.

Furthermore, the company have acted around what measures there is in place to prevent these faults from occurring according to the Quality Manager. One of them is that they have different control stations where an operator works as a quality control checker. This person is responsible for checking certain parts of the product so that they are correct. This is for many reasons but one of them is because the product has different certifications that must be correct and certain parts has to be right otherwise they could cause severe safety breaches. Moreover, despite having these control zones or stations, there is still a big number that goes by them. In order to detect some of the faults, experience is needed because each station only has a certain amount of time before the product leaves to the next station, causing the quality control operators to be restricted on time. However, that leads to some of the minor ones going undetected. The Quality Manager explained that because of the staff turnover it is hard to keep the consistency in production among the operators. Frequently having to recruit new personnel makes the organization having to use resources to learn and educate the new employees and that takes time.

Additionally, the Quality Manager explained that working as a quality control checker requires a certain level of experience to accurately identify specific errors. Without this experience, the job can quickly become overwhelming and stressful. Although the challenges of staff retention on the production line are well known, they remain difficult to address. The work is physically demanding and involves ergonomically strenuous tasks, which become harder to perform with age. Furthermore, the job is highly repetitive, often leading to monotony and disengagement over time, one of the key reasons employees choose to leave.

To gain more knowledge within production, an interview with a Production Line Manager (PLM) was held. The Production Line Manager was asked similar questions to the quality manager. As other interviewees have stated, the Production Line Manager also agreed that the high staff turnover has been an issue over an extended period.

The Production Line Manager also explained that the part of whom they are responsible for is a very attractive part of the line because it is less physically taxing. Usually, this part tends to have people with years of experience and the minor faults are often quick and easy fixes for the operators, however, may require experience to spot them. Today they work in a more specialized way, meaning most employees are more of an expert in their own department, but they lack the overall understanding of the product and how it is put together, which aligns with the quality manager's view.

When asked whether previously undocumented faults from earlier years are now being revealed due to more thorough documentation, the PLM expressed uncertainty. It was difficult to say with confidence, but there was no clear indication that this was the case, at least not within the area of responsibility. While unable to speak for the entire production, the PLM noted that within their specific function, no such trend was evident.

5.1.3 Production and Logistics Flow- and supplier related challenges effects on production

The company has had a very high production volume. When materials didn't show up (because of the material shortage from the suppliers) at the factory, the company had two choices, either stop production, or try to assemble the product anyway without the missing parts (as good as possible). As the Production Logistics Manager explained, when that happens, the yard will quickly be filled with products as they are waiting for the material to arrive. Once the material had arrived the unfinished products went back in production for readjustments of the missing parts. When production stopped, they experienced another problematic situation and that was that the incoming material for the next day or the next coming weeks would still be delivered from the suppliers, causing massive inventory problems. Because of the JIT system (explained in Theoretical Framework) no warehouse for safety stocks or inventory existed. This resulted in an overflow of stored material which was problematic because there was no system in place to keep track records of the inventory. Forcing the company to develop a new digitalized system for keeping track of all the material position and the stock levels.

To prevent such a crisis from reoccurring a new Production Extended Logistic Center (PELC) was created according to the Production Logistic Manager. This is a larger facility closer to the suppliers, where the different parts are stored, as a centralized warehouse. This prevents transport from having low filling percentage and less storage in the factories as it gets easier to control stock levels and reduce overstocking. Next, the company implemented a digitalization tool to assist in crisis like overflow of stock. The third activity implemented is when there is a production stop, the company has found a way to make the parts stop arriving to the factory, and maintain it at the suppliers instead.

The Production Logistic Manager explains that now they are better prepared for a crisis than five years ago, and when there is a disturbance in production today, it is not often it depends on logistics. However, the PL says there are still some issues to work on within logistics. One is the number of different material parts. Due to more models, and the introduction of electric products, the number of parts is about to increase significantly by 2027.

5.1.4 Culture

A positive culture among workers has a significant impact on production and a company's success(Viswanadham, 2000). After conducting seven interviews, one of the most common responses to our question about the rise in production related issues is that there has been an enormous turnover in staff in production. When asking the interviewees what their thoughts were behind people leaving more is that today compared to previous generations, people are educating themselves to a higher extent, so a lot of younger individuals are moving on to study. However, another factor is that this newer generation (gen z, gen x) tend to stay at one company for shorter periods before moving on to another company compared to the older generations (Garlic & Nelson, 2023). This results in a problematic situation because every time someone leaves they have to replace that person and a lot of times it is a person with no experience of that area. Causing the company to spend additional resources on educating new staff and after that there is still a time learning period that varies from person to person but it takes time and mistakes will occur more frequently than someone with experience.

Another interesting insight from the Production Line Manager, emphasized the fact that the workers have a lot less complete knowledge of the product and the production line today compared to 15-20 years ago. Mostly, because back in the days, the operators started at one part of the line then they moved on to another part of the line and kept going like that until they had learned the whole assembly line. So, the people accumulated a lot of general knowledge of the product and therefore, they can both recognize faults easier and fix them.

5.1.5 Conclusions and takeaways for data analysis

After the qualitative study was completed, it was decided that some of the questions below would be interesting to further investigate by cross examining them with quantitative data. This would further strengthen the findings but could also show a contrast between expert opinions and what the data suggest. The following key points will be carried across to the 5.2 Performance Insights from Data Analysis of the OTD Process

- What key factors are contributing to overall production inefficiency?
- How has the high staff turnover affected production? And how much has changed over the years?
- Incoming material shortages.
- How has adjustments and missing parts affected the delivery accuracy?
- How does each phase (Order, Industrial) affect each other?
- What phase is important to investigate further in the future?

One of the challenges in the qualitative analysis was that not all insights from the interviews could be backed up with numbers. Some points, like better documentation would reduce production errors, are difficult to measure directly. These are based on experience and observations rather than clear data. However, for the points that stakeholders believed could be supported with data, further investigation was done, as shown in the bullet points below.

5.2 Performance Insights from Data Analysis of the OTD Process

This sub chapter presents the results of the data analysis used to compare the performance of the two factories. The focus has been on all three main phases of the OTD process: Order, Industrial, and Market. However, most of the attention has been placed on the Industrial phase- since that is where most of the data was available and easiest to collect.

The main goal has been to investigate three key areas: post-production adjustments, delivery performance, and production disturbances. The data used in the analysis comes from two systems: Tool A and Tool B. Tool A contains what is called "open points," which are any issues that occur during production, recorded using issue cards on the line. Tool B covers the full OTD process and contains information on adjustments, delivery accuracy, and how well the production and delivery dates match the plan.

The structure of the sub chapter is as follows:

- First, the relationship between production disturbances - such as adjustments and missing parts - and late deliveries is analyzed. The aim here is to understand how these issues affect the company's ability to meet promised delivery dates.
- Second, the delivery phase is examined by looking at the average time from production completion to customer delivery. This section highlights how delivery performance has developed over time.
- Third, an analysis of production delays is presented, showing trends over the years and differences between the two factories. This helps to understand whether production issues are connected to delays in delivery.
- Fourth, the data from Tool B is presented, focusing on post-production adjustments. This section explores how adjustments affect the OTD process, and also looks at other key disturbances from 2019 to 2024.

Finally, the subchapter introduces the Open Point data analysis. These reactive production issues are examined to better understand their influence on both adjustment frequency and delivery accuracy. Together, these sections provide a clear overview of how each part of the OTD process is performing and highlight the main areas where improvements are needed.

5.2.1 Empirical findings from system data

The intention was to analyze how many products required post-production adjustments. Initially, the results indicated that Factory 1 had fewer products entering the post-production adjustment phase compared to Factory 2 as shown in . However, despite the higher number of adjustments in Factory 2, the average repair time per product was significantly shorter than in Factory 1. Upon closer examination, it became evident that the data from Factory 2 was unreliable. Observations suggested that mechanics or operators were not consistently following the standardized protocol for logging products into the adjustment process. In many cases, the data showed that the timer had started when a product entered the adjustment area, but then immediately stopped, indicating that the task was marked as completed almost instantly. This behavior suggests a failure to follow established procedures, leading to inaccurate repair time recordings. As a result, the repair time data from Factory 2 cannot be considered trustworthy for comparison purposes. The data analyzed reveal that factory 2 has an average adjustment time close to zero in many of the years examined, although the trend is looking a bit better for 2023 and 2024. However, it is still interesting that as factory 1 produces less products than factory 2, but has almost as many number of adjustments as factory 2 has in 2022.

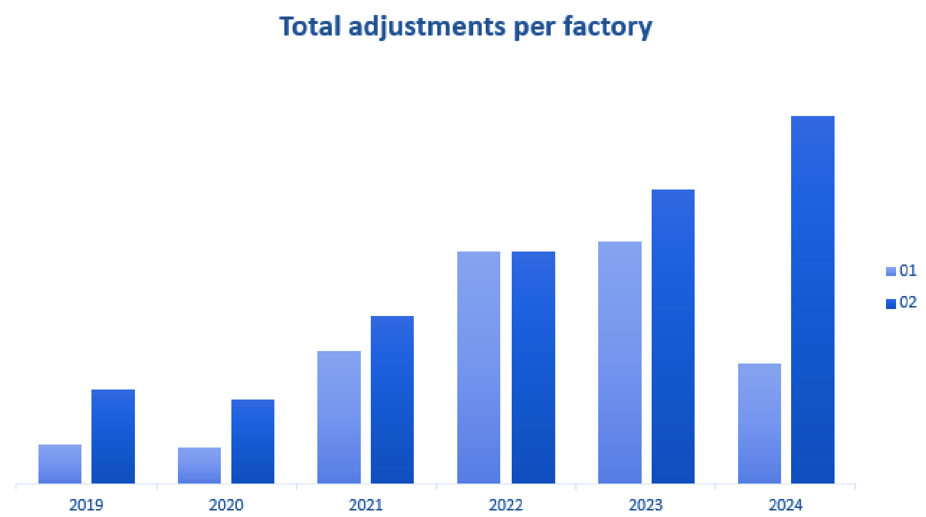

Figure 6 : Total number of adjustments per factory, factory 1 light blue & factory 2 dark blue

5.2.1 Overview of late deliveries when deviations exist

One relevant factor to look at was how many products arrive late to the customer, hence the OTD process is delayed. As shown in Figure 7 a majority of the delays came from factory 2 (Dark blue bars), after the rise of the delays from 2021 and onwards.

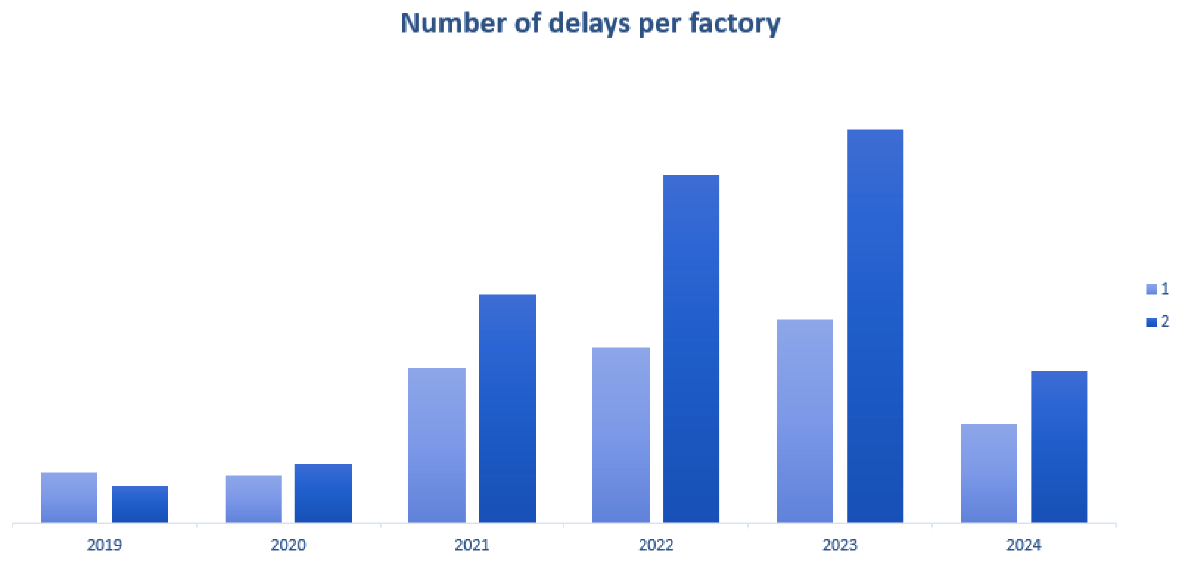

Figure 7 : Number of delays per factory

Since a large number of products have been delayed to customers, the relevant data to analyze was how many days late the products were when adjustments exist in production phase. And in Figure 8 below, you can see that when a product is delayed more than 10 days, a large majority of the products have adjustment. You can also see a trend when going from left to right, that the majority of products that are early don't have adjustment (N), and a majority of the products that are delayed have adjustment (Y). This data is collected from 2019-2024 and is for factory 1 and 2.

Figure 8 is important because here the distribution between how late they are and how much on time they are is illustrated. The main points is that:

- Most common is on time whether the product has adjustment or not (0 days late)
- The second common when the product has adjustment is 10 days late or more.

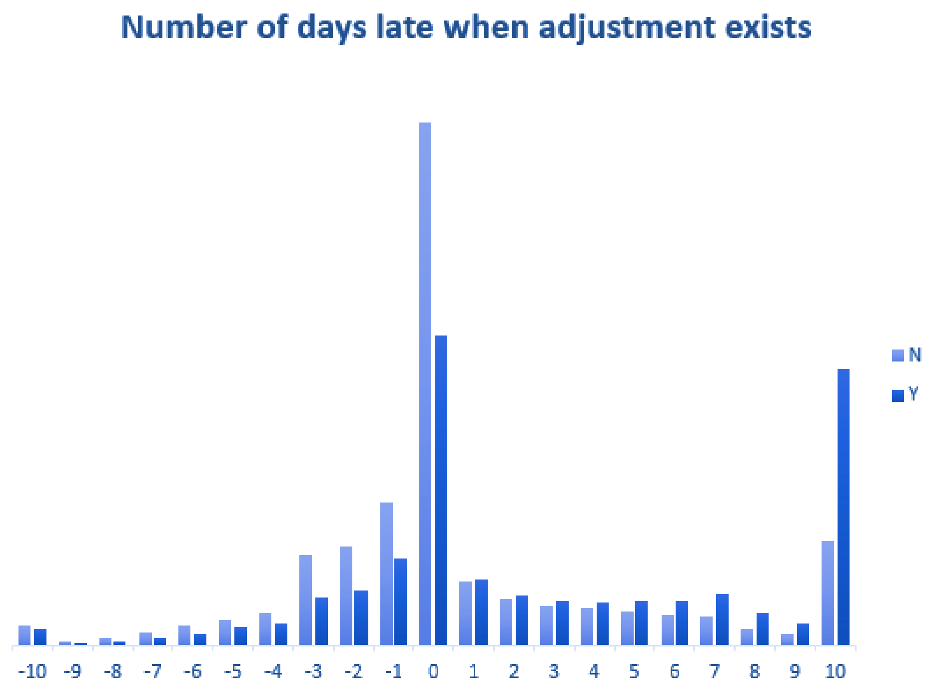

Figure 8 : Number of days late/early when adjustment exists, Adjustment exists = Y, adjustment don't exist = N

Figure 9 was created to investigate another critical area of production-related issues, specifically, the impact of missing parts in production. While missing parts have been highlighted as a major concern within production, the data shows that they do not lead to late deliveries as frequently as adjustments do. This is a positive indicator, especially considering the high volume of missing parts recorded in production. It is important to note, however, one reason for the relatively low number of late deliveries due to missing parts is a decision to deliver to customers even with certain parts missing, provided that the customer approved it.

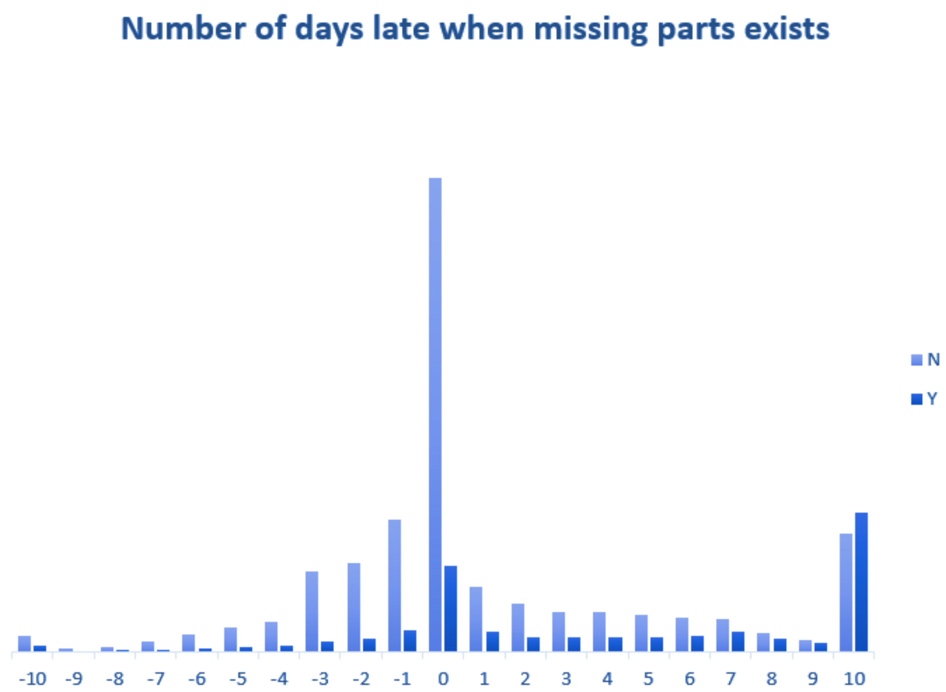

Figure 9: Number of days late/early when missing parts exist, missing parts exists = Y, missing parts don't exists=N

After analyzing how deliveries are affected with adjustment and missing parts the decision to combine both factors seemed interesting. However, the results didn't show any clear evidence that the combination of both results in a late delivery to customer. As Figure 10 had a even distribution between when adjustment and missing parts exists (Y) and didn't exists (N) for 10 days late or more, it showed that when both of these exist it does not differentiate itself too much from when each factor was isolated.

Out of all three figures analyzed within missing parts and adjustment, when late delivery existed, the factor that tended to occur most was when adjustment existed. What is interesting is that 10 days or more is the more common than just one to nine days late. This is critical because it shows that most of the deliveries are very late and not just one or two days when adjustment exists.

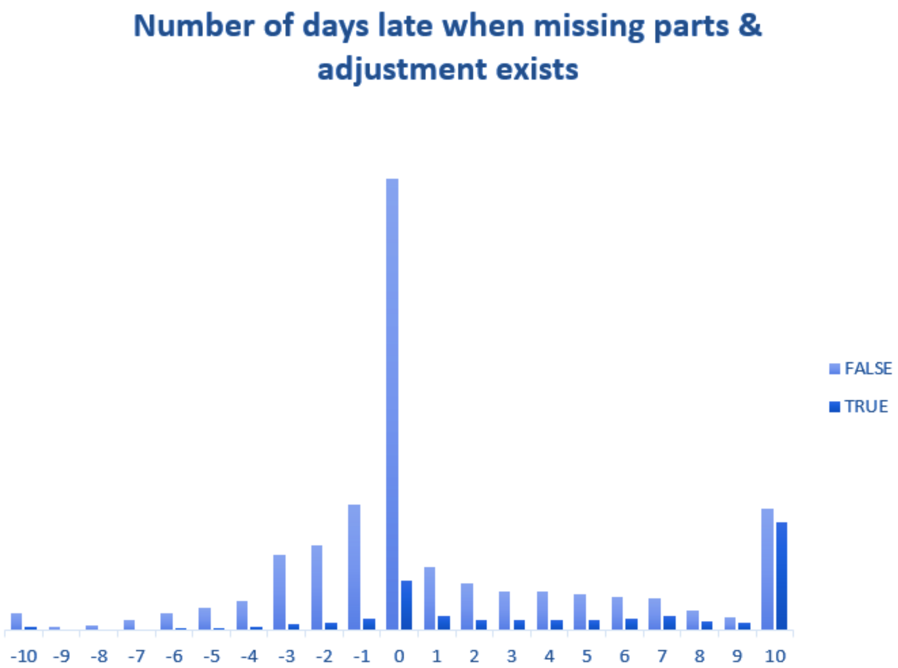

Figure 10: Number of days early/late when both missing parts and adjustment exists

5.2.3 Delivery phase data graphs

For the delivery phase, there were several interesting results and trends that emerged from the data collected. To begin with there was the average time of the delivery phase per factory over the years analyzed. This metric shows the time from production when the production phase ends until the industrial phase ends, and as a result shows the actual delivery phase time. This metric is selected to see if there is a trend going up for the delivery phase time over the years the analysis is spanned over. For factory 1(light blue bars), the average time goes down a bit from 2020 to 2023 but there is no spiking in the metric. For factory 2 (dark blue bars) the average time stays roughly the same over the years as seen in Figure 9. However, factory 1 has a higher average of delivery time due to its location. But overall, it was relatively similar results over the years, and therefore, delivery phase shouldn't be the main contributor to why the products are delayed to customers.

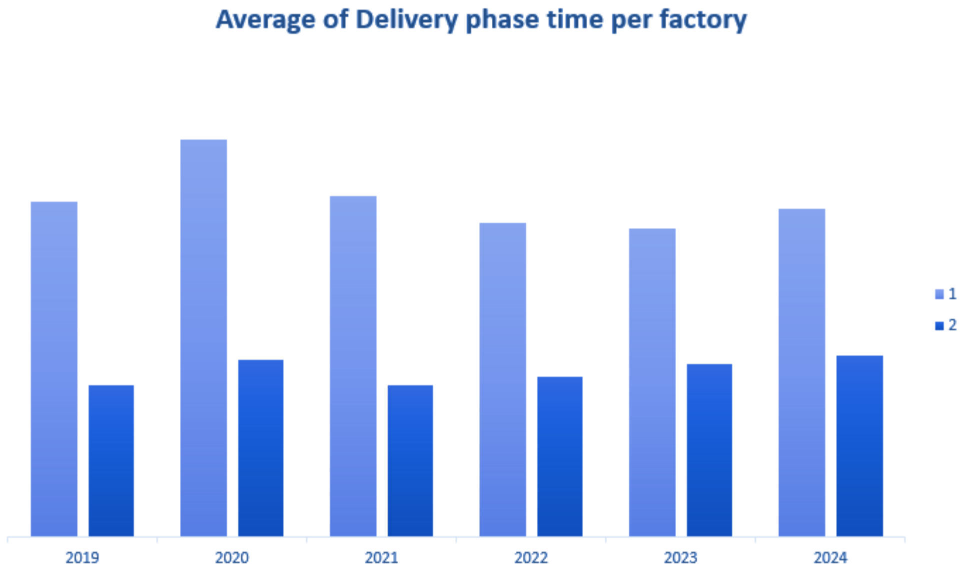

Figure 11 : Average of delivery phase time per factory from 2019-2024

When analyzing performance within the delivery phase, a trend could be found when the product was delivered late to customer and the duration for the delivery phase was above average, as seen in Figure 12 below. Above average in delivery phase means that the products currently in the delivery phase are spending more time than the average expected duration for the delivery phase. The data illustrated that it went up from 2020 and reached its peak in 2023 before showing a decline in 2024 (dark blue bars). This graph follows the same trend as the number of products that was built in the factories over the years analyzed.

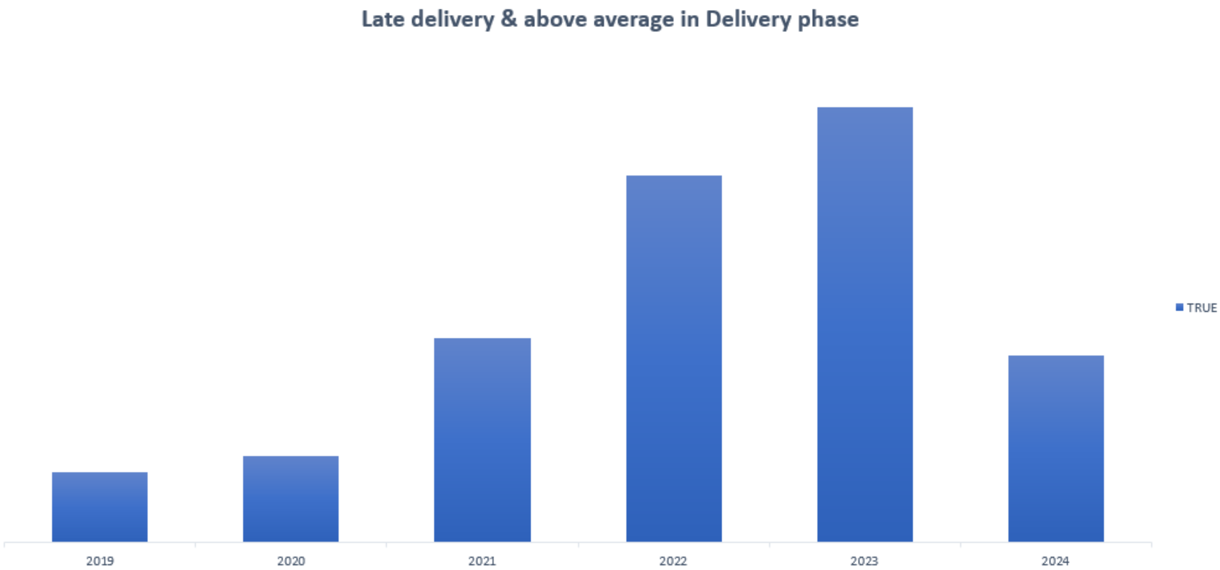

Figure 12 : Late delivery to customer and above average time in delivery phase from 2019-2024

Given the fact that the delivery phase still could be the issue of delayed products and therefore have an increase in nonstandard activities, another factor was analyzed to be certain that delivery phase was not the issue. The factor analyzed was the production phase, when it was completed on time, meaning that the Actual End Date for production was similar to or earlier than planned end date for production phase. As seen in Figure 13 when the production phase was not delayed, the number of delays to customers was significantly lower than expected (dark blue bars), meaning that the delivery phase alone is not the issue and primary bottleneck causing delays to customers, meaning that production phase has to be one of the bottlenecks and key contributor on why products are delayed to customers.

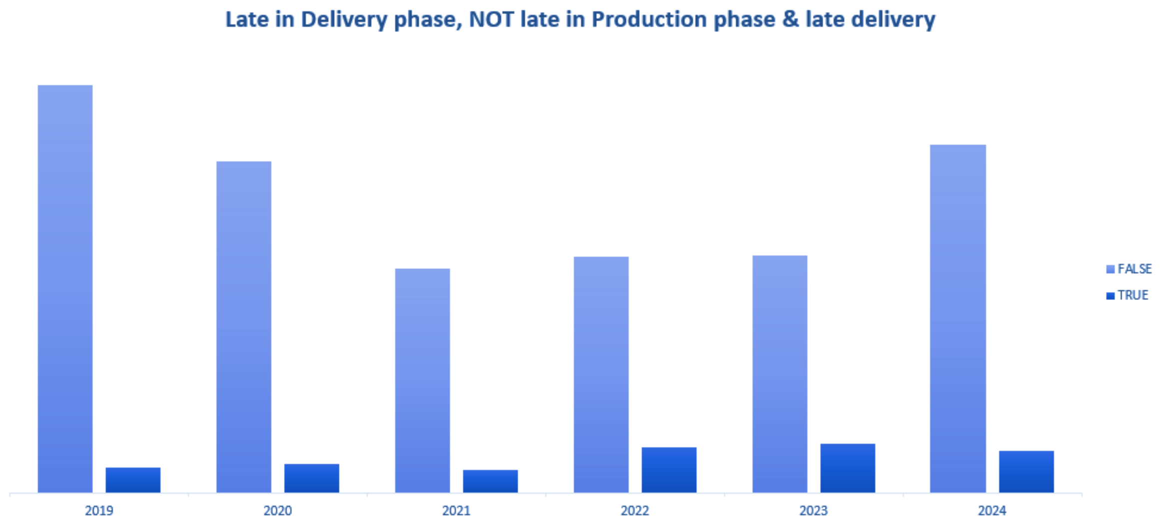

Figure 13 : Not late in production process, above average in delivery process and late delivery to customers, from 2019-2024

5.2.4 Production phase data graphs

To gain a deeper understanding and insights into potential deviations within the OTD process, the next step was to analyze the production process more closely and see if there were any trends to find. After filtering relevant data, a graph showing the number of times production process was late and the product was also delayed to customer at Figure 14 this is the combined total amount of products for both factories, presenting a broader view of the trend. The data indicates a correlation between the factors. When production is late, a large majority of the products are also delayed to the customers (dark blue bars). Additionally, there has been a significant increase in from 2020 and onwards. This trend reinforces the idea that late production has a large effect on downstream processes and affects the customer at the end.

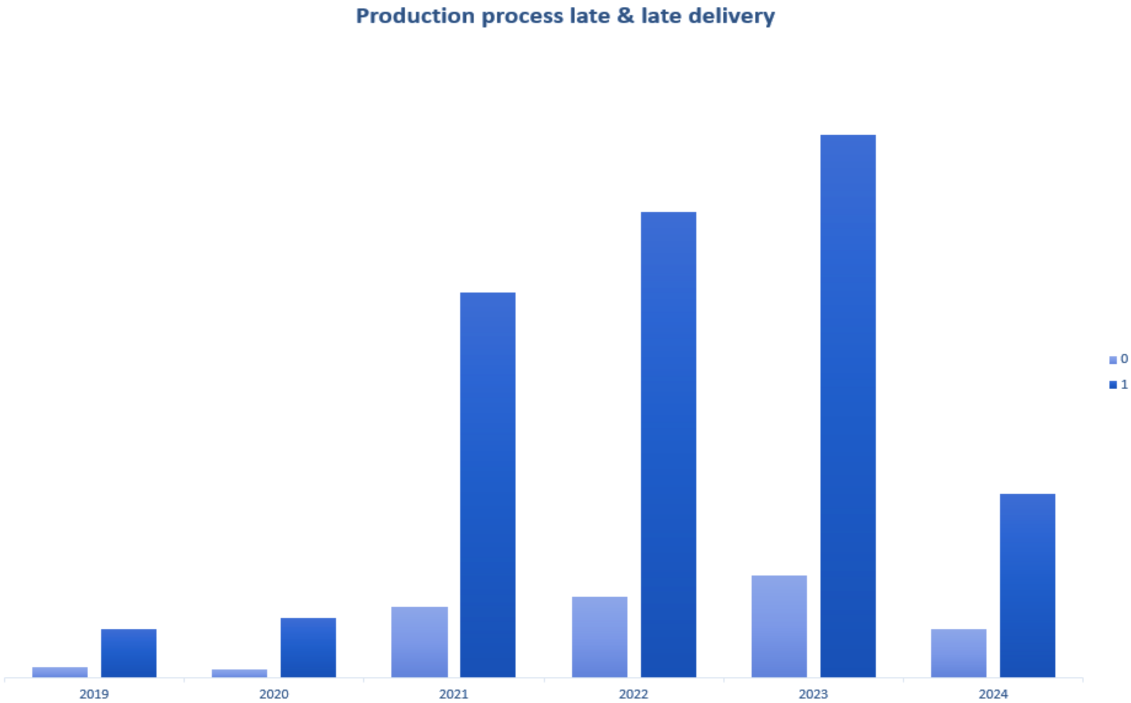

Figure 14 : Late production and late delivery to customers from 2019-2024, where late production & delivery is shown a 1(dark blue bars)

As the production phase was a factor in why it was delayed and therefore had disturbances, further analysis within the production phase was made. One interesting result was when a combination of missing parts, adjustments and campaigns exist, when the products are delayed to customers, as shown Figure 15. Almost none of the products were delayed when analyzing these factors in 2020, but after that, it went up enormously. This trend is similar for both factories, only in 2024 there is a major difference between the two factories as factory 1(light blue bars) had a larger decrease compared to factory 2 (dark blue bars). This shows that when a product are delayed, adjustment, missing parts and campaign can be one of the factors that may contribute to the delay.

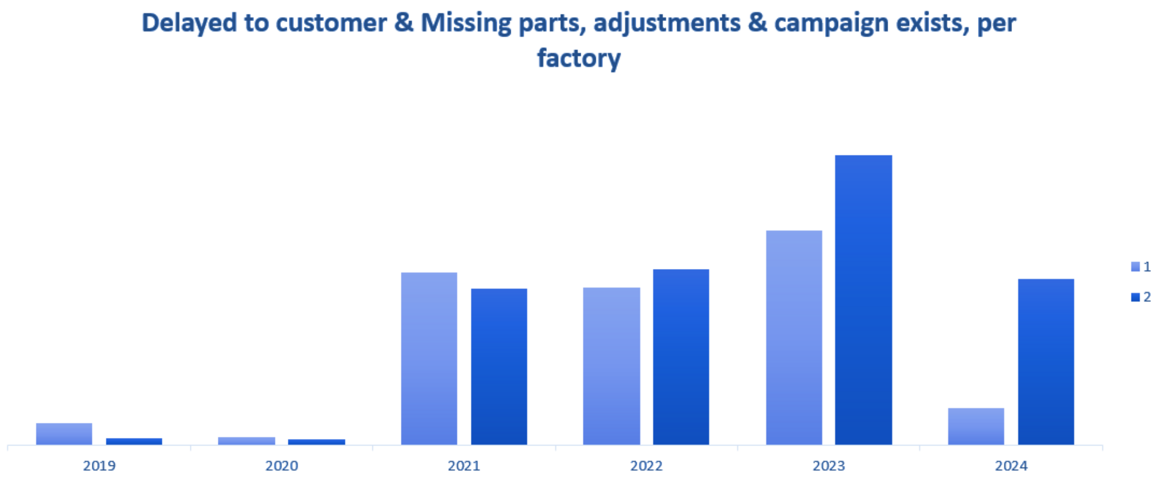

Figure 15: count of how many Products delayed to customer and missing part, adjustment and campaign exists on the product, per factory, factory 1 is light blue bars, and factory 2 has dark blue bars.

Workshops are another factor that have gone up over the years, as more customers want customer adaptation of the products. When the product is delayed and workshop exists, there is a tremendous difference between the factories, as seen in Figure 16 . In 2019, there were almost the same number of delays, but after that, factory 2 (dark blue bars) did go up in contrast to factory 1 (light blue bars), who stayed at the same level throughout the years. One noticeable thing about this is that in both factories the number of products entering the workshop phase went up very much during these years. This also aligns the analysis done in 3.4.4 The 4 Dimensions of Operations The variety increase is evident. As variety has increased and at the same time delays to customer, factory 2 has had a great increase but ending 2024 with a steady decline back to better performing values close to the ones in 2019, 2020.

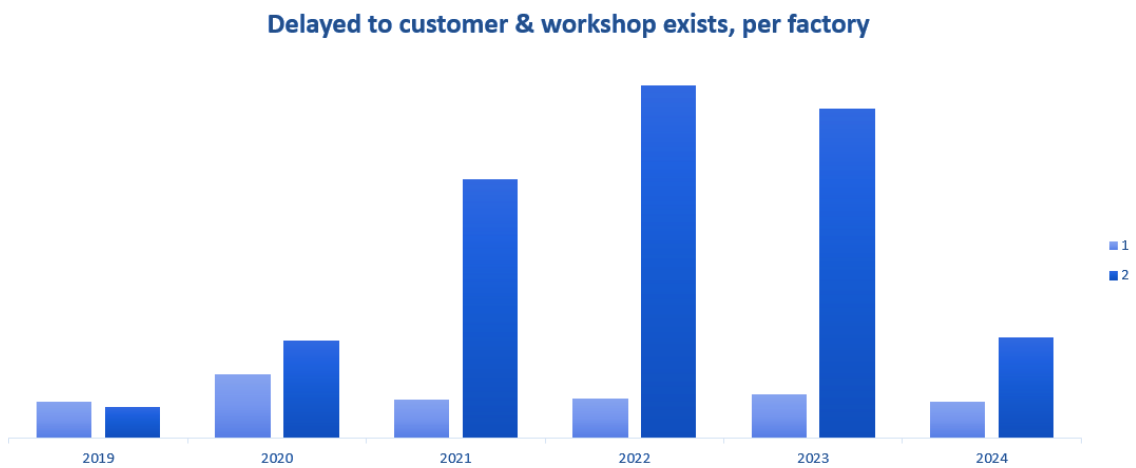

Figure 16: Count of how many products delayed to customer and workshop exists, per factory

When analyzing the production process, a comparison between planned end date and actual end date was performed, meaning how "fast" the production phase is. As a result, the average days was shown of production phase was early or late, for both factories as shown in Figure 17 . Before 2020 a lot of products were produced early from the production phase, however, after 2020 the production phase begin to be more late than early. The factories had a similar trend, but factory 1(light blue bars) has a higher peak during the years 2021-2024 compared to factory 2 (dark blue bars) even though the production capacity is higher in factory 2.

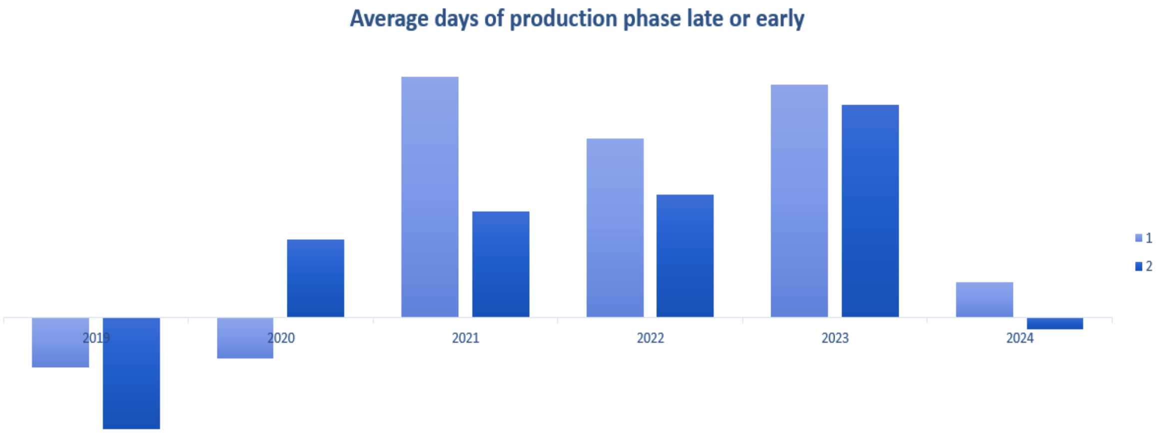

Figure 17 Average days of production phase late (above the zero point mark) or early per factory, from 2019-2024, where factory 1 is light blue bars and factory 2 is dark blue bars.

5.2.5 Correlations between production disturbances and late deliveries

This subchapter aims to find links between production problems and delivery accuracy. Comparing the implications of adjustments, missing parts and how that affects the OTD process.

An important part in the analysis was to see the effects adjustments have on the OTD Process. Leading to finding correlations between disturbances and adjustments is important. Figure 18 shows a significant increase between 2020-2023 with a large decrease between 2023-2024.

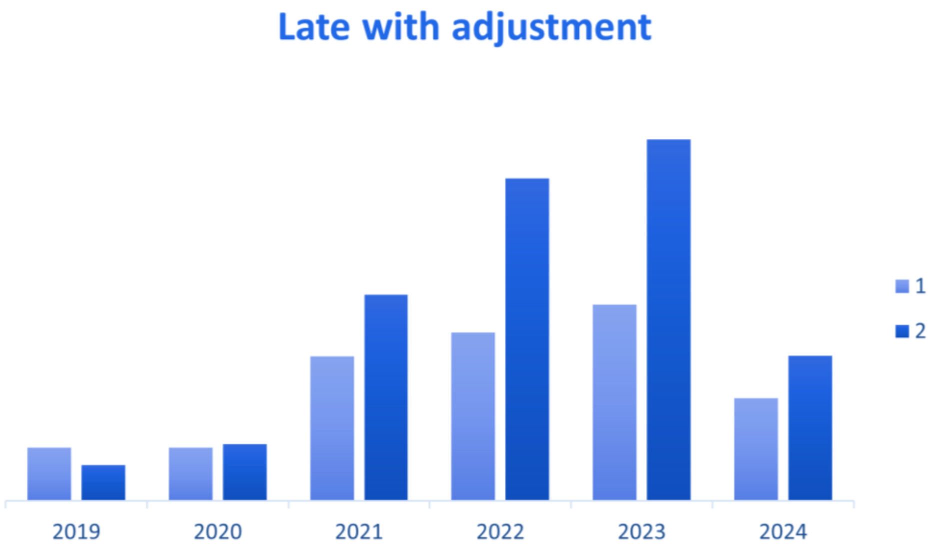

Figure 18: Total number of products late to customers and had adjustment annually per factory.

The graph shows the number of products that were delivered late to customers and were in the adjustment phase. An important fact to keep in mind is that the year 2022 and 2023 were big years in total volume produced which aligns with the 4V analysis in chapter 3.4.4.

Furthermore, the percentage of adjustments of the total volume produced was investigated as highlighted in Figure 19.

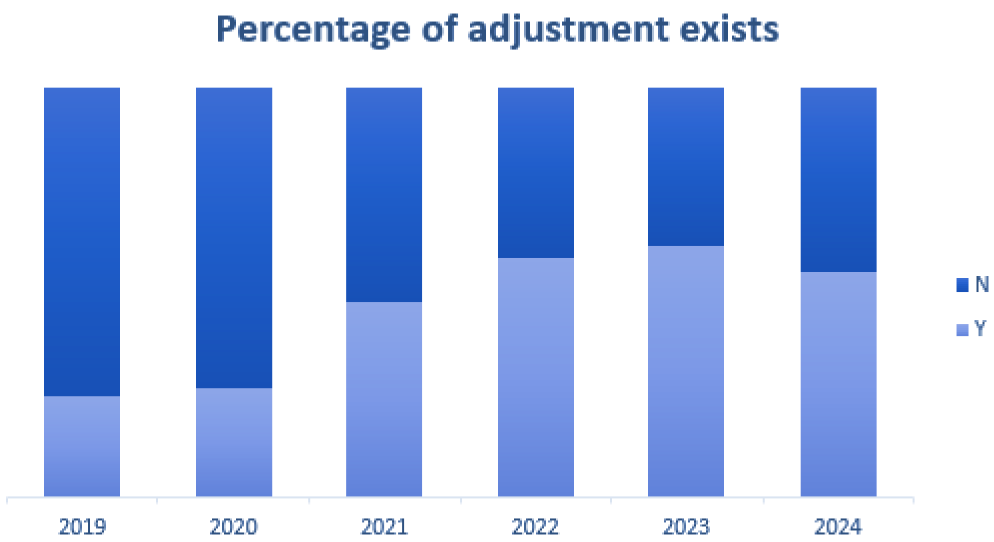

Figure 19 Percentage Adjustments of total volume

The rise in adjustments have been rising since 2019 with a slight decline from 2023-2024. The percentage of products that require adjustments have almost tripled since 2019.

When observing and comparing Figure 18 and Figure 19 it shows a pattern between the increase in total volume produced and the increase in adjustments. At the same time as the percentage of adjustments increased there has also been an increase in late deliveries when there was an adjustment done on the product. This is important because the most important part of a successful business is happy customers and for the company customer satisfaction is crucial because the competition is fierce. Now the rise in late deliveries and adjustments made is crucial.

5.2.6 Statistical Significance for Multiple Variables

To find out if some of the variables that have been studied had any statistical significance a chi-squared test was calculated. A total of 5 variables was accounted for:

1. Adjustment (reference variable)
2. Missing Parts
3. Workshop
4. Campaign
5. Late production

Adjustments stayed consistent and kept as the reference variable when comparing the variables in the chi-squared test. To complement the chi-squared test, Cramér's V was calculated to assess the strength of the association between the variables. While the chi-squared test tells us whether a statistically significant relationship exists, it does not indicate how strong that relationship is. Cramér's V is a standardized effect size measure for categorical variables that range from 0 (no association) to 1 (perfect association).

$$Cramer\ V = \sqrt{\frac{x^2}{n(k-1)}}$$

Figure 20 Cramer's V equation

The results in Table 2 showed that missing parts and late production had a moderate association. This means that, while the relationship is statistically significant (as shown by the chi-squared test) the rest had low association.

Table 2 Summarization of 4 tests with one reference factor (adjustment) being constant and compared to the other 4 variables.

Adjustment (Reference factor)	Missing Parts	Workshop	Campaign	Late Production
Chi- Squared test (P-value)	<0.001	<0.001	<0.001	<0.001
Cramer's V:	0.329	0.023	0.038	0.305
Correlation for Chi-sq	High	High	High	High
Strength for Cramer's	Moderate	Low	Low	Moderate

5.3 Open Point Data Analysis

This subchapter will be diving deeper into production-related problems. Namely "Open points" gathered from Tool A which refer to all types of irregularities in the production process that is not resolved before the end of production line, hence the word "open".

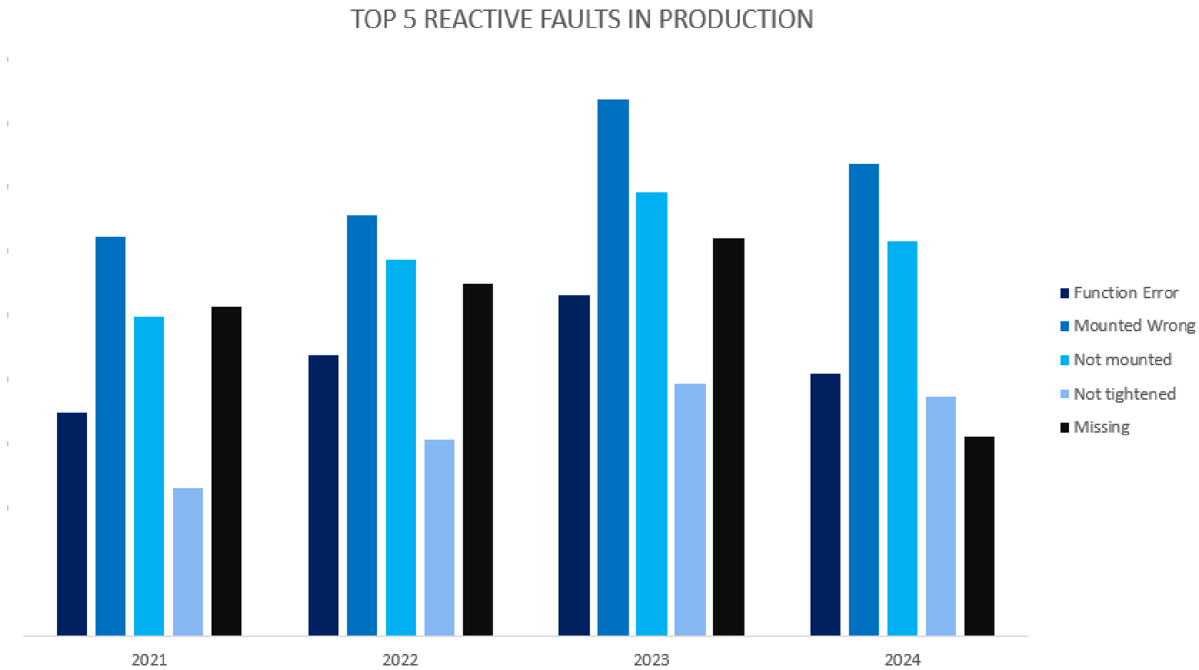

Figure 21 Top 5 reactive faults summarized per year for factory 1

As illustrated in Figure 21, the top five open points fault types have been summarized by year. These five fault categories are:

- Function Error
- Mounted Wrong
- Not mounted
- Not tightened
- Missing

And they account for nearly 70% of all faults that occurred in production. The graph reveals a clear upward trend in the occurrence of the following fault types for factory 1:

- Function error
- Mounted wrong
- Not mounted

Each of these increased steadily from 2021 to 2023, with a minor decline observed from 2023 to 2024. On the other hand, "Not tightened" faults remained about the same levels, showing neither significant increase nor notable decline. Moreover, "Missing" meaning missing parts/material had a steep decrease from 2023 to 2024.

However, the documentation of these faults leave too much room for interpretation. For instance, the category "Mounted wrong" can come from multiple underlying issues. It may refer to an operator mounting a component incorrectly, or it could indicate a misalignment issue where a previous part was already incorrectly positioned, leading to downstream mounting errors. Similarly, the "Not tightened" fault type is ambiguous. It could mean the screw was not tightened at all, was under-tightened, or that it was damaged and could not be tightened properly. All those had an increasing trend from 2021-2023 with a slight decline from 2023-2024.

This uncertainty stresses a limitation in the current data collection approach: it lacks standardization. Problem descriptions in tool A are entered using free-text input, which reduces the ability to conduct a consistent breakdown of the problem.

Although the dataset does not strictly align with the Pareto principle, the concentration of faults within these five types is still significant. Addressing them could yield notable improvements in reducing production errors. Unfortunately, many of these faults are given a low priority score in the fault severity ranking system. As a result, they receive minimal attention, and their root causes remain unaddressed. Moreover, a substantial portion of these issues never make it to the factory's adjustment zone, further diminishing the opportunity for systematic improvement.

Factory 2 was also looked in to when it came to open points. A different report system is used, and therefore it is difficult to directly compare the two factories. The four largest groups of faults reported for factory 2 are Assembly NOK (Not OK), Administration NOK, not functioning, and missing. These 4 fault types cover approximately 80 % of the total faults in factory 2 and can be illustrated in Figure 22 below.

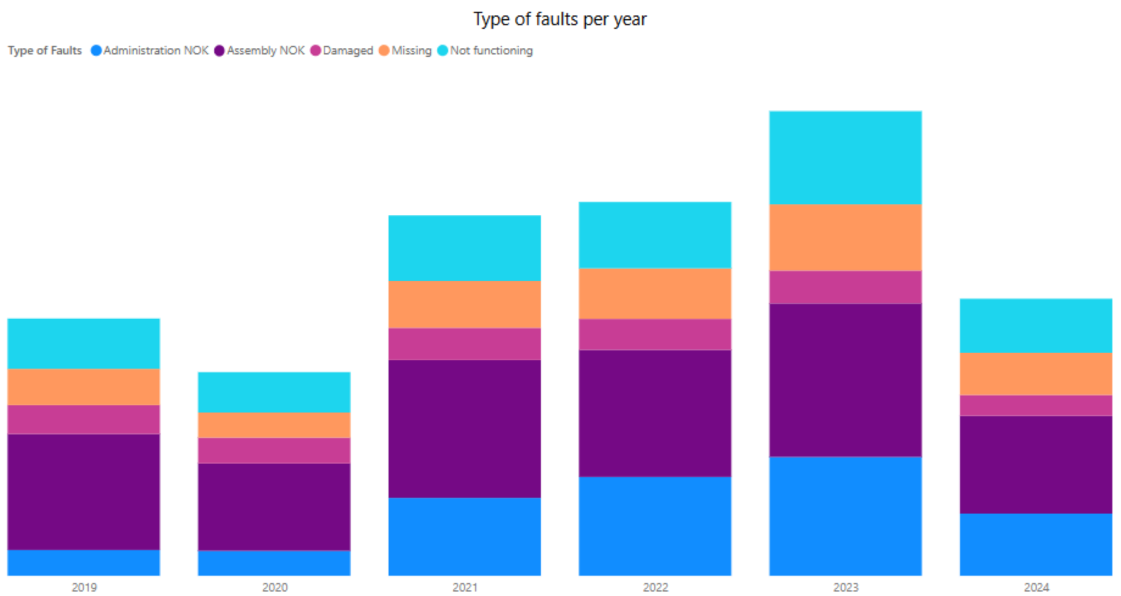

Figure 22: Type of faults in factory 2 over the years 2019-2024

As for Assembly NOK it includes all problems related to the assembly line, such as parts mounted wrong, not tightened and not mounted. This type of open points is the largest for the factory, but the trend over the year show only a slight increase in assembly faults when analyzing the years from 2019-2024.

The second largest group for factory 2 is administration NOK. In this group a large increase in faults has been occurring since after 2020. There could be different explanations for this, but according to interviews, the most common explanation is that the people in factory 2 have another way of working, and this is a similar problem to what they do within the adjustment phase, they are not reporting the problem correctly and according to company standardization. For example, one of the largest fault groups in administration NOK are that the assembly workers don't fill in the report card for the products as they are supposed to do. For example, when a product has a problem on the assembly line and the fault or problem is reported, some can also fix the problem right away. But then it is important to also report that it is fixed, according to interviews with people working in the factory. If it is not reported correctly, the product needs to go into adjustment phase after the assembly line to do a quality check to see if the problem has been fixed or not, and this takes up a lot of extra time and space for the adjustment workers and can be shown in the Figure 6 as the adjustment is higher for factory 2.

The third and fourth largest group within factory 2, not functioning and missing, can be related to the supply chain issues and suppliers to the company. As mentioned earlier in interview with the Production Logistics Manager, there was a shortage of many parts during the years analyzed and therefore many parts were missing, and the company needed to expand and use other suppliers, who produces parts that perhaps wasn't of the right quality or quantity, leading to an increase in the parts not functioning. In Figure 22 an increase in both missing parts, and parts not functioning can be shown, with a peak in 2023.

5.4 KPI summary for both factories.

Table 3 provides an overview of Factory 1's average staff turnover among blue-collar workers including consultants, along with the total number of deliveries late. It also includes the number of "open points," annually which refer to identified production faults, whether resolved or not- excluding any follow-up faults. No data was available for 2019, 2020 and have therefore been given "N/A".

Table 3: Overview over KPI's for factory 1

Factory 1	2019	2020	2021	2022	2023	2024
Staff Turnover (%)	11,88	7,92	7,72	8,52	8,8	10,84
Delays	1552	1439	4742	5359	6228	3014
Sum of open points (OP)	N/A	N/A	67493	73154	87024	72800
Total products produced	6 339	5 997	7 869	10 104	10 873	8 046
Delays/ Product	0.24	0,24	0,63	0,53	0,57	0,37
Faults (OP)/ Product	N/A	N/A	8,57	7,24	8,0	9,04

The idea was to identify potential patterns between periods of high staff turnover and an increase in production faults. However, no clear or consistent pattern emerged. The data does not indicate that higher staff turnover leads directly to lower production quality.

While employee turnover fluctuated slightly over the years, no significant variations were observed, except in 2019, which showed the highest turnover as shown in Table 3 above. The only variables that seem to relate to the number of faults in production is total volume produced annually. As production faults were interesting to dive deeper into, it seemed reasonable to analyze faults per product because many of the graphs are based on volume rather than the ratio, this shows that in table 3 the ratio was 8.57 per product for 2021 and as of 2024 it was 9.04.

Table 4 Factory 2 overview of KPI's

Factory 2	2019	2020	2021	2022	2023	2024
Staff Turnover (%)	8,16	3,24	8,56	10,32	11,68	9,48
Delays	1131	1806	7005	10621	12043	4664
Sum of open points	31 840	25 512	44 140	45 884	55 172	32 544
Total products produced	14 874	12 118	14 998	16 598	18 616	15 642
Delays / Product	0,07	0,1	0,47	0,64	0,65	0,29
Fault (OP) / Product	2,14	2,10	2,94	2,76	2,96	2,08

Factory 2 shares similar patterns as Factory 1 in average staff turnover among blue-collar workers including consultants, along with the total number of deliveries late. The open points start with 31 840 and increase to the maximum of 55 172 for 2023. However, a significant decline is showed between 2023-2024. Year 2021-2022 have no apparent change. But the overall ratio of faults per product is roughly the same as it was in 2019. Faults per product stayed about the same levels from 2019-2024.

Similarly to factory 1, factory 2 seems to follow the same trend, delays also increased and had the peak in 2023 with a staggering 12 043 late deliveries to customers. As for delays per product, in 2019 it was 0.07 and as of 2024 the ratio was closer to 0.3 per product which is a large increase. However, the positive side is that compared to the previous year (2023) the decrease of delays per product is significant.

6. Optimal Flow Analysis: Expected level & prioritizing factors

This chapter aims to provide a high-level overview of the disruptions within the Order to Delivery (OTD) process. Additionally, it presents a proposed visualization of an optimal process flow, informed by insights from the literature study. Since achieving optimal flow across the entire OTD process can be viewed as aligning the broader supply chain, the chapter also introduces five Key Performance Indicators (KPIs). These KPIs were developed systematically, based on both relevant literature and the perspectives of experienced employees. They are proposed as areas of focus to help stabilize and improve the OTD process moving forward.

6.1 Analysis of high-Level Disturbances in the OTD Process

The company's structure for the OTD process leaves little tolerance for deviating from the OTD Process. In an interview with a Digital Product Manager, it was emphasized that one of the key factors of an optimal flow is ensuring that the Planned Production End (PPE) is met as scheduled. Equally important is the Confirmed Delivery Date (CDD), the promised delivery date to the customer. Which serves as a critical KPI in the OTD process.

For the OTD there are essentially 5 main scenarios that can occur and are shown in Figure 23 below.

1. Everything goes according to the plan (Production & distribution on time).
2. Production is completed earlier than planned. (PPE not followed)
3. Production is delayed.
4. Early Production with ASAP acceptance from market.
5. Distribution late.

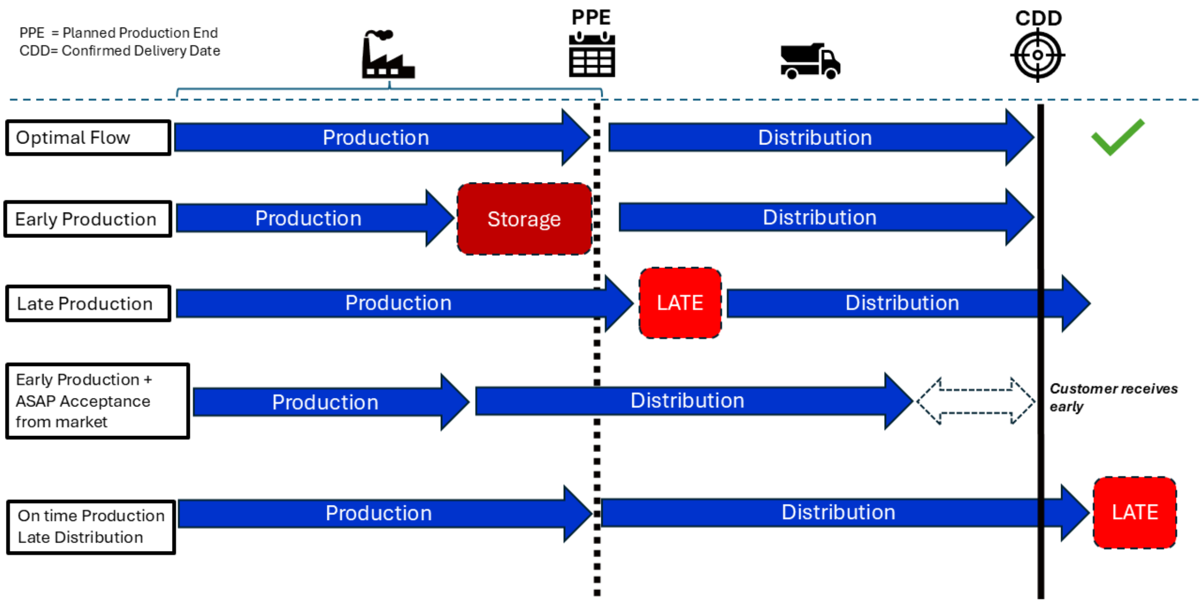

Figure 23 OTD Process with disturbances and key KPI's

Scenario 2, 3, 5 introduce disturbances into the flow and deviations from the planned process.

In the third scenario (production delayed) a domino effect takes place. The company often attempts to compensate by accelerating the distribution phase, which shortens the time available for delivery and being late from production increases the risk of missing the CDD. As illustrated in Figure 23, the OTD process is sensitive to such delays, highlighting the importance of PPE being followed.

The second scenario, production being completed too early also disrupts the flow. In such cases, products are stored in the yard until it is time for the original scheduled distribution date. They are not shipped earlier unless the customer explicitly agrees to receive the product ahead of schedule, a process referred to as "ASAP acceptance from market" (scenario number 4). Without this approval, early production results in a longer inventory than planned, which from a financial perspective is disadvantageous because it becomes tied up capital. Additionally, when a product is produced earlier, the company would like to deliver it earlier, but they cannot because it triggers premature invoicing and the CDD is what they agreed upon. There is, however, a little bit of a buffer built in; the product can be delivered a few days earlier than agreed upon.

From the customers' perspective there are several reasons for not wanting to receive them earlier, particularly because in many cases it has not been anticipated in their financial planning according to the Product Digital Manager. There are also additional complications for the customer such as them perhaps not being able to store the product anywhere due to storage capacity not being planned for or the demand for the product not being accounted for resulting in the product standing still, again showing the importance of CDD being adhered to.

The significance of aligning with the CDD lies not only in customer satisfaction but also in maintaining a stable and predictable OTD process. Any deviation from the planned production timeline, whether early or late, introduces misalignment between what was expected by the customer, what was planned internally, and what actually occurred. These disruptions highlight the importance of precision and synchronization throughout the OTD process to achieve optimal flow.

6.2 Prioritizing factors for Optimal flow within OTD Process

Based on the factors within supply chain for the optimal flow, shown in Table 1 in theoretical framework, a ranking of these factors was made to find which were the most important factors for the company to work with to establish an optimal flow within the OTD Process and corresponding supply chain. For the supply chain factors, a Pugh matrix was created to evaluate the factors against each other to find out which factor is the best. The factor with the highest overall score is the best. The Pugh matrix for the supply chain factors are shown Figure 24 below and the top five factors are:

- Frequency of redesigns of products (D)
- Frequency of delays for critical material (F)
- The quality of critical material (G)
- Level of customization (P)
- Ability to adjust internal production capacity (Q)

These top-ranked factors indicate that the interface between sourcing and production flexibility is the most important and critical area for the company to manage. In the Pugh Matrix the factors are compared to each other and are given a plus (+) when the factor is more important than the factor compared to, and a minus (-) when the factor is less important, and a zero (0) when the factor is similar to the factor compared.

	Pughmatrix																	
Utfärdare: Fredrik & Martin																		
Criterias	Criterias																	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
A	0	-	+	+	+	+	+	+	-	-	-	-	+	+	-	-	+	-
B	+	0	+	+	+	+	+	-	+	-	+	-	-	+	+	+	+	-
C	-	-	0	+	-	+	+	+	-	0	-	-	+	0	-	+	+	0
D	-	-	-	0	-	+	+	-	-	-	-	-	0	-	-	-	0	0
E	-	-	+	+	0	+	+	-	-	0	+	-	0	0	-	0	+	+
F	-	-	-	-	-	0	0	-	-	-	-	-	-	-	-	-	0	-
G	-	-	-	-	-	0	0	-	-	-	-	-	-	-	-	-	+	0
H	-	+	-	+	+	+	+	0	-	0	+	-	0	-	-	0	+	+
I	+	-	+	+	+	+	+	+	0	+	+	+	+	+	+	+	+	+
J	+	+	0	+	0	+	+	0	-	0	0	-	-	+	-	0	+	+
K	+	-	+	+	-	+	+	-	-	0	0	-	-	0	-	+	+	0
L	+	+	+	+	+	+	+	+	-	+	+	0	+	+	+	+	+	+
M	-	+	-	0	0	+	+	0	-	+	+	-	0	0	-	+	+	0
N	-	-	0	+	0	+	+	+	-	-	0	-	0	0	-	0	+	0
O	+	-	+	+	+	+	+	+	-	+	+	-	+	+	0	+	+	+
P	+	-	-	+	0	+	+	0	-	0	-	-	-	0	-	0	+	-
Q	-	-	-	0	-	0	-	-	-	-	-	-	-	-	-	-	0	-
R	+	+	0	0	-	+	0	-	-	-	0	-	0	0	-	+	+	0
Σ+	8	5	7	12	6	15	14	6	1	4	7	1	5	6	3	8	15	6
Σ 0	1	1	4	4	5	3	3	4	1	6	4	1	6	7	1	5	3	7
Σ -	9	12	7	2	7	0	1	8	16	8	7	16	7	5	14	5	0	5
Score	-3	-7	0	10	-1	15	13	-2	-15	-4	0	-15	-2	1	-11	3	15	1
Ranking				4		1	3									5	1	

Figure 24: Pugh matrix of optimal flow factors

When comparing the factors from the Pugh Matrix with the fault types from the open points, you can see several strong correlations between them. For example, the more redesigned of a product are (factor D), new parts and processes enter the assembly phase, meaning that the operator on the assembly line needs to learn a new work step, such as a new order of mounting the parts. The frequency of delays (factor F) has also a connection with the open points as many open points are missing parts. For the quality of critical material (factor G), a similarity between the factor and function error in open points exists. The level of customization (factor P) has increased for the products, and more products have entered the workshop process during the years analyzed. For the ability to adjust to internal production capacity (factor Q), it has a correlation between several factors. When production utilization is high, several assembly faults occur, such as mounted wrong. When the utilization is low, too many products can enter the delivery phase too early, so the products can stand on the yard for too long as the production phase can be done early as shown in Figure 17. For all five factors, they all can be a part of the disturbances in the OTD process, especially in the assembly process. All factors can also increase the administration faults that increased in factory 2.

As the company has faced challenges with late deliveries to customers, the optimal flow needs to be reliable and precise. In the OTD process, a focus on Confirmed Delivery date (CDD) when it comes to delivery reliability is of great importance. Delivery reliability refers to the company's ability to consistently deliver products or components on or before CDD. It reflects how trustworthy and predictable the delivery performance is over time. It can be inferred that high delivery reliability is critical for building customer trust and maintaining efficient downstream operations. It is likely that if delivery reliability is low, customers may receive products later than expected, leading to dissatisfaction and disruption in their own operations.

In the company's current OTD process, issues such as delays between production end, actual shipment, rework requirements, or material shortages reduce both reliability and precision. Improving the accuracy of planning tools like PPE and CDD will directly enhance both metrics.

To reach this goal of optimal flow within the company, and to have a reliable and precise process, the following equation needs to be considered:

Equation 4: Optimal flow equation

$$PDD = CDD = ADD = DDD$$

Where PDD is Planned delivery date, CDD is Confirmed delivery date, ADD is Actual delivery date and DDD is Desired delivery date. When all four dates align, it can be reflected as a fully optimal flow within the OTD process. As PDD is set in the order phase, CDD and ADD is set in the industrial phase and DDD is set by the market. all is connected to this formula. This requires improvements in forecasting, production planning, production, supplier reliability and internal coordination. If working towards this, the company can reduce lead times by having less nonstandard activities in the OTD process and therefore increase customer satisfaction.

7. Discussion

In the chapter of discussion, the research questions are discussed based on the results of the data, interviews and other sources. The discussion is divided into subchapters that cover the most important findings throughout the OTD process.

7.1 Organizational & Operational Differences

During the study, a clear difference between the factories became evident on how they influence the efficiency and reliability of the OTD process. Multiple different factors explain why the factories perform and act differently and why they perhaps need to be different as well. One major difference between the factories are the cultural differences, as they are located in different countries, with different ways of thinking towards the processes, such as how they manage to report when an open point exists.

The workshop process has increased a lot, as the customers want more adaptation on the products, but as seen in Figure 16 the workshop can also be one of the reasons why the products are late to customers, especially from factory 2. One of the reasons behind this trend could be that factory 2 has more complex customer adaptations compared to factory 1 and therefore has more time in the workshop process. Although the workshop process is regarded as a standard activity within the OTD process, it may affect and disturb the processes more than you might think.

7.2 The importance of sticking to the production plan for reaching an optimal flow

When analyzing the production process, one noticeable detail was the relationship between Confirmed Delivery Date (CDD) and the actual end date of production. During the years 2021-2023 it was more common that Actual end date production was so late and was still being built, after the date when the product should be received at the customers. This means that a large deviation of some kind has happened in the production process, whether due to material supply, rework or scheduling issues. However, according to the data this is not so common anymore, the trend has shifted and now it's the other way around, the production is finished before Planned Production End (PPE). This might seem positive, but it comes with other challenges instead. For example, the products stand in the yard for too long and take up limited space and might lead to the products entering the adjustment phase again for additional checkup. The observed trend could indicate that the planned production are currently overestimated and it creates a misalignment in planning accuracy. This will be an issue for the factories, as the yard space might decrease in the next few years, and therefore it is extra important that the planning of products is correct.

7.4 Signs of Stabilization and Process Improvement in 2024.

When the data was analyzed, a trend was shown that for almost all data analyzed in Tool A and Tool B, the trend went down for 2024. Data collected in open points, but also in number of products built, products delayed, adjustment exists, and missing parts exists was all going down for the year 2024. On one hand, this trend shows that some improvements in the process could already have been made, such as problems within the supply chain and sourcing, where the company has found other partners to cooperate with. Also, improvements within the internal logistics have been made, as stated by the Production Logistics Manager where the company has a new Production Extended Logistic Center, more digitalization tools and have put an end on when material overflow the factories when production are standing still. But there can be other reasons why this trend is shown. As less products are being built in 2024 compared to the record year 2023, less open points and adjustments also occur in the data.

7.3 Correlation between key production disturbances and literature review.

The five factors that were generated through the Pugh matrix (Figure 24) were similar to the five largest open points problems (Figure 21). Moreover, the five factors also align with the insights gathered from the interviews. When analyzing the data, it becomes clear that Factory 2 experiences more delays than Factory 1, as shown in Figure 7 . This is not surprising, given that Factory 2 produces a higher volume of products. However, Factory 1 and 2 has almost the same number of delays per product, as shown in Table 3 and Table 4 , which indicates that higher number of variants or frequent redesign can be an issue. This is further supported by the insight from the Quality Manager, who explained that there has been an increase in the number of new product variants in recent years. The resulting disruptions however, such as faults or process adjustments, only had a short-term impact within the production. These issues mainly occurred during the initial implementation of the new variants on the assembly line at Factory 1, after which the process stabilized.

Furthermore, the frequency of redesigns has increased over the years. Redesigns include new model introductions, smaller model updates and redesigns in general that affect the models they have according to the interviewees. What could have a negative effect on the production is the updates of current models, fosters more variation in new areas they don't have the same amount of knowledge and more variants for each station to learn in the production line, which can lead to more faults.

The insights from the Production Logistics Manager explained that the shortage of materials and critical components has been a huge issue. First the pandemic and then the semi-conductor's crisis, as well as the Suez Canal crisis, which delayed or made a shortage of critical components for the product. The factor "Frequency of delays for critical material" might have a correlation with the
5.3 Open Point Data Analysis, as one of the factors, "missing" was in the top five for the open points data, which can be interpreted as when material or parts are missing, delayed, or shortage.

The "quality of critical material" is an important factor and can be tied to the number of functional errors in open points, as seen in Figure 21 . Another word for functional errors can be quality errors. This data point has increased for the years analyzed and can be due to a shift in suppliers, as the company changed their sourcing strategy, going from multiple sourcing strategy until recently having a single sourcing strategy. Having multiple sources can imply bad quality of the parts that the company needs as it leads to less supplier audits and quality control, and the function errors therefore go up in the factories. However, a shift is seen for year 2024 as functional errors are going down and therefore, the quality of critical material can have increased and functional error decreased due to the single sourcing strategy. Single sourcing can strengthen supply chain quality as it usually creates a stronger buyer-supplier relationships (Namndar, et. Al, 2018). The buyers are then more likely to invest in supplier audits, collaboration and even co-development of the parts to improve quality levels. According to Namndar, et. Al (2018) multiple sourcing have a more complex logistic chain, and the buyer has a limited negotiation power and weaker partnership, this can lead to the supplier prioritize other customers before the company, and therefore both quality can decrease and supply chain becomes less stable.

Standardization is often used to increase speed and reduce variation, which helps operators make fewer mistakes and improves overall stability (George, M. L. 2002). However, in the context of the company, compared to others in the industry, they offer quite a high level of customer adaptation, both through workshop input and direct customer requests.

Furthermore, at what point does Customer Adaptation (CA) become too much? Several frameworks such as 4V's, Lean theory, Six Sigma, explained in the Theoretical Framework highlight the fact that high levels of customization often lead to greater variation in production issues. This is something to reflect on whether the combination of customer adaptation and a modular approach might be nearing its limit.

Established theories like the 4Vs framework (Slack et al., 2004) point to the challenges that come with high "variety" in production. When this is combined with high "volume," it places a greater burden on quality assurance and increases the chances of errors or mismatches between modules or components. Modularity does make it easier to offer custom options, but it also introduces more variation into the process, which can lead to problems in both assembly and quality control. This situation also makes it harder to achieve economies of scale, as repeated patterns are broken up more frequently.

Ability to adjust internal production capacity

The ability to adjust internal production capacity is an important factor in the effectiveness for the OTD process. The company has changed the production capacity multiple times over the years analyzed and is critical as the company works with a made-to order process, without causing significant delays or disruptions. According to Quality Manager, the company recently reduced its production capacity to better align with the order volume. To maintain flexibility, the company has chosen to hire consultants instead of permanent employees for production, enabling them to scale down production capacity quicker by releasing the consultants first, before the permanent employees. Over the years analyzed, the company has had a lot of fluctuations within the production capacity as the orders go up and down. This has led to a high turnover of consultants and disrupted continuity within production. This lack of stability can have led to a higher rate within the open points faults in production. However, as of today the number of consultants has decreased compared to the peak during covid-19 and that can indicate a more stable production environment.

7.5 A Closer Look at Staff Turnover

An interesting point of discussion is the staff turnover within the company. During the interviews, several stakeholders discussed and emphasized that staff turnover has been high in recent years and suggested that this would be a significant factor in why there had been so many disruptions and faults in the OTD process. High staff turnover led to a loss of experience and increased training demand of new employees, and at the same time maintaining consistent quality and efficiency on the production line. But when the data regarding staff turnover was examined, the findings showed that the staff turnover over time was quite stable and hadn’t gone up so much during the years analyzed as the stakeholder thought. For blue-collar laborers, the trend was similar for both factories. As the trend was high before the uprise in the unstable OTD process, this could say that staff turnover wasn’t such a large factor in the problem as the stakeholders thought, it was rather something else within the OTD process.

However, this data is only looked at on a broader view, as it shows all the personnel from the factories. If you break it down on the station level for the production line, there could be other trends here that follow the open points data. For the assembly line in factory 1, station 2 and 3 have the highest number of open points, both in total and in increase over the years, and according to interviewees the two stations have higher staff turnover compared to other stations. But this is something that needs to be analyzed more to see if there is any correlation between them.

7.6 Quality of data

One key factor when analyzing the OTD process is the quality of the data findings. High quality data is important both for the company and the OTD process, but also for the thesis. Both qualitative and quantitative data were used, and the quality of data is important to shaping the reliability and validity of the findings. For the quantitative data, where the data came from the internal databases (Tool A & B), a challenge with the data was that all data didn't exist. The work of the thesis should analyze data from before covid -19 until today, 2019- 2024, and for Tool A, the one with the open points, data could only be extracted from 2021 to 2024. This meant that comparison on how it looked before covid-19 could not be made, and therefore a trend couldn't be shown if the amount of open points did go up or not. This limited the ability to track long term trends and establish stronger statistical validity.

Another factor in the quality of data is that the data can lie. Errors in data entry, mostly from human errors, occur in the data. For example, when looking at the data Tool B, the adjustment phase time for factory 2 has a mean time of nearly zero, compared to factory 1. When further analyzing this, it was shown that in factory 2, the workers manually added both start time and stop time at the same time for the adjustment phase, and therefore the data doesn't tell the truth about the adjustment phase. Similarly for other data that are handled manually, there could be human errors due to similarities in names of what to choose, and errors from lack of knowledge in the system. For example, in open points data, the operators can choose between if a part is not mounted, but they can also choose if a screw is missing, and both can be correct. So, the data can lie in different ways. In factory 2 they have administration NOK as the second largest fault description. But when the products enter the adjustment phase, it isn't necessary something that needs to be adjusted because the administration faults have been fixed earlier, only not been reported correctly or it wasn't any fault. This is why proper reporting of data is important, and how it can create disturbances in the OTD process and products be delayed to customers.

The Tool B database is of great importance for the thesis. However, there is so much more data that could be analyzed in that database. So far, the work has been to look at it at a higher level, but if all the data from that database should be analyzed by looking further into the OTD phases, it could take a lot longer time, and due to time restrictions, this couldn't be done. A combination of the databases would be a better way for the OTD process, by having all open points in the OTD process database. That way you could see where in the process the problem occurs and why.

7.7 Bullwhip Effect: Chain Reactions of Disruptions

A relevant concept when analyzing the company's Order to Delivery (OTD) process is the Bullwhip Effect, a phenomenon where small fluctuations in demand at the consumer level cause increasingly larger fluctuations upstream in the supply chain. In the case of this company, both internal and external challenges over a short period have likely contributed to such an effect, creating instability across the supply chain and ultimately impacting the OTD performance. Paik & Bagchi, (2007).

Externally, the company has faced a series of disruptions: the Covid-19 pandemic, global supply chain breakdowns, material shortages, and sourcing difficulties have all created significant uncertainty. These unpredictable conditions forced both the company and its suppliers to frequently revise forecasts for products and materials. This constant adjustment undermines long-term planning and increases the risk of either overstocking or understocking, a classic trigger for the bullwhip effect. Paik & Bagchi, (2007).

Internally, factors such as frequent redesigns, high product customization, staff turnover, and the introduction of new models added further complexity. Together, these internal and external factors contributed to a bullwhip effect, resulting in more products entering the adjustment phase and disrupting flow stability within the OTD process.

The key insight is that in a supply chain as large as this one, recovery and stabilization take time. While there is often pressure to achieve quick results, it is important to recognize that reducing the bullwhip effect and restoring process stability is a gradual effort that requires coordinated planning, transparent communication, and consistency across all levels of the supply chain.

8. Conclusion

The analysis of the instability in the Order to Delivery (OTD) process has shown that this is a multivariable problem, meaning it cannot be solved by eliminating one single disturbance factor. It reveals that some of the factors are correlated and have contributed to the increase in deviation from the standard activity process. Based on the findings, the most significant factors to disturbances in the OTD process are as follows:

- Higher customer adaption
- High staff turnover
- Material shortages
- Quality problems related to sourcing
- Number of redesigns (including updates and new model introduction)
- Lack of quality data

The data findings suggest when production problems were rising, an increase in late deliveries could be seen. Improving the factors to disturbances will generate a reduction in the open points from the production phase. The investigation showed that the top 5 open points (Remarks, missing parts, function error, not mounted, mounted wrong) stood for almost 70% of the production-related problems. Reducing the number of open points will surely lower the frequency of adjustments, fostering a smoother production which contributes to the optimal flow. To do that the company should focus on the factors to the disturbances in the bullet points above.

The delivery phase does not seem to be the main disturbance of the OTD process. Therefore, it is not a priority to develop at this stage. Similarly, while staff turnover did not change to the degree that a lot of employees seem to believe. The turnover only changed a little bit from year to year, but quite stable. However, the turnover is still quite high in terms of the absolute values. Of course, a lot of time, energy and resources are spent on educating new personnel which many interviewees agree is contributing to the unstable OTD process.

Furthermore, the pattern between late deliveries and productions problems has been verified statistically from the data analysis. The importance of sticking to key OTD KPI's such as Planned Production End (PPE), Planned Delivery Date (PDD) and Confirmed Delivery Date (CDD) is crucial. These are important to follow to reach the optimal flow because there is little tolerance for deviations, whether they produce too early or too late, this still causes a disturbance.

In summary, to achieve an optimal flow, the quantitative data, qualitative interviews suggest cross-functional collaboration and alignment across all phases of the OTD process. A smooth production is very important, both for reducing the disturbances in the OTD process but also for reaching the optimal flow. The production requires the right conditions to be able to improve, such as steady material flow which puts pressure on external suppliers, meaning the order phase is equally important.

Attachments

Table 5 Different types of data and success in gathering data

Type of Data	Factory:	Successfully gathered
Open Points from 2021-2024 Tool A	1	No
Open Points from 2019-2024 Tool A	2	Yes
Number of faults in assembly	1 & 2	Yes
Tool B Data	1 & 2	Yes
Delivery CDD Report	1	Yes
Staff Turnover data	1 & 2	Yes

Table 6 Interviewee list

Topic of interview	Position	Interview Form
Order Phase	Forecast Manager	Teams
Data collection	Data Scientist	Teams
Quality effects	Quality Manager	In person
Production	Line Production Manager	Teams
Material Flow & Logistics	Material Controller	Teams
Production Logistics	Head of P&L	Teams
Delivery Phase	Digital Product Manager	Teams

Questionnaire for Semi structured interviews:
What is in your opinion the biggest contributors to the unstable OTD process the last 5-6 years?

What are the consequences of higher ratio of adjustments being made in the factories?

Why has the number of adjustments increased?

What can be done to decrease the adjustments?

How could for each phase (Order, Industrial) improve the flow? And what would an optimal flow look like?

What are the most important KPI's in the OTD Process for a stable production?

What are the most important KPI's in the OTD Process for an optimal flow?

How are you at your department currently working differently than before the pandemic? What has changed and what's been implemented?

What have been the biggest challenges since the pandemic started?

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