Process Improvements to reduce carbon emissions

A Green Lean Six Sigma Approach

Master thesis in Quality and Operations Management

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Abstract

In the current situation, carbon emissions are significantly contributing to climate change by trapping heat in the atmosphere through the burning of fossil fuels and producing non-sustainable goods. Because of this, it is important to cut carbon emissions by minimizing waste and finding sustainable ways to distribute goods to clients. Reducing emissions also results in greener earth, more drought resilience, less climate change, and a safer environment. By doing away with waste in its operations and creating environmentally friendly ways to deliver its products to clients, the company studied in this thesis hopes to cut its transportation-related emissions by half by the year 2030.

As a result, the goal of this thesis is to enhance the processes by lowering carbon emissions utilizing the green lean six sigma approaches. Understanding the process variations of late materials, 90-Kits, and poor quality which lead to a substantial quantity of carbon emissions in its operations is the focus of this master's thesis. The authors apply a six-sigma methodology using a multi-phase DMAIC technique to pinpoint the bottlenecks that are responsible for process deviations such as delayed material, 90-Kits, and poor quality.

It became clear that the forecasting and sourcing processes were important contributors to the process variations and rising emissions. To decrease process waste and improve accuracy and dependability, forecasting and sourcing models are also integrated. Additionally, a KPI dashboard was created to track the development of various KPIs, which is important for enhancing process performance and reducing or eliminating process variation by taking the appropriate steps when necessary. The final limitation of this study is that because the thesis is restricted to a single area of the supply chain, some of the conclusions cannot be generalized. As a next step to continue the thesis work, suggestions for future projects have also been offered.

Keywords: Process Improvements, Green lean six sigma, Forecasting methods, KPI dashboard, Carbon emissions, Material tracking.

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Navaneet Subbaram, Gothenburg, September 2022
Raghul Subramanian, Gothenburg, September 2022

Contents

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

BOM	Bill of materials
CAQDAS	Computer-aided qualitative data analysis
CI	Continuous improvement
CC's	Customer centers
DCs	Distribution centers
DMAIC	Define-Measure-Analyze-Improve-Control
ERP	Enterprise resource planning
GBM	Global business manager
GLSS	Green lean Six Sigma
KPI	Key performance indicator
MO	Manufacturing order
MRP	Material resource planning
PC's	Production centers
PDCA	Plan-Do-Check-Act
P-FMEA	Process failure mode effect analysis
RBM	Regional business manager
RQ	Research question
SMED	Single minute exchange of dies
SRP	Sales requirement pragnosis
TA	Thematic analysis
TPS	Toyota production system
VSM	Value stream mapping
URE	Underground division

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1

Introduction

This chapter gives the reader a brief description of the company at which the thesis was conducted and magnifies the overall background of the research problem. It describes the purpose and scope of the thesis from both theoretical and practical perspectives. Three research questions were framed for the reader to have a glimpse of the goal statement and finally, the outline of the report is presented. The thesis work is an extension of former research conducted at the company to calculate carbon emissions and find process deviations.

1.1 Company: Epiroc Rock Drills AB

Epiroc is one of the leading manufacturers of mining and infrastructure equipment across the globe. Founded in the year 1873, Epiroc was part of the Atlas Copco group until June 18, 2018, after which an independent organization was formed, Epiroc Rock Drills AB (Rock Drills AB, n.d.-a). Spanning over 150 countries, Epiroc develops and provides innovative and safe equipment, such as drill rigs, rock excavation, construction equipment, and tools for underground applications (Rock Drills AB, n.d.-a). It also offers world-class service and solutions for automation, digitization, and electrification. With more than 15,500 employees, Epiroc's revenue was 40 billion SEK in the year 2021 (Rock Drills AB, n.d.-a).

1.1.1 Underground Division (URE)

To narrow down the scope, the thesis was carried out in the Underground Division (URE) of Operation at Örebro, Sweden, which is shown in the figure 1.1. Operating in more than two countries, the URE division is the largest among all divisions in Örebro with around 1000 employees in operations and R&D departments (Rock Drills AB, n.d.-a). URE division manufactures around eight types of products including drilling and material handling equipment such as Boltec, Boomers, Cablectec, Raise-Boring, Simba, Häggloader, Loader, and Mine Trucks and claims to manufacture over 400 machines in the first two-quarters of 2022 (Rock Drills AB, n.d.-a).

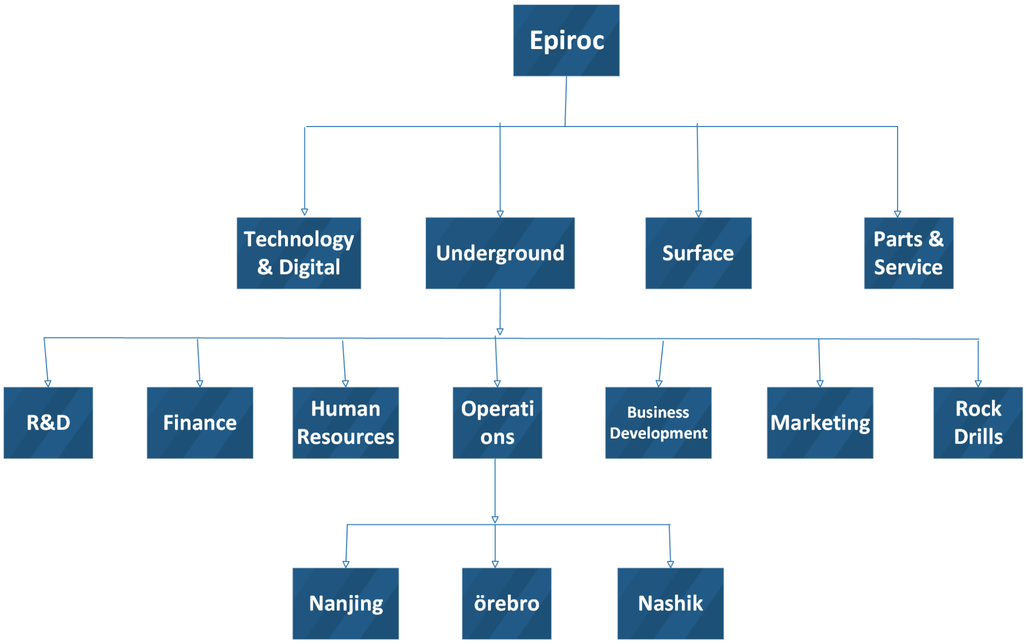


Figure 1.1: Organisation Chart of Epiroc

1.1.2 Agenda 2030

Epiroc's sustainability goals for the next decade include halving the carbon emissions from operations, transport, and major suppliers as well as from customer's use of Epiroc equipment (Rock Drills AB, n.d.-b). From the operations point of view, the long-term goal of Epiroc is to halve the carbon by utilizing 90% of renewable energy in individual operations. The transport sector is focusing on this aspect by reducing the air freight of the components which are shipped from the suppliers and the shipment of the machines to the customers (Rock Drills AB, n.d.-b). In relation to the products, the aim is to offer a full range of fossil-fuel products and halve the carbon emissions from the machines sold in 2030 when compared to 2019 (Rock Drills AB, n.d.-b). Finally, Epiroc is also looking to cut down the carbon emissions with respect to relevant suppliers. The carbon emissions have been reduced by 18% from 2018 to 2019 with respect to the transportation involving inbound and outbound logistics (Rock Drills AB, n.d.-b). In the further sections, the authors have focused on the scope of the thesis which is related to the higher amount of carbon emissions caused by the deviations in certain processes.

1.2 Background and Problem Description

This section deals with the background of the thesis, i.e., brief detail about the process deviations which result in excess transportation and problems faced by Epiroc in terms of carbon emissions. In the current situation at Epiroc Rock Drills AB, the process deviations causing the URE division excess transportation can be accredited to quality deficiency, delayed material, warehousing, quality assurance, washing, scaling and 90-kits (Höglund & Allanson, 2021). 90-kits is a type of order or package of components in which the missed or the delayed materials are shipped to the respective customer. The customer would have received the machine but there might be a few components missing or damaged, these components are shipped to customers as 90-kits. Researchers in the past have calculated the amount of carbon emissions caused by these process deviations. In the upcoming sections under the scope of the thesis, the authors have carried out the Pareto Analysis to give the readers an understanding of the process deviations which cause the higher volumes of carbon emissions.

The growing outsourcing process has resulted in fragmentation of production processes and the creation of global supply chains and distribution centers (Ángeles Cadarso, López, Gómez, & Ángeles Tobarra, 2010). This outsourcing strategy has increased final and intermediate warehouse and imports, but also the distance that goods travel in different stages until they reach the final consumers, as well as the requirements of transport per unit of output and the volume of carbon emissions generated in transportation. (Ángeles Cadarso et al., 2010).

After a few discussions with the company, it was clear that the deviations in-house were causing a lot of discrepancies in the processes which resulted in alternative solutions leading to excess transportation and an increase in carbon emissions (Höglund & Allanson, 2021). From recent research, it could be noticed that the company was unaware of the causality between the process followed in various departments and the carbon emissions (Höglund & Allanson, 2021). The discussions also gave the authors an understanding that some processes in the company are undefined and non-standardized. Due to this, the company has been entangled in various scenarios leading to process deviations that increase carbon emissions. Hence, Epiroc is focused on improving the processes in various departments and integrating a few major steps between forecasting the machines and sourcing the components to inch towards the agenda 2030.

1.3 Research Question

1.3.1 Purpose

Epiroc is getting closer to reaching its goal of lowering carbon emissions in transportation by lowering process deviations. As a result, the purpose of the thesis aims to decrease or eliminate process deviations such as delayed materials, 90-kits, and poor quality, which result in needless transportation and carbon emissions. The thesis will be achieved using green lean six sigma approaches and technologies to produce real outcomes(See sections 2.1 & 2.5), provide ideas for changes, and demonstrate a plan for controlling and sustaining. This aids the company in increasing sales, increasing output, and reducing climate change.

Since there is no standard definition for the sustainable transportation system, it is largely defined through impacts of the processes on the economy, environment, and general social well-being and measured by system effectiveness and efficiency, and the impacts of the system on the natural habitat (Mihyeon Jeon & Amekudzi, 2005). To understand the impacts and X-factors which contribute to the process effectiveness and efficiency, the first RQ was formulated:

RQ1: What are the most important key elements, X-factors that contribute to process deviations that result in excess transportation and carbon emissions?.

The second RQ was formulated to get an understanding of the methods and models that can be utilized by the company to improve its in-house processes to reduce carbon emissions.

RQ2: What actions can be taken to reduce or eliminate deviations in the processes which lead to excess transportation causing carbon emissions?.

As a result, green methodologies may be described as a program that aims to lessen the negative environmental effect of product and service production and consumption by employing these strategies, hence improving an organization's environmental footprint and overproduction (Garza-Reyes, 2015). To understand how the methodology is beneficial to the company, the third RQ's is formulated.

RQ3: How can the methodology of green lean six sigma be beneficial to reduce the carbon emissions and benefits the company in the longer run?..

1.4 Goal Statement

1.4.1 Scope

Most businesses utilize quality tools for a variety of goals linked to quality control, quality assurance, and improvements. Although there are many high-quality tools available for certain domains, fields, and techniques, some of the best tools may be utilized across several domains (Liliana, 2016). In companies, there are seven core quality instruments. These technologies may give a wealth of information about a company's difficulties, contributing to the development of solutions (Liliana, 2016). Histogram, cause-effect diagram, Pareto diagram, correlation diagram, control chart, data stratification, and brainstorming are the seven tools (Liliana, 2016). The deluge of information compels busy executives to seek focused techniques that allow them to make the most of their limited time (Grosfeld-Nir, Ronen, & Kozlovsky, 2007). In this context, one of the most significant managerial techniques for identifying aspects worthy of attention is the Pareto methodology (Grosfeld-Nir et al., 2007). A Pareto Chart is based on the Pareto Principle, which states that 20% of the cause categories often account for 80% of the problem (Carleton, 2016). By displaying the relative frequency or size in a descending bar graph, a Pareto Chart can assist in concentrating attention on the cause categories with the greatest potential for development. Figure 1.2 shows a Pareto chart with distinct causes of problems on the x-axis and the accompanying carbon emissions on the y-axis. In Figure 1.2, delayed materials and 90-kit are responsible for 80% of the problem, resulting in carbon emissions.

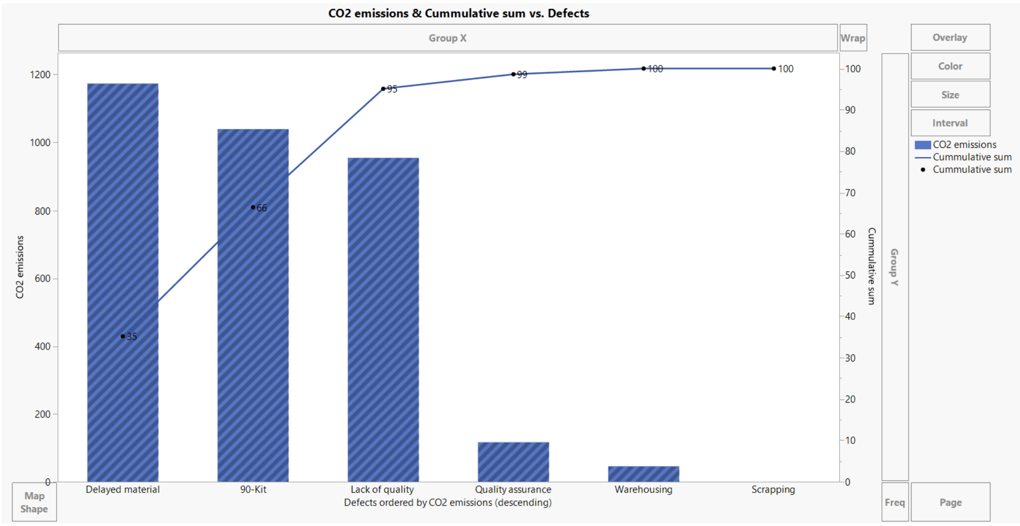


Figure 1.2: Pareto Chart for process deviations

Cause and Effect diagrams (also known as Fishbone or Ishikawa Diagrams) allow a team to identify, examine, and visually represent major alternative reasons associated with a problem or situation in increasing depth to determine the underlying cause (s) (Carleton, 2016). It allows a team to concentrate on the problem's content rather than the problem's history or team members' disparate personal interests (Carleton, 2016). Furthermore, it creates a visual representation of a team's combined knowledge and agreement on a topic (Carleton, 2016). This helps to create support for the solutions that arise. It helps the team to focus on the causes rather than the symptoms (Carleton, 2016). A preliminary cause and effect are shown from the former thesis in relation to mapping the process deviations in the URE division transportation (Höglund & Allanson, 2021). The cause-and-effect diagram is shown in Figure 1.3, with the main issue statement being "process deviations resulting in wasteful transportation causing carbon emissions' and five individual cause categories that are contributing to the issue. The reasons are analyzed with the aid of 5 why's to uncover the underlying cause of the problem, as indicated in the picture. However, the sub-causes of Machine and Money are explored in connection to the problem which is shown in Figure 1.3.

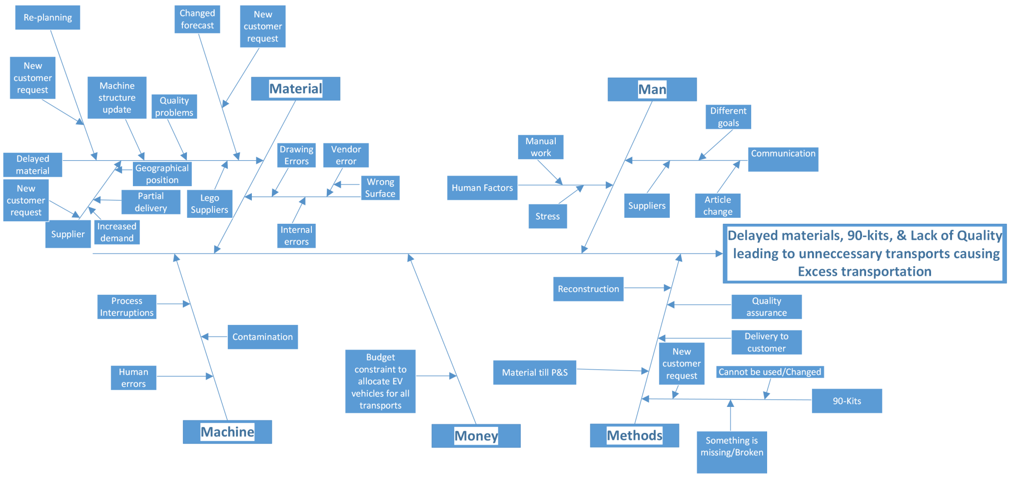


Figure 1.3: Cause & effect Diagram using the causes identified initially (Höglund & Allanson, 2021)

1.5 Delimitations

In this thesis there are some delimitations made:

To begin, the scope of the thesis study has been narrowed to merely the Epiroc underground division at örebro. The other divisions, such as Technology & Digital, Surface, and Parts & Service, were deemed out of scope and excluded from the research owing to time constraints. Second, the use of green lean six sigma is limited to process anomalies such as late materials, 90-kits, and a lack of quality. Third, the scope was confined to one specific region of the supply chain due to time constraints, and this was also the company's direction due to the influence and severity of carbon emissions. Fourth, it was not within the scope of this thesis to execute and follow up on the results of the suggested improvement in the underground division procedure. Finally, the thesis does not include the development of a reliable supply chain, logistic solutions, or long-term solutions.

1.6 Outline

The outline of the thesis is found in the figure 1.4 and refer to the table 1.1 for the description of what each chapter entails.

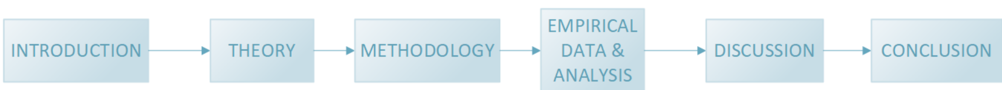


Figure 1.4: Outline of the Thesis

Table 1.1: Outline of the thesis

Chapter	Chapter Description
Introduction	The first chapter begins with a presentation of the company where the thesis was completed, a description of the problem and the research problem, the purpose and scope of the thesis, as well as previous work URE division has carried out to map process deviations causing excess transportation, and the thesis' delimitation. Finally, the thesis structure is provided.
Theory	This chapter begins with the theory of concepts related to lean, six sigma, lean six sigma, green lean six sigma, sustainability, carbon emissions, transportation sustainability, and change management that were utilized or linked to the thesis project.
Methodology	This chapter details the scientific procedures utilized to complete the thesis project, including the research approach chosen for the thesis, as well as the data gathering and analysis methodologies. Following that, methodological issues, including method criticisms, are provided. Finally, there is a part that discusses ethical considerations.
Empirical data and analysis	The empirical findings and data obtained in the form of semi-structured interviews are presented in this chapter. This chapter also shows the reader the results of the analysis, which was done in the form of DMAIC stages.
Discussion	This chapter focuses on the many aspects that must be considered while interpreting the results. Theoretical findings, DMAIC analysis, and recommended process changes are also presented in this chapter.
Conclusion	The last chapter of the thesis explains the goal of the research and the outcomes. The work's conclusion is next delivered, based on the prior chapter's topic and the issue the thesis was originally intended to address.

2

Theory

This chapter begins with the theory of concepts related to lean, six sigma, lean six sigma, green lean six sigma, sustainability, carbon emissions, transportation sustainability, and change management that were utilized or linked to the thesis project.

2.1 Six Sigma

Introduction to Six Sigma
In the 1980s, Bill Smith, a reliability engineer at Motorola, developed Six Sigma in the form we know it today. The phrase "Six Sigma" refers to a statistical measurement of a system's defect rate (Pepper & Spedding, 2010). Motorola won the Malcolm Baldrige National Quality Award in 1988, which sparked interest in six sigma in other businesses. According to Pojasek (2003), most Six Sigma programs are concerned with process improvement. These initiatives aim to reduce the sources of process variation while maintaining the underlying process. Six sigma can alternatively be defined as a continuous and breakthrough improvement program for minimizing variance (Andersson, Eriksson, & Torstensson, 2006). Process improvement teams, in Six Sigma words, identify the crucial "X's" (causes) that result in undesirable "Y's" (defects) (Pojasek, 2003).

Six sigma is currently used in practically every industry, and several worldwide corporations have built their own six sigma programs (Andersson et al., 2006). The basic goal of eliminating variance in a product or service is to ensure customer satisfaction (Andersson et al., 2006). It gives an organized and systematic method to process improvement, based on statistical approaches, with the goal of a defect rate of 3.4 defects per million chances, or Six Sigma (Pepper & Spedding, 2010). For example, if the post office achieved a 99 percent quality rating, there would be 3,000 misdelivery for every 300,000 letters sent, compared to only one misdelivery if they achieved a level of sic sigma (Pepper & Spedding, 2010).

DMAIC PROCESS:
Six Sigma is used in the context of improvement efforts. The conversion of the firm strategy into operational goals is generally the basis for project selection (De Koning,

Verver, van den Heuvel, Bisgaard, & Does, 2006). Define, measure, analyze, improve, and control (DMAIC) are the five stages of Six Sigma that are strictly followed anytime an issue, major or small, is handled (De Koning et al., 2006). Six Sigma project teams use a five-step technique known as "DMAIC" to solve problems:

Define the issue and the customer's requirements (D)
The Define stage of the DMAIC process identifies the project opportunity and verifies or validates that it has genuine breakthrough potential (Montgomery & Woodall, 2008). Six Sigma experts start by characterizing the issue. Eliciting information about consumers and their needs, as well as the issues that are causing the business to fall short of client expectations (Pojasek, 2003).

Defects should be measured, and operations should be processed (M)
The Measure step's goal is to assess and comprehend the present condition of the process. This includes gathering information on quality, cost, and throughput/cycle time (Montgomery & Woodall, 2008).

Analyze data to determine the source of the problem (A)
After the data has been obtained, the Six Sigma model is used to analyze it. The goal is to provide data that offers insight into the process and its issues (Pojasek, 2003). Identifying the underlying and most essential sources of errors and/or unpredictability in the process is one of these discoveries (Pojasek, 2003).

Improve the procedure to eliminate faults' causes (I)
In the Improve stage, creative thinking to specific process adjustments and other actions that may be taken to have the desired impact on process performance (Montgomery & Woodall, 2008).

Control the process to avoid the recurrence of faults
The Control step's goals are to finish the project's remaining tasks and pass over the enhanced process to the process owner, along with a process control plan and other appropriate processes, to guarantee that the project's benefits are institutionalized (Montgomery & Woodall, 2008).

Six sigma limitations
First and foremost, Six Sigma training and solutions can be prohibitively expensive for many firms, and the proper selection of improvement projects is crucial (Pepper & Spedding, 2010). The intricacy of Six Sigma methodologies is one of its recognized flaws. Rigid adherence to the Six Sigma problem-solving approach may be deemed "overkill" and wasteful in the case of basic problems with apparent and easy-to-implement solutions (De Koning et al., 2006). The limitation of product visibility for defect/waste monitoring and control is an issue in the process sector (Prashar, 2020). To put it another way, any technological enhancements to the processes will not be sustained unless people are properly managed and new employees are properly trained (Pepper & Spedding, 2010).

2.2 Six Sigma in Process Improvements

Six Sigma in service operations
According to Antony (2006), the term sigma refers to a metric that indicates how far a service's performance deviates from its average performance. The decreasing environmental effect of business operations has led businesses throughout the world to adopt proven continuous improvement (CI) approaches to meet their environmental goals (Prashar, 2020). Six Sigma is another CI technique that has gained traction for attaining operational and service excellence goals in organizations (SS) (Prashar, 2020). Despite several six sigma success stories in manufacturing, many service organizations are still skeptical about the benefits of introducing, developing, implementing, and deploying six sigma in the service business (Antony, Antony, Kumar, & Cho, 2007). DMAIC was a well-known CI approach for obtaining economic advantages through improved product/service quality, shorter delivery times, lower operating costs, as well as higher customer satisfaction (Prashar, 2020).

The main purpose of a six-sigma approach is to decrease variance within a service performance characteristic's tolerance or specification limits. It is critical to assess or quantify variance to improve the quality of a typical service and then propose feasible ways to decrease variation (Antony, 2006). Later, the concept was utilized for more general tasks in operations management, such as quality improvement, efficiency improvement, cost reduction, and other pursuits, as well as in services, healthcare, and other sorts of operations outside of manufacturing (De Mast & Lokkerbol, 2012). A flaw in a service process may be described as anything that does not fulfill the demands or expectations of the client (Antony, 2004). A flaw at a hospital, for example, might be an incorrect admission procedure, a lack of essential training by a staff member, staff misbehavior, refusal to assist patients with specific questions, and so on (Antony, 2004).

Six sigma in service quality
In service operations, the goal of a six-sigma approach is to understand how faults arise and then create process modifications to decrease the incidence of such defects, so improving the total customer experience and thus increasing customer satisfaction (Antony et al., 2007). Companies that want to differentiate their services in a highly competitive and frequently ruthless climate are increasingly focusing on service quality (Nakhai & Neves, 2009). Another key reason for the implementation of the six-sigma approach in many service firms is that today's consumers are more concerned with "process variability" than with "process average or mean" in the delivery of services (Antony et al., 2007).

Two main tendencies are at work: services have become the dominating sector of the economy in industrialized countries, and products are increasingly being provided as bundles of commodities and services in response to a better knowledge of customer demands (Nakhai & Neves, 2009). Even traditional industrial facilities have largely transformed into "service factories". Quality is generally described as a measure of how effectively the service level given satisfies customer expectations in the service industry (Nakhai & Neves, 2009). The use of Lean tools and methodologies reveals important areas where Six Sigma may be used. Lean methodologies are best utilized to examine and enhance the company on an operational level by removing non-value-adding tasks in a targeted manner (Hess & Benjamin, 2015). It is critical to assess or quantify variance to improve the quality of a typical service and then propose feasible ways to decrease variation (Antony, 2006). It is crucial to make sure that the attributes you are measuring from the processes are important for improving customer happiness and service quality (Antony, 2006).

Data collection in service operations
Data is not easily available for analysis, and data collection in service environments is more complex than in production. The primary issue is with the data's accuracy and completeness (Antony et al., 2007). The difficulty of obtaining high-quality data, particularly in procedures when no data is accessible, to begin with (Antony, 2006). As a result, service companies must show their clients "what's in it for them" to get them to participate in the data gathering process. Because of the human behavioral interaction involved in service delivery, measuring customer satisfaction in a service context is more complex (Antony et al., 2007).

2.3 Lean Production

Introduction to lean
The lean idea, as in lean manufacturing, lean production, and so on, is one of the most widely used and successful attempts among the several quality management systems that have been established (Andersson et al., 2006). According to De Koning et al. (2006), lean is a set of ideas, practices, tools, and strategies aimed at eliminating waste, synchronizing labor flows, and controlling variability in manufacturing processes. In a nutshell, lean is about managing resources in line with customer demands and eliminating waste (including the waste of time) (De Koning et al., 2006).

According to Andersson et al. (2006), because lean concepts are based on customer value, they apply to a wide range of production. The difference between value-added and non-value-added operations is critical in Lean (De Koning et al., 2006). Value-added activities help customers get what they desire out of a product or service. Everything else is a waste of time and money (De Koning et al., 2006).

Toyota production system
The Toyota Production System (TPS) laid the groundwork for today's lean thinking. This technique of production was pioneered by Taiichi Ohno and their companions while working for the Toyota motor firm shortly after WWII (Pepper & Spedding, 2010). During Sakichi's continuous improvement of the loom, two essential concepts of the Toyota Production System emerged: halting when there is a problem and identifying out-of-standard circumstances so that errors are not passed to the next level of production (Liker & Convis, 2012). Kaizen is not just a collection of initiatives or one-time events for Toyota; it is a way of life. It is the most essential aspect

of the company's operation. It is what most Toyota executives do when they lead: they support everyday kaizen (Liker & Convis, 2012).

Due to a lack of finance and resources, Eiji Toyoda ordered his employees to remove any waste. "Anything other than the bare minimum of equipment, materials, parts, space, and time that are necessary to add value to the product" was classified as waste (Pepper & Spedding, 2010). Seven types of waste have been identified: (1) excessive production; (2) faults; (3) needless inventory; (4) inefficient processing; (5) excessive transportation; (6) waiting; and (7) unnecessary motion (Pepper & Spedding, 2010).

According to Liker and Hoseus (n.d.), Toyota's culture has grown since the company's inception, and it is the company's fundamental competency. The Toyota Way is mostly about culture—how employees think, and act is firmly established in the company's philosophy and beliefs. It is all about respect for people and constant progress, and it has been that way from the company's inception (Liker & Hoseus, n.d.). Decreased work-in-process, greater inventory turns, increased capacity, reduced cycle time, and enhanced customer satisfaction are all advantages of lean manufacturing (Andersson et al., 2006). Lean, on the other hand, is lacking in terms of organizational infrastructure, deployment strategies, analytical tools, quality assurance, and control (De Koning et al., 2006).

LEAN LIMITATIONS
The capacity of lean production systems and supply chains to cope with unpredictability, a major feature of the lean method, was also a target of criticism (Hines, Holweg, & Rich, 2004). For three primary reasons, lean implementation has not been as effective here as it has been in mass-producing rivals. To begin with, large product portfolios indicate that each "job" is likely to be unique, preventing standardization of manufacturing methods (Pepper & Spedding, 2010). Second, the features of the items impose manufacturing limits. Third, smaller enterprises or job shops simply cannot compete with the larger firms' dominance or resources, causing them to remain inflexible in their supply chains (Pepper & Spedding, 2010). Poor psychology, a lack of accountability, financial issues, a lack of knowledge and training, and demand volatility are all important negatives that act as roadblocks to lean implementation (Gupta & Jain, 2013).

2.4 Lean in Process Improvements

Lean culture
The management system has an impact on culture, which is one of the most essential variables that influence how things are done in a company. The conventions and ideals of a company's workers, as well as the way they conduct themselves, are reflected in its culture (Iranmanesh, Zailani, Hyun, Ali, & Kim, 2019). The discipline, everyday activities, and tools required to build and sustain a constant, rigorous focus on the process are all part of the lean management system (Mann, 2005). Recognizing the client as a priority and developing people as the most essen-

tial resource to attain that excellence by enabling continuous improvement (kaizen) throughout the organization is at the heart of that concept (Zarbo, 2012). Employees become a source of sustained competitive advantage because of their dedication and engagement. As a way of increasing product quality and eliminating waste throughout the operations, CI activities are a basic idea in Lean operations (Angelis & Fernandes, 2007). This mindset must be backed up by a management framework that allows employees to work toward better quality goals while blatantly detecting flaws (errors) and then utilizing technological process improvement tools to redesign more efficient, waste-free work (Zarbo, 2012).

The propagation of lean culture among employees may aid management in successfully and efficiently applying lean manufacturing processes and, as a result, attaining lean manufacturing goals (Iranmanesh et al., 2019). If implemented appropriately, lean results in an organization's ability to learn (Angelis & Fernandes, 2007). As these activities become common, lean culture emerges gradually and nearly unnoticeable (Mann, 2005). The leader is responsible for changing the workplace culture as well as the frameworks in place to encourage people to improve their processes constantly (Zarbo, 2012).

Lean and its tools in Service operation

In the industrial industry, lean adoption has proved quite effective. The service industries are now implementing lean methodologies to improve their efficiency in providing high-quality services (Vignesh, Suresh, & Aramvalarthan, 2016). The elimination of waste, zero defects, pull instead of push, multi functional teams, decentralization of roles, vertical information systems, and continuous improvement were all examined as Lean principles (Ahlstrom, 2004). The actual problem is determining which Lean techniques to utilize and how to use them successfully based on the characteristics of service operations (Alsmadi, Almani, & Jerisat, 2012).

Although distinct difficulties like intangibility, variety of interactions, lack of standardization, and customer co-production characterize service operations, they always entail a multitude of input-processing-output processes (Alsmadi et al., 2012). In service operations, the process flow is generally unseen, and process ownership is frequently unclear. Furthermore, the process flow is frequently unmeasured, posing a significant risk of misalignment with client requirements (Direction, 2005). Another possibility is that there is a danger with the waste elimination principle because what one client perceives as trash, another may regard as something valuable (Ahlstrom, 2004). Furthermore, service activities are often pulled rather than pushed in nature; the service cannot be kept and must be generated as needed (Ahlstrom, 2004).

Various techniques such as Kaizen, Minute exchange of dies (SMED), Six Sigma, Kanban, Value Stream Mapping (VSM), 5S, Total Quality Management (TQM), Theory of Constraints (TOC), Total Productive Maintenance (TPM), Business Process Management (BPM), Visual Management, and others help to support the lean transformation by removing waste, variability and overburden and delivering improvements in specific areas (Neha, Singh, Simran, & Pramod, 2013).

Lean administration and leadership
It is critical to remember that each function and employee has a client, whether that consumer is internal or external. Further quality improvements can be discovered by agreeing on precise requirements for delivery from supplier to customer. Importantly, time and how it is spent is a primary emphasis of Lean, to enhance customer responsiveness and ensure that colleagues' lives are not squandered while at work doing useless activities (Emiliani & Stec, 2005). Another distinction is that when a production pause occurs, the physical flow is simpler to perceive, and quality flaws are easier to notice in a manufacturing process. Senior executives are interested in implementing Lean principles and practices because of numerous benefits, including improved product and service quality, increased market share, increased margins, increased revenue, increased productivity, improved customer focus, faster response to changing market conditions, and increased asset efficiency (Emiliani & Stec, 2005).

2.5 Green Lean Six Sigma

Introduction to Green lean six sigma
According to Gholami et al. (2021), GLSS is a circular business strategy aimed at reducing waste and improving the capability of processes and systems with minimal environmental pollution, thus increasing long-term profitability, and producing environmentally sustainable products while minimizing wastes, emissions, and faults. Organizations are being pushed to produce ecologically friendly, recyclable goods and provide greener services because of environmental concerns (Sagnak & Kazancoglu, 2016). As a result, taking the green way has become a well-established concept and operational technique for increasing organizational efficiency while reducing the environmental impacts of products and services without affecting the financial objectives of the companies concerned (Gholami et al., 2021). This will enable them to improve not only profitability, efficiency, responsiveness, quality, and customer satisfaction, but also to comply with environmental regulations and contribute to the solution of some of humanity's most pressing problems, such as climate change, environmental degradation, and natural resource scarcity (Garza-Reyes, Kumar, Chaikittisilp, & Tan, 2018).

Integration of green lean approaches
Concerns about the environment have prompted businesses to take the lead in developing greener manufacturing methods and services, as well as designing recyclable items (Garza-Reyes, 2015). As a result, the green paradigm has arisen as a concept and operational technique for organizations to enhance their environmental efficiency and decrease the environmental effect of their goods and services while still meeting their financial goals (Garza-Reyes, 2015). As a result, the green concept has arisen as a practical strategy for businesses to reduce the negative environmental effects of their products or services while increasing environmental efficiency (Sagnak & Kazancoglu, 2016). The goal of this strategy is to improve quality, profitability, customer happiness, process efficiency, and responsiveness, among other measures (Yadav et al., 2021). This research aids entrepreneurs and ecologists in establishing sustainable industrial practices such as GLSS, which reduces environmental harm

by supporting the 5'Rs: reduce, reuse, recycle, recover, and residual management (Yadav et al., 2021).

Even though both Green and lean focus on improving operational processes, lean emphasizes staff reduction, space reduction, increased capacity utilization, system flexibility, and the usage of standard parts. Reduce, reuse, and recycle (3Rs), as well as rework, return, and remanufacture, are examples of green activities (Garza-Reyes, 2015). The GLSS approach makes it easier for industrial organizations to meet organizational and environmental goals. It is significant that industrial managers and practitioners should identify potential hot spots that require immediate action to improve organizational sustainability (Yadav et al., 2021). GLSS is a new idea that has the potential to be beneficial since it encourages social responsibility, which businesses may employ to comply with environmental laws and regulations (Chugani, Kumar, Garza-Reyes, Rocha-Lona, & Upadhyay, 2017). To supplement GLSS integration, the enablers facilitate the integration of the GLSS approach, as well as associated tools and execution methodologies. The most significant enablers to executing the GLSS strategy in manufacturing businesses have been identified as management commitment and team efforts (Yadav et al., 2021). Improved planning, coordination, and control result in successful GLS program execution, or, in other words, organizational preparedness (Kaswan & Rathi, 2020).

Effects of Green lean six sigma
Attempting a Lean Six Sigma program is advantageous since it guarantees that issues that are overlooked when using the methodologies separately are addressed. It assists businesses in reducing faults and increasing delivery speed while keeping prices low (Chugani et al., 2017). 5S, kaizen events, value stream mapping, cellular manufacturing, standard work, visual management, just in time, SMED, supplier relationship, Poka yoke, Six Sigma, statistical process control, analysis tools, and plant layout reconfiguration are some of the ways that may be used (Cherrafi, Elfezazi, Chiarini, Mokhlis, & Benhida, 2016). VSM is one of the most utilized techniques in Lean implementation since it highlights process flaws that can be changed to boost efficiency. Lean can also help to create more environmentally friendly supply chains. By eliminating waste that adds no value to the product, lean adoption can improve supply chains (Chugani et al., 2017).

Lean and Six Sigma, for example, attempt to minimize waste and variance while also providing a better culture in which to implement sustainability principles, tools, and practices. By minimizing raw material use, energy consumption, water consumption, excessive carbon emissions, and recycling, sustainability attempts to decrease waste and increase process efficiency (Cherrafi et al., 2016). As a result, an organization that is focused on customer demands and considers people to be vital for decision-making while being flexible is created (Chugani et al., 2017).

Enablers and barriers of green lean six sigma
Impediments such as a lack of coordination and communication among team members and departments, as well as supplier reluctance to change, are all caused by

the barriers (Hussain, He, Ahmad, Iqbal, et al., 2019). Furthermore, senior management's commitment to long-term performance improvement ranks second among enlisted facilitators. The management's involvement, patronage, and vision are critical in adopting sustainability ideas in firms (Kaswan & Rathi, 2020). This category or quadrant has four barriers: "suppliers' reluctance to change," "low-quality raw material," "inadequate method to identify activities in the building process to apply green, lean, and Six Sigma," and "lack of tools to analyze environmental consequences" (Hussain et al., 2019). Management has a significant influence on the organization's reaction to green initiatives, and it must allocate appropriate human, technical, and financial resources to green technology implementation (Kaswan & Rathi, 2020).

2.6 Improving Transport Sustainability

Besides efficiency measures, environmental protection and sustainability are gaining more and more importance. To improve the freight flow efficiency sustainably, the companies require a systematic tool to study the freight flow over all three major surface modes and their connections and to identify the best way to improve freight transportation (Kelle, Song, Jin, Schneider, & Claypool, 2019).

The sustainability aspect of transportation systems has turned into an important activity as evidenced by a growing number of initiatives around the world to define and measure sustainability in transportation planning and infrastructure provision (Mihyeon Jeon & Amekudzi, 2005). While there is no standard definition for transportation system sustainability, it is largely defined through the impacts of the system on the economy, environment, and general social well-being which can be related to the triple bottom line and measured by system effectiveness and efficiency, and the impacts of the system on the natural climate (Mihyeon Jeon & Amekudzi, 2005). A lot of frameworks based on important causal relationships between infrastructure, processes in-house, and the broader environment are largely being utilized to develop and determine indicating systems for measuring sustainability in transportation systems (Mihyeon Jeon & Amekudzi, 2005). According to Mihyeon Jeon and Amekudzi (2005), the major three frameworks can be placed into three categories: (i) Linkages-based frameworks, (ii) impacts-based frameworks, and (iii) influence-oriented frameworks. The linkages-based framework for indicators and metrics captures the full range of indicators and metrics that cause conditions affecting sustainability including the impacts and reactive actions that can be taken to address them (Mihyeon Jeon & Amekudzi, 2005). Sustainability has become a necessity for the future. As international shipping, the lifeblood of the global economy, moves toward door-to-door, strategic planning for the sustainability of such movements becomes extremely important and challenging (Wu, Zhang, & Luo, 2020).

Sustainability issues have received increased attention among manufacturing units and other businesses. Business sustainability initiatives are often conducted under a variety of titles, with "corporate sustainability" being among the most prominent

(Steurer, Langer, Konrad, & Martinuzzi, 2005). Business sustainability initiatives are often strongly associated with "corporate social responsibility (CSR)" initiatives (Ahi & Searcy, 2013). Although some would argue against the practice, sustainability and CSR are often used as synonyms in a corporate context. An analysis of definitions of corporate sustainability, business sustainability, and CSR shows that they share several key features (Ahi & Searcy, 2013).

2.7 Risk Management

There is no doubt that risk talk and ideas of risk management have become more prominent in recent year (Power, 2004). In recent years, the supply chain has become increasingly globalized (Fang, Zhao, Fransoo, & Van Woensel, 2013). As a result, the worlds of all the components are more prone to discrepancies or disruptions. With proactive planning, the companies can acknowledge the potential disruptions and can recover quickly (Fang et al., 2013). Supply disruptions and material shortages can occur due to major events, but they can also be caused by less effective events. Supply risks have a greater impact on organizations that fail to acknowledge the risks involved and organizations that rely solely on reactive actions (Fang et al., 2013). But this can be mitigated with effective and efficient management of risks to lower the negative impact (Fang et al., 2013). Fang et al. (2013) describe three major strategies to manage supply risks: mitigation, contingency, and passive acceptance. Firstly, mitigation strategies can be defined as actions that the organization takes before risk and sustains the cost of action irrespective of whether the risk prevails such as setting up alternative sources which can provide the same result (Fang et al., 2013). Secondly, contingency strategies are strategies that are implemented when the organization acts during the occurrence of the risk, i.e., contingent sourcing from buffer suppliers for procurement. Lastly, a strategy of acceptance is used when the cost of mitigating uncertainty through mitigation and contingency planning outweighs the losses of accepting risks (Fang et al., 2013).

2.8 Process Models and Measurements

Strategic planning has become popular in businesses across the globe as a guide for building profitable product portfolios (Dalrymple, 1987). For building effective production plans, accurate short-term demand forecasting is essential. However, a short projection time suggests that product demand is volatile, making it difficult to track product development trends (Chang, Yu, & Jin, 2016). Determining actual developing data patterns using forecasting models based on historical observations is difficult, and such models' forecasting performance is poor, whereas forecasting using the most recent limited data can improve management efficiency and maintain an enterprise's competitive advantages (Chang et al., 2016). The authors of this thesis utilize one of the popular models in the product development process that is adapted for sales forecasting and sourcing of the components for procurement known as the Stage-Gate Model.

Stage-Gate Model
Stage-Gate techniques are well-known and frequently used in businesses around the world to bring order to the sometimes-chaotic process of product development (Grönlund, Sjödin, & Frishammar, 2010). It can be described as both conceptual and an operational model in the product development process. The focus is on controlling the product development process to improve efficacy and efficiency by bringing discipline to a process that is often described as haphazard and ineffective (Grönlund et al., 2010). The original Stage-Gate process was the result of extensive research on how successful companies were structuring their product development processes (Grönlund et al., 2010). The Stage-Gate process is made up of a succession of phases where important tasks are completed and the steps are supplemented by gates or milestones where interim results are assessed (Grönlund et al., 2010).

Activities in the early stages are usually focused on identifying possibilities and building the forecast, whereas later stages are focused on concept confirmation from the cross-functional departments (Grönlund et al., 2010). Hence, stages are often cross-functional, and each activity is carried out in parallel with the others to speed up the time to market. The gates serve as stop/go and prioritizing points when the project's future decisions are decided and gates are usually guarded by a cross-functional group of senior managers known as gatekeepers, who assess the inputs based on their quality of execution, business reason, and action plan quality (Grönlund et al., 2010). The gates perform the important function of canceling or re-defining the previous steps that fail to meet the objectives and that may cause issues in the later half (Grönlund et al., 2010). The gates consist of three significant elements which are named deliverables, criteria, and output. The deliverables are inputs to the gate review which must be defined in advance, i.e., the project managers' and team members' contributions (Grönlund et al., 2010). These ideas and deliverables are then evaluated by criteria. The criteria can usually be organized into a scorecard and possess both qualitative and quantitative milestones and finally, the outputs represent the actual result of the gate checkpoint (Grönlund et al., 2010). According to Grönlund et al. (2010), the research shows that the stage-gate process has been highly appreciated and if it is well-implemented it energizes and speeds up the development processes.

2.8.1 Key Performance Indicator

Key performance indicators (KPIs) are important instruments used by the management to understand whether the processes they follow are on the right track and provide them with desired results (Marr, 2012). Effective managers and decision makers usually understand every aspect of the processes and the corresponding performance by distilling them into critical KPIs (Marr, 2012). For KPIs to be vital instruments that help the organization identify efficiency, firstly the organizations should define the strategy and then link the performance indicators to that. KPIs must be relevant to organizational goals, and their use demonstrates if the organization achieves its objectives at the expected level (Sližytė & Bakanauskienė, 2007). KPIs differ depending on the organization, every department should include its KPI, and it provides a clear picture of what is important and what must be accomplished for everyone in the organization (Sližytė & Bakanauskienė, 2007). According to Marr (2012), Performance frameworks, dashboards, or scorecards are used by organizations to group the KPIs into one file or report so that it can be easier for the management to understand the overview of how the processes are performing.

3

Methodology

This chapter details the scientific procedures utilized to complete the thesis project, including the research approach chosen for the thesis, as well as the data gathering and analysis methodologies. Following that, methodological issues, including method criticisms, are provided. Finally, there is a part that discusses ethical considerations.

3.1 Research Process

This section illustrates the methodology adopted for the thesis work to enhance the research process. The authors started the thesis work with the initial meeting with the organization supervisor where the scope and expected outcome of the thesis work was explained. After the discussions, the authors utilized the Pareto chart and cause & effect diagram to comprehensively define the scope of the thesis work through academic examiner assistance. Both documents were sent to the University for approval. To align the requirements of the University and Organization, both authors were regularly closely in contact with the academic examiner and organization supervisor. After analyzing the scope of the thesis, the authors decided to incorporate Green Lean Six Sigma Methodology for identifying the causes of the process deviations and to provide an improvement plan. The literature study during the thesis work was an important aspect of the research since new strategies and process models had to be implemented. The initial interviews and documents corresponding to the sourcing process, order preparation process, and forecasting process were utilized to understand the ongoing processes in the company. The authors have used the DMAIC process to carry out the thesis work. In the define phase, the scope and definition of the thesis were documented. Semi-structured interviews were conducted with eleven employees in the measure phase along with the documents provided by them. In the Analysis phase, the authors used a few software and tools to analyze the interviews and align the themes for the same. After analyzing the current scenario and causes through a fishbone diagram, the improvement actions and models were framed. Lastly, to control the improvement actions, the

PDCA plan was recommended by the researchers for sustaining the actions. The improvement actions, control plans, and recommendations were presented to the organization management and University.

3.2 Research Strategy

According to Bryman and Bell (2019), there are two distinctive research strategies, they are qualitative and quantitative research. This means the strategies are just a general orientation to conduct business research. It is shown in the figure 3.1

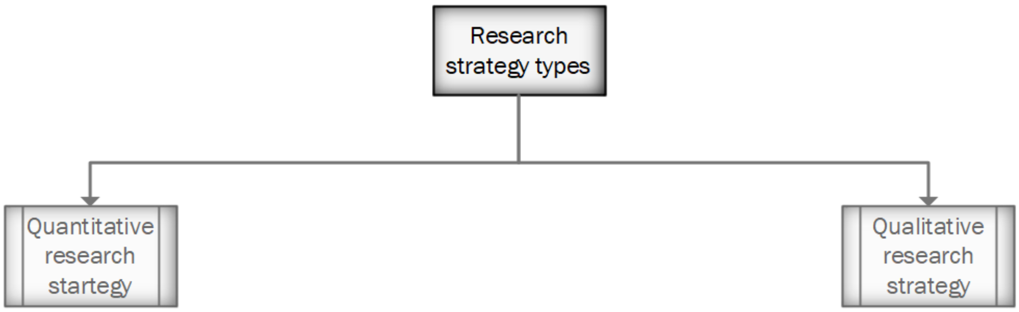


Figure 3.1: Types of Research Strategy

Quantitative research is a research strategy that focuses on quantitative data and its analysis, and also uses a deductive approach to the relationship between existing theory and research, where the researchers emphasize testing and analyzing the theories (Bryman & Bell, 2019). According to Bryman and Bell (2019), the researcher and subject of investigation are not in contact, and the social setting of the research is usually static. The important aspect of quantitative research is that researchers carry out the study in an artificial scenario and the data is streamed as robust from the measurement (Bryman & Bell, 2019).

The qualitative research strategy focuses on words and images rather than quantification of data, also it is predominantly an inductive approach to the relationship between theory and research, where the researchers emphasize creating new theories (Bryman & Bell, 2019). According to Bryman and Bell (2019), the researcher and the subject of investigation are integrally involved and the social setting during the research changes with time. Finally, in contrast to quantitative research, case of qualitative research the study is carried out in natural environments, and the data is extracted from extensive involvement with the subject (Bryman & Bell, 2019).

For this thesis work, the researchers have incorporated a qualitative research strategy in search of more precise results. The main agenda behind choosing a qualitative research strategy was due to the nature of the data that could be extracted for the research and the nature of the thesis work was related to acquiring data through semi-structured interviews. According to Bryman and Bell (2019), the crucial steps to be followed in qualitative research strategy are generating research questions, selecting appropriate subjects, acquiring relevant data, interpreting the data based on the literature, theoretical framework, and conclusions.

3.3 Research Approach

From census data obtained from hundreds of thousands of people; from monitoring what is occurring on a street today to historical analysis of what was happening hundreds of years ago, social scientists investigate a wide range of phenomena (Tuli, 2010). After then, mainstream psychologists seek to apply their conceptualizations to a variety of content domains to better understand what it takes to experience this or that phenomenon (Marton, 1986). Only when the reader has sufficient comprehension of the discipline's philosophical principles and theoretical assumptions can social research be meaningfully and effectively understood (Moon & Blackman, 2014). Psychologists are fascinated by people's perceptions and conceptualizations of the world (Marton, 1986). When researchers fail to identify and comprehend the principles and assumptions that underpin their professions, the integrity and validity of their study design might be jeopardized (Moon & Blackman, 2014). It is necessary to provide an outline of what research is all about to comprehend the quantitative approach (Apuke, 2017). As a result, research is defined as "a scientific and methodical search for relevant knowledge on a particular issue" (Apuke, 2017).

Types of research approach:
There are three types of research approaches: deductive, inductive, and abductive (Bryman & Bell, 2019). In terms of the goals of the various research methods, the inductive and abductive techniques both attempt to produce theory, whilst the deductive approach aims to test or evaluate that theory (Kovács & Spens, 2005). However, abduction's major goal is to generate a "new" phenomenon's knowledge, whereas induction's goal is to generalize conclusions from empirical evidence (Kovács & Spens, 2005). The inductive research technique was applied in this thesis, with a significant contribution to qualitative data.

Researchers in social science utilizes a variety of research procedures, which may be split into quantitative and qualitative research approaches, to describe, examine, and comprehend these social phenomena (Tuli, 2010). The hunt for 'facts' in quantitative research may be viewed as a sequence of 'what?' queries (Barnham, 2015). Qualitative research, on the other hand, is almost commonly linked with 'why?' inquiries, owing to its origins in motivational research and the assumption that such interrogative tactics might help us reach 'deeper' levels (Barnham, 2015). Quantitative data is also utilized to construct the models and tools used in the DMAIC stages, albeit only to a modest extent. The data is acquired and evaluated based on the data received from the qualitative and quantitative approaches. To learn more about the instruments and procedures used to collect data, go to the section on data collecting.

Ontological and Epistemological positions:
Research philosophy involves essential assumptions about how one observes or interprets the social environment, as well as ontological and epistemological stances. It entails considering epistemology and ontology, two fundamental distinctions that will influence how a researcher approaches the research process (Bahari, 2010). Ontology—our knowledge of what reality is; epistemology—our understanding of how we may know reality; and methodology or research strategy—our understanding of the best approach to conduct research given our ontological and epistemological assumptions (Bryman & Bell, 2019). Conservation science relies on ontology to assist researchers to determine how definite they can be about the (nature or existence of) items they are studying (Moon & Blackman, 2014). In conservation science, epistemology is crucial because it determines how researchers frame their study in their quest for knowledge (Moon & Blackman, 2014). Because the research procedure is mostly qualitative, an ontological perspective with an objectivist approach was used in this study to comprehend the individual objective reality of the problem.

3.4 DMAIC

3.4.1 Define

The following tools were used: Project charter, Effective scoping, Pareto chart, Fishbone diagram, and Value stream mapping. Customer demands, project goals, project scope, project success criteria, team members, and project deadlines are all defined in the project charter. The Pareto chart is used as a starting point for identifying the top deviations that are causing 80% of the process's difficulties. The fishbone diagram is used in the definition to reveal the previously recognized link and to go deeper into a specific topic related to the thesis's aim. From a process standpoint, effective scoping is utilized to concentrate the scope of the DMAIC project. It aids the teams in identifying the project-relevant process aspects. Finally, value stream mapping is utilized to discover long-term prospects for improving lead time and waste reduction. It aids in the visualization of information and material flow as well as the identification of process bottlenecks. Further there are few terminologies like large Y, small y, and x have been used throughout the thesis. Large Y defines the focus of the problem that have been studied. Small y defines the factors that are investigated to improve the large Y. Finally, X are the underlying causes of the factors leading to small y which in turn leads to large Y.

3.4.2 Measure

The measure phase's overarching goal was to collect both quantitative and qualitative data for the issue statement. Quantitative data was collected in the form of reports, excel sheets, and documents to help us understand how many 90-kits are produced, machine delays, and the most common incoming supplier quality problems. Because the process is neither visible nor measurable, we focused on qualitative data and performed semi-structured interviews using open and closed-ended questionnaires to gain a deeper knowledge of the issues.

3.4.3 Analyze

The general goal of this phase is to uncover the underlying pattern and information in the data collected during the measure phase. To identify the correlations between different variables, tools such as the fishbone diagram, matrix analysis, data validation, and text mining were employed. The results acquired from utilizing the tools would be further studied in the Improve phase in constructing a model, offering a solution, or making suggestions for a process improvement plan to avoid or eliminate process deviations once the data had been analyzed.

3.4.4 Improve

To create improved suggestions, the project team held brainstorming sessions. A second meeting was conducted to see if the suggestions were realistic and if the implementation plan could be restarted as indicated. In addition, project teams were involved to define the improvement plan's ideas to make it stronger. To begin, a forecasting model in the form of a stage gate process was developed to standardize and eliminate delays in the carbon emissions reduction process. Second, a performance KPI dashboard was created to assist the organization in keeping track of its KPIs and taking appropriate action, as necessary. Finally, proposals on a variety of themes have been proposed as a future step toward making the process more robust and eliminating or halving emissions.

3.4.5 Control

Control plan, short-term models, and updated P-FMEA were employed in this phase. All these tools were employed to keep the improvement plan on track and avoid reverting to previous working practices. Importantly, a control plan would be useful for tracking the implementation of the improvement recommendations. A short-term model has been proposed to encourage employees to adopt a new method of working and to make the adjustments a habit that can be improved over time. Finally, an updated P-Fmea have been demonstrated to visualise the impact of the improvement plan through RPN value have been developed. This have been demonstrated to depict the benefits of continuously improving the process, which increases the triple bottom line of sustainability.

3.5 Research Design

A research design establishes a framework for gathering and analyzing data. The research design chosen reflects considerations regarding the importance accorded to various aspects of the research process (Bryman & Bell, 2019). Experimental design and its variations, including quasi-experiments; cross-sectional or social survey design; longitudinal design; case study design; and comparative design are various types (Bryman & Bell, 2019). This is shown in the figure 3.2. When an in-depth understanding of a topic, event, or phenomena of interest in its natural real-life setting is required, the case study technique is particularly effective (Crowe et al., 2011). Because the thesis comprises a deep and intensive investigation of a single instance, the author of the thesis considered that it belongs within the category of "case study design". As a result, a case study research design is the most appropriate research strategy for this thesis.

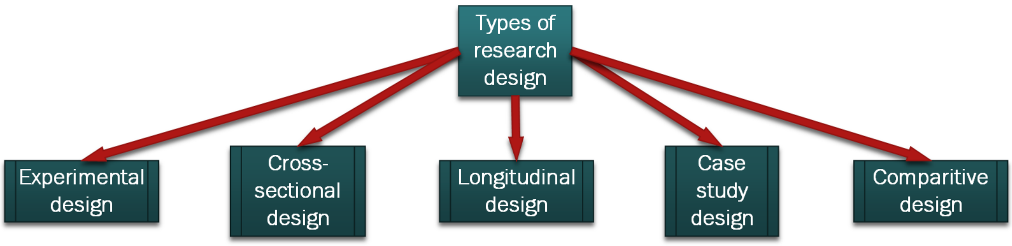


Figure 3.2: Research Design Types

Case study design:
Case study research is an inquiry and analysis of a single or more cases, to capture the complexity of the research object (Hyett, Kenny, & Dickson-Swift, 2014). A single organization, place, person, or event might be the focus of a case. Case study researchers frequently claim that their goal is to conduct a thorough investigation of a particular case that will serve as the foundation for theoretical analysis (Bryman & Bell, 2019). As a result, case studies allow the researcher to get a comprehensive grasp of the study topic and may make defining, interpreting, and explaining a research problem or scenario easier (Baskarada, 2014).

The case study approach usually involves the collection of multiple sources of evidence, using a variety of quantitative and more commonly qualitative techniques to develop a thorough understanding of the case (Crowe et al., 2011). One of the most essential sources of case study data is interviews. There are numerous types of interviews available, including open-ended, focused, and structured interviews, as well as surveys (Tellis, 1997). The purpose of the case study design with a qualitative method and semi-structured interviews was to obtain in-depth information on the research topic and to properly comprehend the research problem.

3.6 Literature Study

The literature study was completed as a first stage of the thesis to obtain the necessary theoretical background in connection to the topics that were employed in the thesis. Because this is an iterative procedure, the literature review was carried out throughout the process. Six sigma, green manufacturing, and lean ideas were explored as part of the thesis, and the integration of green, lean, and six sigma concepts was researched because the thesis incorporates a combination of all three concepts. Concepts related to model forecasting, sourcing methods, key performance indicators, and modularization were also examined as part of the theory.

All of this was significant because the goal of the thesis was to remove or decrease process deviations and create improvements, therefore the literature mentioned above was crucial in building the improvement plan. Finally, the theory's final component was change management. Because the thesis and the solution presented are intended to be applied in real-time and to benefit the firm. All of this necessitates working in a new manner of doing things, thus change management was incorporated into the theory to ensure a seamless transition from old to new ways of doing things.

3.7 Data Collection

Qualitative analysis allows the researcher to collect information and get insights that might otherwise be missed using typical data analysis methodologies (Lawrence & Tar, 2013). A grounded theory has been found, developed, and tentatively proven via systematic data gathering and analysis of facts related to a certain occurrence (Lawrence & Tar, 2013). The point of orientation in qualitative research is the perspective of individuals being studied on what they consider essential and meaningful (Bryman & Bell, 2019). Quantitative data is collected in the form of reports, papers, excel sheets, and charts in this thesis. Most of the data was gathered qualitatively through semi-structured interviews. The qualitative data for this thesis was gathered through semi-structured interviews with professionals from many departments, including Marketing, R&D, Order preparation, Sourcing & Purchasing, Quality, Production planning, and Material handling. Review the questions created for the interviews in Appendix.

3.7.1 Sampling

The probability sampling technique and the non-probability sampling technique are the two sorts of sampling procedures (Bryman & Bell, 2019). When performing qualitative research, researchers often choose one of three sampling methods: convenience sample, judgment sample, or theoretical sample (Oppong, 2013). The different types of sampling are shown in the figure 3.3

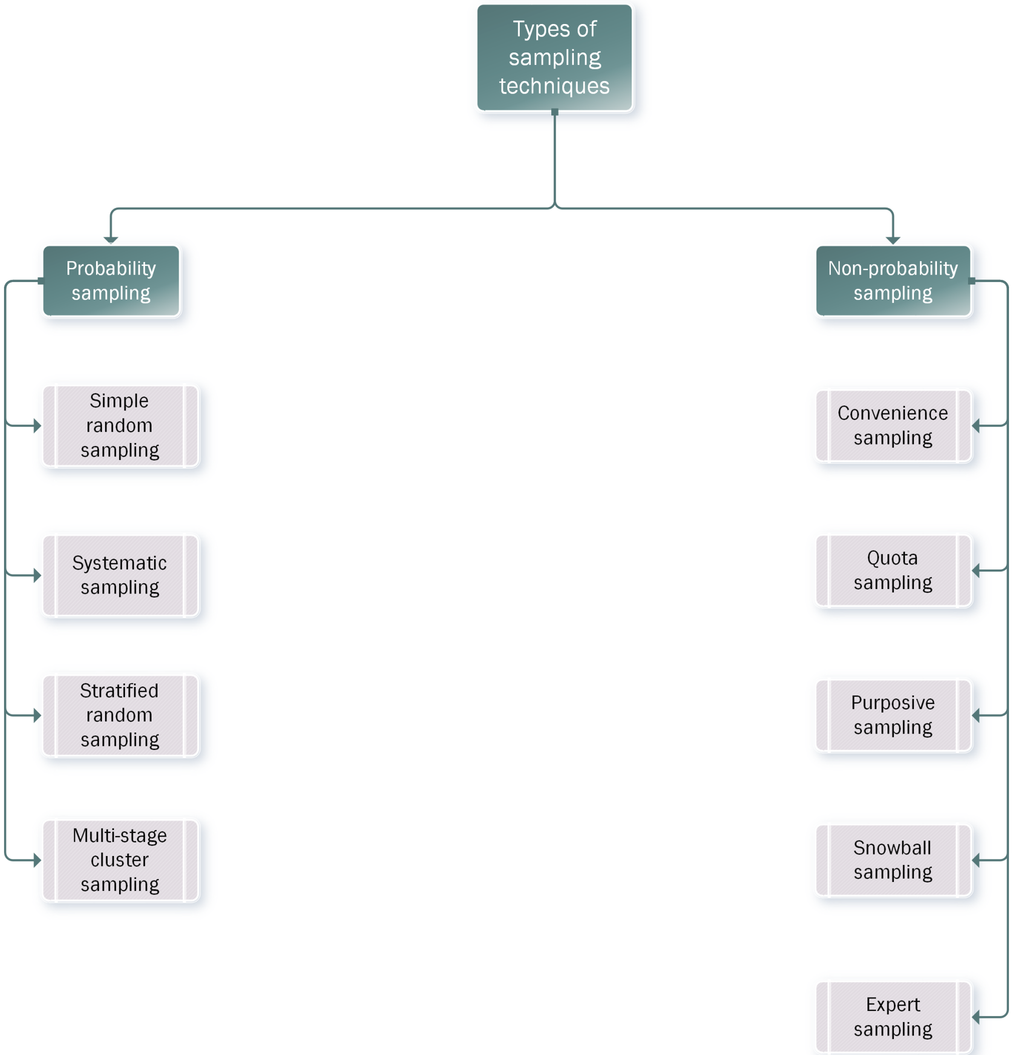


Figure 3.3: Types of Sampling

Purposive sampling:
Purposive sampling, also known as judgment sampling, is the purposeful selection of a participant based on the traits that the subject possesses (Etikan, Musa, Alkassim, et al., 2016). It is a non-random strategy that does not require any underlying ideas or a predetermined quantity of participants. Simply said, the researcher determines what information is required and sets out to discover people who can and will supply it based on their expertise or experience (Etikan et al., 2016). The basic concept is to keep sampling theoretically until a category is completely saturated with data (Bryman & Bell, 2019). Theoretical saturation conveys the idea that purposive sampling has a process component to it, given that it implicitly involves a data collection process that is linked to data review and analysis, and data collection ends when new data collection yields no additional insight into the research problem being addressed (Oppong, 2013). Purposive sampling was employed in this thesis

to pick respondents with the best expertise to reply to the research questions that were posed.

Expert sampling:
Here, the researcher obtains the consent of people who are experts or well-known experts in the field and begins the process of gathering data directly from individuals or groups of respondents (Etikan & Bala, 2017). It also entails organizing a sample group of persons who can illustrate using their experience or who are experts in a certain field. The purpose of adopting expert sampling is to have a better means of constructing the opinions of people who are experts in a certain field (Etikan & Bala, 2017). In addition, expert sampling was used, in which the author's used information from experts in their respective fields to better grasp the situation and conduct in-depth studies. Expert sampling improves the validity of confirmation when compared to another sampling method.

Snowball sampling:
Snowball sampling is a sort of purposive sampling in which the researcher finds out about additional people who could be important to include in the inquiry from a small group of people (Oppong, 2013). The downside is that the selection of the entire sample is dependent on the selection of individuals from the start of the stage, who may belong to a certain clique or have significant biases (Etikan & Bala, 2017). To acquire a better grasp of the situation, snowball sampling was initially utilized with a small sample of people. After gathering information from a certain group of people, the author went on to additional relevant persons who were the source of our samples. The sample respondents were chosen for their relevance to the subject under investigation. Furthermore, the sample size has not been determined, although the authors have said that data gathering would terminate once the interviews have achieved saturation.

3.7.2 Interviews

Interviews are used to obtain data in research when the researcher needs rich, useful, and in-depth information, according to (Denscombe, 2017). According to Bryman and Bell (2019), there are three sorts of interviews. Structured interviews, unstructured interviews, and semi-structured interviews are the three types of interviews. It goes on to say that structured interviews are often used for quantitative research, whereas unstructured and semi-structured interviews are typically utilized for qualitative study. Refer the table 3.1 for the interviewee sample used for this study. The interview guide can be found in the appendix A.6.

Table 3.1: Interviewee sample

S,NO	Interviewee	Department	Duration
1	Interviewee 1	Global Supply Hub & Transportation	1 Hour
2	Interviewee 2	Production & Material Handling	1 Hour
3	Interviewee 3	Commercial Specialist	1 Hour
4	Interviewee 4	Transportation Sourcing Specialist	1 Hour
5	Interviewee 5	SHEQ	1 Hour
6	Interviewee 6	SHEQ	1 Hour
7	Interviewee 7	Purchasing & Planning	1 Hour
8	Interviewee 8	Research & Development	1 Hour
9	Interviewee 9	Sales & Marketing	1 Hour
10	Interviewee 10	Production planning	1 Hour
11	Interviewee 11	Quality	1 Hour

Semi-structured interviews:
In qualitative research, interviews are the most common data gathering method, and the semi-structured format is the most used interview methodology (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). The interview questions are planned on time and written utilizing the interview guide. The key subjects of the research are covered in the interview guide. It provides a concentrated structure for the interview conversation, although it should not be rigorously followed. Instead, the goal is to learn more about the research topic by gathering similar types of information from each participant and giving them directions on what to talk about (Kallio et al., 2016). Follow-up questions were used to help participants comprehend the major themes and to steer the dialogue back to the research issue (Kallio et al., 2016). The interviews performed for the thesis were semi-structured. Eleven employees representing various departments participated in the interviews. The interviews lasted 45 minutes to an hour and were done using an online platform such as Zoom or Microsoft Teams. To get a better understanding of the situation, the authors utilized the interview guide to start the interviews and then followed up with appropriate questions as the respondents answered.

To have a permanent record of the interview using a digital voice recording helps to listen to it again and again (Bryman & Bell, 2019). The most essential thing to remember is to leave enough time for transcription and to be realistic about how many interviews you can transcribe in the time you have available (Bryman & Bell, 2019). The interviews were taped and transcribed, with the transcriptions being provided to the interviewees to ensure that the data was accurate.

3.7.3 Secondary data

The re-use of pre-existing qualitative data collected from prior research investigations is known as secondary analysis (Heaton, 2008). The writers of the thesis gathered data from a prior thesis and used the results to narrow the scope and obtain information for this thesis that would help them go on with the following phases. The former thesis information is employed at the initial stage to push the thesis further. Secondary analysis can be used for one of two purposes: it can be used to study new or additional research topics, or it can be used to validate existing research findings (Heaton, 2008).

Organizations create a variety of papers that include pictures, such as reports, branding, and websites. There are also a variety of publicly accessible graphic documents that are useful for business researchers (Bryman & Bell, 2019). Quantitative data was collected in the form of papers, documents, charts, photographs, and excel sheets for our thesis. Qualitative interviews were employed as a key source of data collecting because the procedure could not be assessed quantitatively.

3.7.4 Thematic analysis

It is a method of unobtrusively investigating huge volumes of textual material to detect trends and patterns in the words used, their frequency, their connections, and the structures and discourses of communication (Vaismoradi, Turunen, & Bondas, 2013). Content analysis is used to characterize the qualities of a document's content by looking at who says what, to whom, and with what impact (Vaismoradi et al., 2013). Thematic analysis (TA) is a technique for methodically detecting, organizing, and interpreting patterns of meaning (themes) in a set of data (Braun & Clarke, 2012). Qualitative material was transcribed and examined in our thesis. The use of themes and codes, for example, is a popular technique for qualitative data analysis. TA enables the researcher to see and make sense of common or shared meanings and experiences by concentrating on meaning across a data collection (Braun & Clarke, 2012).

A valuable idea will generally be discovered, and individuals of the organization under investigation will be able to recognize it and apply it to their own experiences, which is one criterion for determining whether a concept is useful (Bryman & Bell, 2019). The data was evaluated amongst various respondents and a matrix analysis was created after the themes and codes were formed. It aided in the capturing of hidden information as well as the understanding of common perceptions among respondents on each theme and code created. Almost all codes will be a combination of descriptive and interpretive. A theme "represents some level of structured response or meaning within the data set and captures something essential about the data in connection to the research issue" (Braun & Clarke, 2012). Different codes and themes that arose from the interviews were created by the thesis authors. The codes and themes were chosen based on how the respondents expressed themselves aloud, and the frequency with which they were used by various respondents.

3.7.5 Computer-assisted data analysis

The emergence of computer software that simplifies the analysis of qualitative data has been one of the most important breakthroughs in qualitative research (Bryman & Bell, 2019). In terms of both the spread of programs that conduct such analysis and the number of individuals utilizing them, computer-aided qualitative data analysis software, or CAQDAS as it is sometimes abbreviated, has been a growing topic (Bryman & Bell, 2019). The ability to modify the way data is shown in a way that makes linkages between categories more evident by employing text formatting and linking to other documents and categories is one advantage of using a tool like NVIVO (Bringer, Johnston, & Brackenridge, 2006). Computer-assisted software was also employed to examine the data in our thesis. The program is from JMP, and the text mining tool is a feature of the product. As an input to the program, raw data transcription was employed. The program takes this as input and generates a list of various words and phrases based on the raw data from the interview. This output was utilized to investigate the underlying issues and their causes.

The capacity to deal with huge volumes of qualitative data, reduced time spent on manual data handling chores, more flexibility and thoroughness in data processing, more rigorous data analysis, and a more visible audit trail in data analysis are all advantages of adopting QDAS (John & Johnson, 2000). One of the most common criticisms of CAQDAS is that it does not and cannot assist in judgments on the coding of textual resources or the interpretation of results (Bryman & Bell, 2019). The program assisted in the discovery of previously unknown knowledge and the exploration of new vistas. Finally, the findings of the software and manual data analysis were compared to ensure that they were accurate. The computer program aided in the management of vast amounts of data and cut down on the amount of time spent on it.

3.8 Research Quality

Because of the differences in frameworks, sampling procedures, sample size, and purposes of qualitative research, the traditional quantitative methodological standards of validity, reliability, and empirical generalizability are often not directly applicable to qualitative research (Kitto, Chesters, & Grbich, 2008). Instead, criteria like rigor, credibility, and relevance are employed to assess a study's quality or "trustworthiness" (Kitto et al., 2008). Credibility, Transferability, Dependability, and Confirmability are the four criteria to assess a research quality (Bryman & Bell, 2019). The figure 3.4 shows different types of research quality in qualitative study.

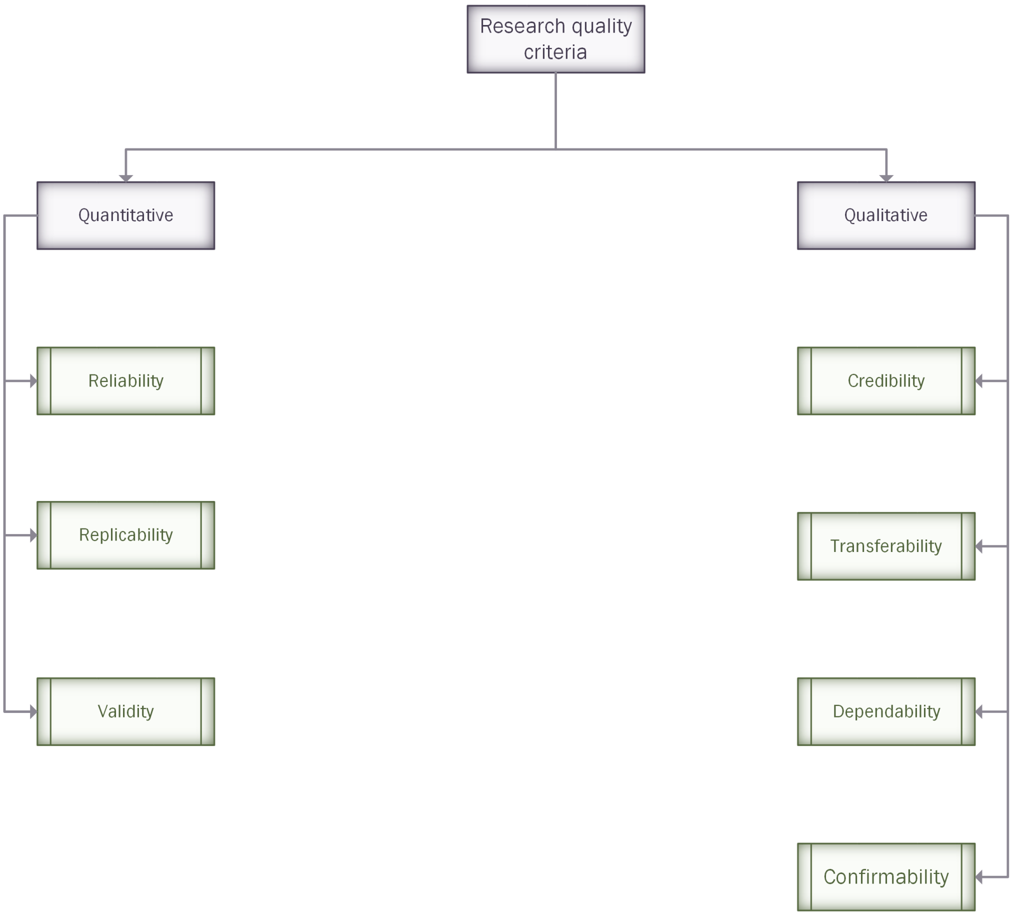


Figure 3.4: Types of Research Quality

Credibility:
The term "credibility" relates to the study findings' reliability, verisimilitude, and plausibility (Tracy, 2010). Establishing the credibility of findings requires both ensuring that research is conducted by accepted research practices and presenting research findings to the people who were investigated (Bryman & Bell, 2019). Thick description is one of the most significant ways to establish credibility in qualitative research. This entails in-depth depiction that elucidates culturally placed meanings as well as a great deal of tangible information (Tracy, 2010). The qualitative data acquired from the semi-structured interviews are transcribed for credibility purposes. To boost the research's credibility, the transcribed interviews are delivered to each interviewee.

Transferability:
Qualitative results tend to be oriented on the contextual distinctiveness and relevance of the element of the social world being investigated, as qualitative research often requires the close study of a small group or individuals sharing specific traits (Bryman & Bell, 2019). The transferability of this research is enhanced since it

engaged persons from several departments who had comparable qualities to the research challenge.

Dependability:
Bryman and Bell (2019) offer the concept of dependability as a counterpart to reliability in quantitative research and to establish the trustworthiness of qualitative research. This entails using an 'auditing' method to verify that comprehensive records are preserved for all stages of the research process and that they are easily accessible (Bryman & Bell, 2019). The authors have a comprehensive record of the research process from problem formulation to respondent selection, notes, interview transcripts, and data analysis in an easily accessible format, which increases the study's dependability.

Confirmability:
While complete objectivity is impossible in business research, confirmability ensures that the researcher acted in good faith; in other words, it should be obvious that he or she did not let personal values or theoretical inclinations sway the research's conduct and findings (Bryman & Bell, 2019). In the study of social phenomena, triangulation entails employing more than one technique or source of data (Bryman & Bell, 2019). This study has a high level of conformability since the researchers make every effort to keep the procedure as visible as possible for the participants. Furthermore, the study guarantees that the data obtained is checked with the appropriate participants to eliminate research bias in the results and to improve the quality of the data gathered. Furthermore, the audit trail contributes to the research's confirmability by providing transparency into how data is acquired, evaluated, and interpreted. Finally, theoretical perspectives increase the potency of the researchers' concepts through triangulation techniques, resulting in greater confidence in findings.

3.9 Ethical Considerations

In business research, there are four key categories of ethical principles. Participants' safety, informed consent, privacy, and deception are among them (Bryman & Bell, 2019).

Avoidance of harm
Most individuals consider research that is likely to hurt participants to be inappropriate. But what is the risk? Physical hurt, harm to participants' growth or self-esteem, stress, harm to job prospects or future employment, and 'causing persons to do abhorrent behaviors' are all examples of harm (Bryman & Bell, 2019). According to the AOM Code of Ethics, the researcher must carefully assess the risk of damage to study participants, and that risk should be reduced to the degree possible (Bryman & Bell, 2019). Confidentiality and anonymity are concerns that complicate many types of qualitative research, where considerable care must

be taken to avoid identifying people, organizations, or locations (Bryman & Bell, 2019). Inform participants about how their data will be used, as well as what will happen to case materials, images, and audio and video recordings, and obtain their consent (Gajjar, 2013). In this study, the researchers verified that the volunteers would not suffer any harm because of their participation. The respondents in the interviews were given pseudonyms by the researchers. Researchers also managed the data with the utmost discretion in terms of how it might be used in the future.

Informed consent

The notion of voluntary informed consent aims to guarantee that potential research participants are provided as much information about a study as possible so that they may make an educated decision about whether they want to take part in it (Bryman & Bell, 2019). Participants should also be told whether observation techniques or recording equipment will be utilized, according to the concept of informed consent (Bryman & Bell, 2019). When done correctly, the consent procedure guarantees that people are willingly engaging in research while being fully informed about the risks and benefits (Gajjar, 2013). If researchers want to share their data with others, they should clarify how they will be shared and whether the data will remain anonymous throughout the permission procedure (Gajjar, 2013). Second, in terms of informed consent, the authors have supplied sufficient information about the study before the interview. Also, if the participants want, they are free to exit the interview at any moment. In addition, the authors have informed the participants about the observation techniques and recording equipment that will be utilized in the study and have gotten their agreement.

Privacy

The obligation to respect the privacy of study participants is the third ethical criterion. Many of us hold the right to privacy in high respect, and breaches of that right in the name of study are not tolerated (Bryman & Bell, 2019). When someone consents to be interviewed, they have the right to decline to answer specific questions for whatever reasons they believe are valid (Bryman & Bell, 2019). Only after a comprehensive explanation of the research methodology do the participants consent to participate in this study (Arifin, 2018). Finally, the author assured that every interviewee can refuse to answer some questions for whatever reasons they believe are legitimate.

Preventing deception

When researchers misrepresent their study as something other than what it is, they are engaging in deception (Bryman & Bell, 2019). The ethical objection to deception appears to be divided into two categories. To begin with, it is not a polite thing to do. There is also the issue of professional self-interest to consider (Bryman & Bell, 2019). Finally, the author avoided deception by making the study procedure as open as possible to participants and earning their trust and faith in it.

4

Define

The client demands are specified in the Define phase, and the processes and products that need to be improved are recognized (Carleton, 2016). The Define Phase of the Green Lean Six Sigma improvement process is the first step. The project's executives construct a Project Charter, a high-level vision of the process, and begin to understand the demands of the process's consumers during this phase (Krishnan & Prasath, 2013). This is a vital step of Green Lean Six Sigma where your teams define the scope of their activities for themselves and your organization's leadership (Krishnan & Prasath, 2013).

4.1 Project Charter and One-Pager

Customer requirements, project scope, project goals, project success criteria, team members, and project deadlines are all defined in a project charter (Carleton, 2016). The project one pager may be found in detail in Appendix A.1.

The usage of a project charter assisted in describing the business case, identifying the consumers involved, benefits to the customers, measures to improve, individuals involved and interdepartmental contacts, support necessary, and lastly project's constraints. The project one-pager was created to give the firm information on who is on the steering committee, as well as their backgrounds and roles in this thesis at Epiroc Drills AB. Aside from that, the problem topic has been stated, as well as the thesis' conclusion.

4.2 Value Stream Mapping

Value Stream Mapping (VSM) is a lean manufacturing technique, and it has been categorized to support and implement the lean approach (Singh, Garg, & Sharma, 2011). In other words, VSM is an improvement tool utilized in an organization to visualize the processes and information flow to the upcoming departments (Singh et al., 2011). According to Singh et al. (2011), by recording information regarding station cycle time, uptime or resource usage, set-up time or change over time, work-in-process inventory, manpower requirements, and the information flow from raw materials to finished items, VSM differs from standard recording techniques. Kaizen bursts are utilized in VSM to understand the bottlenecks and identify the improvements areas. It is important to map both intra- and inter-company value-adding streams, which are those aspects of the business that add value to the product or service under evaluation (Singh et al., 2011).

The authors have utilized these concepts for developing a value stream map for the processes being followed at the organization to magnify the bottlenecks as shown in the figure 4.1. To break down the main process or the effect of the process deviations, the authors considered the 'Excess Transportation' as the production control, the production department which was the main input, and the machines produced were the output of the process. The complete process led to excess transportation due to the process deviations which were occurring before the components, or the machines were put for the production department. Hence, the sub-processes which were a part of the parent process are as follows: Sales and Marketing (Machine Forecast), Sourcing & Purchasing (Material planning or component forecast), Machine Structure Specification (R&D), Order preparation (Manufacturing Order), Production Planning (Confirmation after MO), Machine Assembly and end with the final product. The data table was filled in for all the sub-processes to understand the time taken for each task. The data table consisted of the following factors: number of machines manufactured per year, number of employees in the sub-process or department, value-added time per machine, total time is taken to complete the process, and lastly the complete accuracy. The information between all the sub-processes is carried out through electronic media.

After finalizing the Value stream map for the 'Excess Transportation' scenario, considering the initial semi-structured interviews, the authors marked the Kaizen Burst or the improvement areas in the VSM as shown in figure 4.1. For magnifying the bottlenecks, the VSM was created for the bottleneck processes to understand the non-value-added activities. The bottleneck sub-process considered to be analyzed are Marketing/Machine forecasting process, Sourcing/purchasing process, Order preparation process, and machine structure specification process.

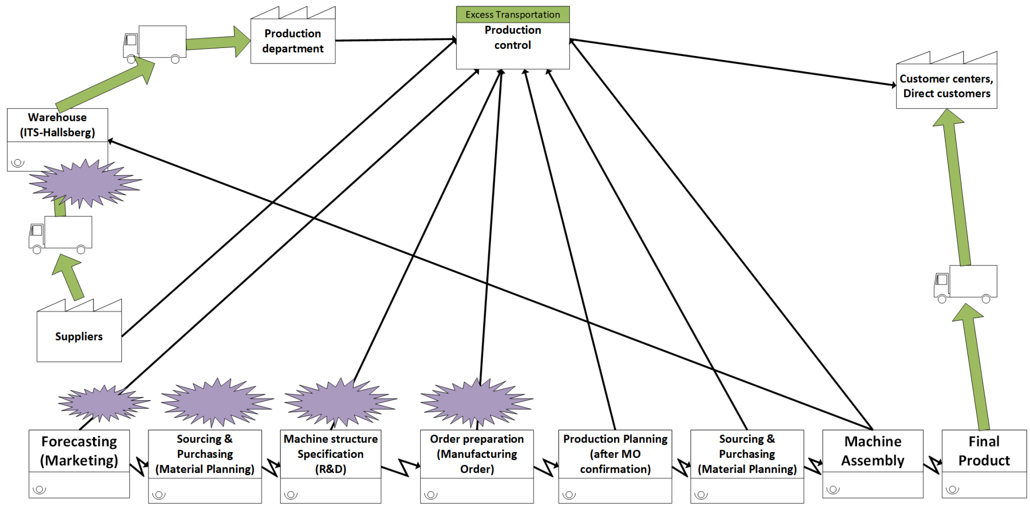


Figure 4.1: Higher Level Value Stream Mapping

4.3 Effective Scoping

Effective scoping is critical for transitioning from classic push-thinking to current pull-thinking, which focuses on customer satisfaction (Carleton, 2016). A SIPOC—which stands for Suppliers, Inputs, Processes, Outputs, and Customers—helps to concentrate the scope of a DMAIC project from a process viewpoint during the Define phase. It aids teams in identifying the project-relevant process aspects (Carleton, 2016). Process elements include • – Suppliers who provide the process's inputs • – Inputs that are necessary to create the outputs • – High-level process stages • – Process outputs • – Customers who get the process's results (Carleton, 2016).

A SIPOC is a high-level review of the investigation's as-is procedure. It assists teams in defining the precise process elements that are within the project's scope, as well as in staying wide enough to include all process stages and inputs that may aid in identifying probable root causes while being manageable (Carleton, 2016). It will be used as a starting point for generating a more complete process map in the Measure phase (Carleton, 2016). The project sponsors, process owners, and supervisors all participated in effective scoping. The goal of this research is to minimize carbon emissions causing excess transportation. The effective scoping tools is shown in appendix A.2.

Steps for effective scoping:
The outcome of the as-is procedure is the first step toward effective scoping. Excess transportation demands resulting in carbon emissions, and machinery from the Orebro plant's underground division are the physical outputs of the first stage.

Customers for the second phase of effective scoping include mining companies, contractors, construction companies, and even Epiroc and its suppliers. The machines that are built and assembled at Orebro are being air freighted to the clients due to material delays, lack of quality, and 90-kits. The increased transportation requirements are owing to the machine's delayed delivery to its clients. Because the thesis's purpose is to minimize carbon emissions, another customer, such as the climate and environment, is being considered because it is being impacted by excessive transportation demands.

The third phase is to enhance the first step and list the Large Y. The improvement suggestion is presented in the third step in Figure 4, which is to eliminate excess transportation demands and halve carbon emissions, which is the company's need and overall aim. The fourth phase is to comprehend and improve the large Y; the small y should be examined to improve the large Y's aim. The goal of this thesis is to prevent or eliminate process deviations such as delayed material, 90-kits, and poor quality (small y) that result in carbon emissions (8184 tonnes). The small y has its underlying system and characteristics that govern it, leading to an increase in transportation requirements. The small y must be understood and developed to improve the large Y. Since carbon emissions are rapidly growing due to increased transportation demands, the baseline for carbon emissions in 2019 is 8184 tonnes, 5199 tonnes in 2021, and 7700 tonnes in 2022. Since the emission rates are high, and Epiroc's 2030 plan calls for halving carbon emissions in transportation, it has been a motivating force to develop improvements in this sector to minimize carbon emissions and enhance the processes that cause them. As a sixth stage, the authors guarantee that by reducing excess transportation demands (large Y), other large Y such as social and economic sustainability, inspection reliability, the cycle time of operations, quality, and lead time between operations would not be impacted.

The large Y determined may bring certain changes in the process. There may be modifications in the present workflow, transportation demands, and an improvement in sustainability characteristics because of decreasing superfluous transportation. Production planning and material handling, sourcing, and purchasing, quality, transportation planning, sales and marketing, and research and development are all required to achieve it. Finally, the output (extra transportation requirements) was flown from Orebro to suppliers and back to Orebro.

The inputs necessary to create the result (Big Y) are mentioned in the eighth step. These are the inputs to the process that may contain variance that the improvement team does not have control over.

- Forecasting details
- Machine specifications
- Order preparation
- Production planning
- Purchasing and Sourcing
- Machine Assembly
- Machine Testing

The Epiroc Orebro factory and its suppliers, who supply the materials and are involved in this process, may contain hidden, undisclosed sources of variation. Because the process requires information from only the suppliers and the plant to affect (Big Y) and (small y).

Finally, some requirements in the system from the input required by the process are • Material standards • Firm order • Drawings (Final BOM) for manufacturing • Assembly instructions • Quality inspection of the components/modules • Skilled employees for operations.

4.4 Identified Big Y

The discovered big Y from the process may be stated as "Reducing excess transportation needs and halving carbon emission in transportation" after utilizing the effective scoping tool and conducting interviews and discussions with experts and supervisors. The small y has been recognized as a source of significant parameters to enhance the identified big Y in the process. It is shown in the figure 4.2. Due to material delays, 90-Kits, and a lack of quality, a significant gap in the process has been identified that is producing deviations, emissions, and unnecessary transportation. The significant deviations indicated will be investigated to increase the process output. It is necessary to identify and categorize non-value-added operations. This will be accomplished using value stream mapping (VSM). To do so, fresh data and good communication are required, and it is critical to comprehend why the small y is triggered in the first place, resulting in extra transportation demands (large Y). Value stream mapping (VSM) is critical for identifying process bottlenecks and ensuring that the team understands their perspectives on whether the value is added. The large Y and little Y that have been identified are shown in the figure 4.2.

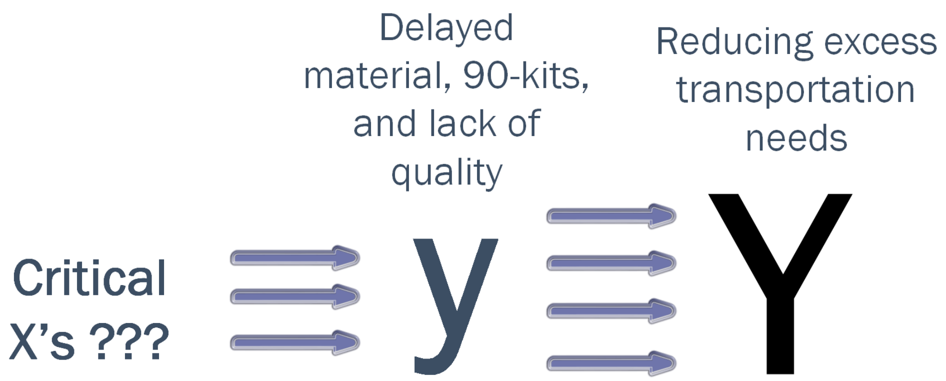


Figure 4.2: Identified BigY

4.5 Summary of D-Phase

During the define phase, the researchers learned about the internal process and problem, allowing them to pinpoint the areas with the most improvement potential. Material delays, 90-kits, and lack of quality are the areas with the most improvement probable, as they all result in additional transportation demands, which contribute to carbon emissions. The main issues are material delays and 90-kits, which are caused by a variety of contributing factors. IT support, lack of standardization, delays in materials, and, on occasion, losing track of their material, resulting in material delays and 90-kits in the assembly process. As a result, air freight is required to transport the product to the consumer. Effective scoping is a strategy that has been used to gain a bird's eye perspective of the process and to offer the writers an idea of where they should focus more on the thesis and examine it in depth. Value stream mapping was constructed for small y using the results of effective scoping, and identified the bottlenecks in the process (important x's) that are the causes of small y. This simplified the process's understanding and created a solid platform for further observations and analysis. Although there were some questions about which factors may be utilized to further the model development process, the availability of data was considered a solid place to begin.

This project has various advantages for Epiroc Drills AB, the most important of which is the standardization of operations to prevent material delays, as well as the 90-kits. On an economic level, there are various motivators for this project. The first is the desire to reach an agreement on how to put the model into reality so that the advantages may be seen, as well as the medium to long-term improvements that are expected because of this project. Green Lean Six Sigma has sparked a lot of interest in the organization in the long run. The project's goal is to investigate and offer strategies to get started with Green Lean/Six Sigma efforts.

5

Measure

The purpose of the measure phase is to mainly identify the sub-processes involved in the main setting. Measurement is crucial throughout the project's life cycle, and the team's first focus on data gathering is on two things: defining the process's start point or baseline and looking for indications to determine the process's root cause. Because data collecting requires time and effort, it is a good idea to think about both from the beginning of the project (Krishnan & Prasath, 2013). The value stream mapping for the sub-processes such as order preparation, forecasting, machine structure specification, and sourcing was mapped out to identify the bottlenecks in the corresponding processes. The authors have also identified information related to the total number of machines forecasted and manufactured as quantitative data to support the argument for the process deviations due to variations in the machine structure specifications. The measure phase included initial interviews with the department managers or employees to understand the processes, sub-processes, and output through extensive communication. Tools such as process flow and value stream maps were utilized by the authors to explain the qualitative data acquired through interaction and interviews with the employees.

5.1 Value Stream Mapping

As mentioned in the above section under the 'define' phase regarding the identification of bottlenecks, the researchers observed excessive carbon emissions were caused by the process deviations and bottlenecks in the processes mentioned in the previous section 4.2. The following four sub-sections explain the value stream mapping for the individual processes for a better understanding of the readers.

5.1.1 Machine Forecast Process

The department involved in the machine forecast process is sales and marketing. The sales team collects information from the CC's and DC's about the market demand, trends, and requirements of the customer. The information collected from the sales team is translated to Pre-SRP(Pre-Sales requirement prognosis, see section 5.4) from the marketing team to understand the customer needs depending on the specifications and variants. The production department reviews the Pre-SRP and approves the production slot for further steps. Once the production department approves the slot, the SRP is released for the next 18 months, and this is an iterative process followed once in 6 weeks. The SRP is further translated into the MRP system by the order preparation department. This information is utilized by the sourcing and purchasing team to procure the components depending on the requirement for the production. Lastly, the M3 is updated, and MO confirmation is reverted to the production department for detailed manufacturing dates. The value stream map is shown in the below figure 5.1.

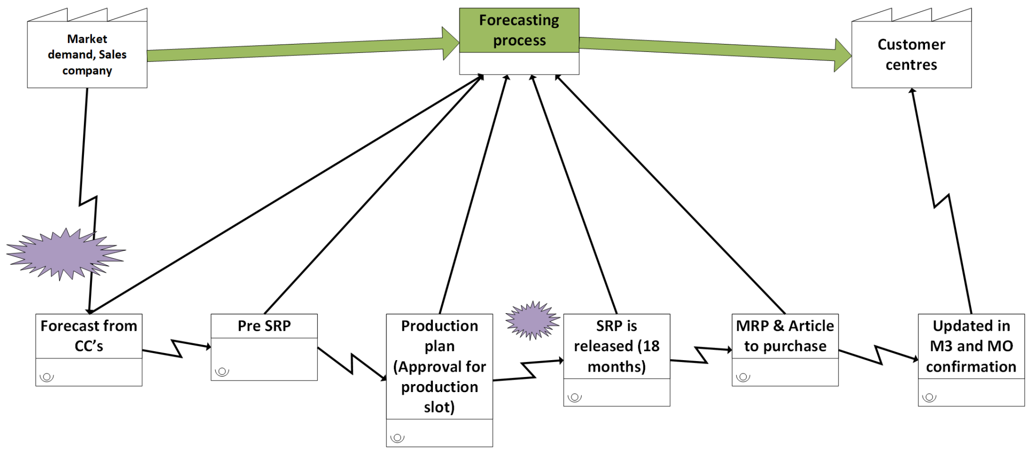


Figure 5.1: Machine Forecast Process

5.1.2 Sourcing and Purchasing process

In this section, the authors explain the VSM for the purchasing process. The input for the purchasing department is from the SRP and the machine forecast is from the marketing department. The customers for the sourcing & purchasing team in a production setting are usually the suppliers and sub-suppliers. The information from SRP is translated to the purchase order according to the requirement and provided to the respective supplier. For identifying the deviations or bottlenecks in the purchasing process, the authors mapped out the completed process. The purchasing department uses the forecast BOM provided by R&D to publish the requirement of the components to the suppliers.

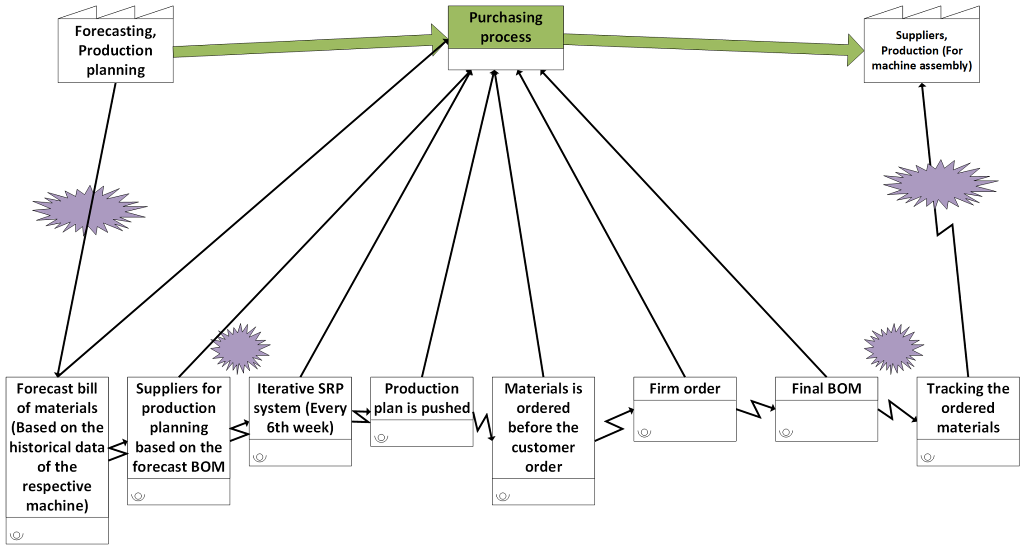


Figure 5.2: Sourcing Process

Suppliers review the MRP received from the purchasing and plan the production accordingly based on the forecast BOM to deliver the components on time. The sourcing & the purchasing department receive an iterative forecast every 6 weeks. After the forecast BOM is published, the production plan is also pushed into the system. The purchasing department uses this information to order the components before the customer order is confirmed. Lastly, the firm order is received from the marketing department which might lead to a few changes in specifications or the number of components ordered from the suppliers. Refer to the figure 5.2 below to understand the information flow between the departments.

5.1.3 Machine Structure Specification (R&D)

This section gives the reader the details of the processes involved in the R&D department. The researchers analyzed that the supplier or the input for the R&D is the forecasting information from the marketing department and the customer or output is the order preparation team. As indicated in the figure 5.3, once the R&D department receives the information from the forecasting, the R&D department divides the projects and developments based on the requirement of the customers, i.e., the machine order type. Machine order types are classified as: Standard machine order type, Adapted machine order type, and Special machine order type. The cost analysis and the design hours are then allocated depending on the machine order type. This analysis and information regarding the production slot confirmation are discussed with customers. The confirmation from the customer is gathered to complete the BOM for the machine order type depending on the design hours which is denoted in the figure 5.3.

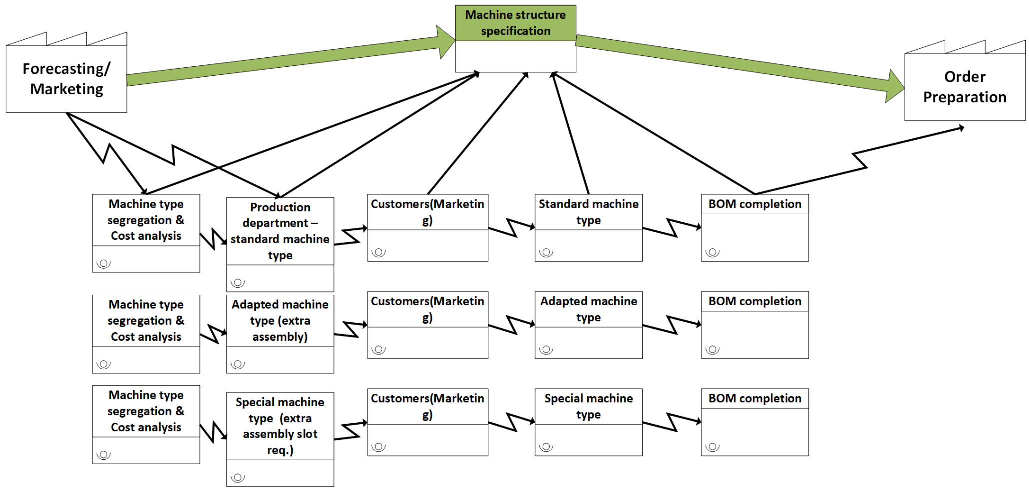


Figure 5.3: Machine Structure Specification Process

5.1.4 Order Preparation

Considering the final bottleneck process, the order preparation department receives the information from R&D and delivers the output to the production planning department. Breaking the process as shown in figure 5.4, the information received from the marketing department is translated into M3 and MRP system for visibility to other departments. The important step in the process is the change notice issue from the department depending on the changes from the R&D department based on requests from customers. Once the changes are made, the order is prepared and sent for final confirmation. This confirmation is named the MO confirmation delivered to the production planning department. This information is updated in the ERP system which is visible to the production planning team. In the upcoming sections, the authors discuss the extensive measure of qualitative data acquired.

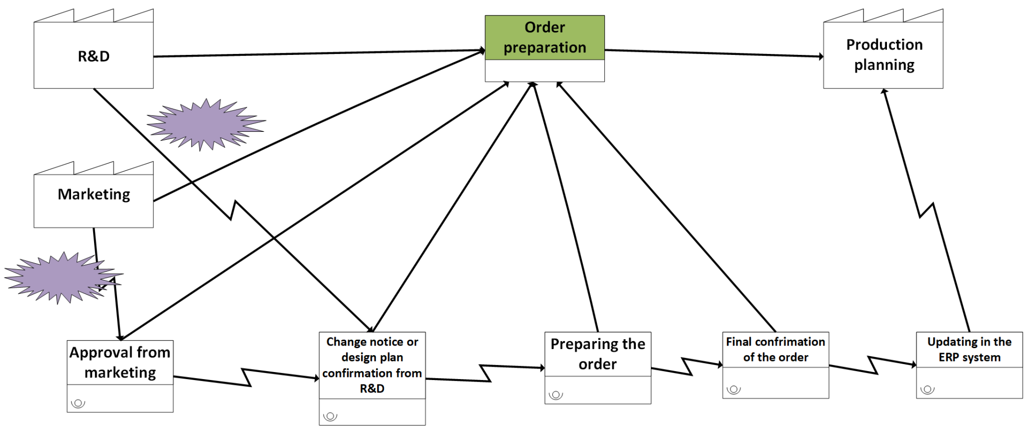


Figure 5.4: Order Preparation Process

5.2 Collaboration between Supplier and Production Purchaser

The collaboration between suppliers has improved because of the improved information flow between suppliers and Epiroc. It is shown in the figure 5.5. Epiroc has systems in place with suppliers for confirming and reconfirming orders, notifying late orders, improving delivery dates, and lastly managing information flow.

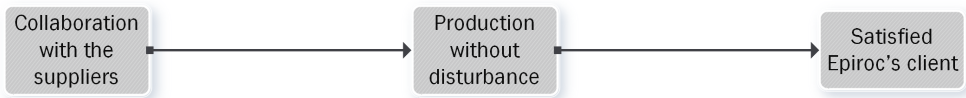


Figure 5.5: Collaboration between Supplier and Purchaser

Order confirmation and reconfirmation
Epiroc offers their suppliers 48 hours to confirm an order; if the provider does not respond within that period, the purchaser must inquire about the order confirmation with the supplier. If the supplier requires additional time, this should be communicated. When an order is confirmed, the supplier not only acknowledges it but also verifies the price and delivery date. The order confirmation must be correct from the start, and the purchaser at Epiroc should be alerted if any delivery dates are delayed. The delivery dates must be updated regularly.

Late orders
updated delivery is one of the most prevalent reasons for late orders. Epiroc is required to contact suppliers for new delivery dates or confirmation that the order has been sent.

Improve confirmed delivery dates
One of the most common reasons for requesting changes is that the order has been delayed and the delivery dates are later than requested. In this instance, Epiroc's buyer must always ask its supplier to increase delivery dates, and the supplier must employ all available resources to meet Epiroc's demands.

Improve the information flow
Epiroc is always willing to assist suppliers with their knowledge and skills to minimize mistakes and, as a result, improve the information flow and avoid any postponement. When there is a forecasting error, the possibility of delayed delivery, or delayed supplies, suppliers can always approach the production purchaser for assistance. In turn, the supplier is expected to confirm orders, amend delivery dates,

and inform the Epiroc purchaser of any potential risk of postponement. All this aids Epiroc's ability to communicate more effectively with its suppliers.

5.3 Forecast Planning

There are various standards and procedures to follow when developing a prediction from a client forecast to a firm order. This information aids the author in comprehending how the sourcing department uses the forecast technique to acquire material. The forecast planning process is shown in the figure 5.6

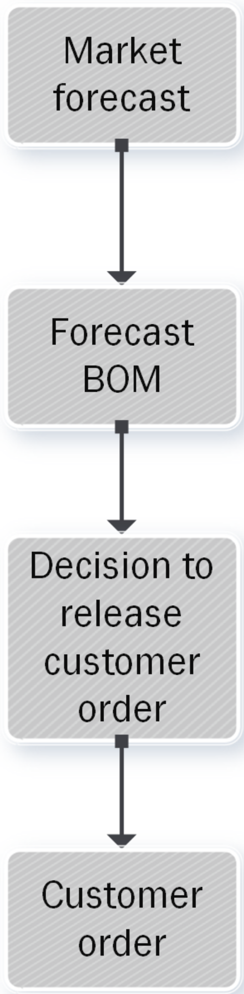


Figure 5.6: Forecast Planning

Market forecast
The first phase entails releasing a fresh market forecast, which covers the market demand for the following five quarters.

Forecast BOM

In step 2, the market requirement will be entered into the MRP system, allowing the supplier to view the forecast alongside the bill of materials. The bill of material created at this step is only based on past usage, therefore if a part number xxx has been utilized 50% on machine yy, it will be loaded with a demand percentage of 0.5 per machine.

Decisions on when to release the client order

This stage will take place a set number of weeks before assembly begins. Following that, a decision will be taken whether to release the customer order to an available slot or to cancel or postpone the session. Furthermore, most materials are ordered before the customer's order.

Customer order

The customer order will be released at this phase. The anticipated machinery will be eliminated and replaced with a firm bill of materials.

5.4 Forecasting and SRP Planning Process

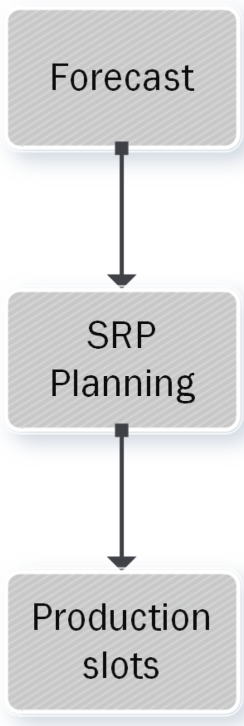


Figure 5.7: Forecasting and SRP Planning Process

The forecasting and SRP planning processes will be described. The information is gathered through reports from the marketing department. The forecasting and SRP planning process is shown in the figure 5.7.

5.4.1 Forecasting Process

There are four processes in the forecasting process before the data is entered into the SRP planning. Requests from CCs, RBM assessment, compilation, and eventually input to the SRP are all part of the process. Refer the figure 5.8 for the steps involved in the process.

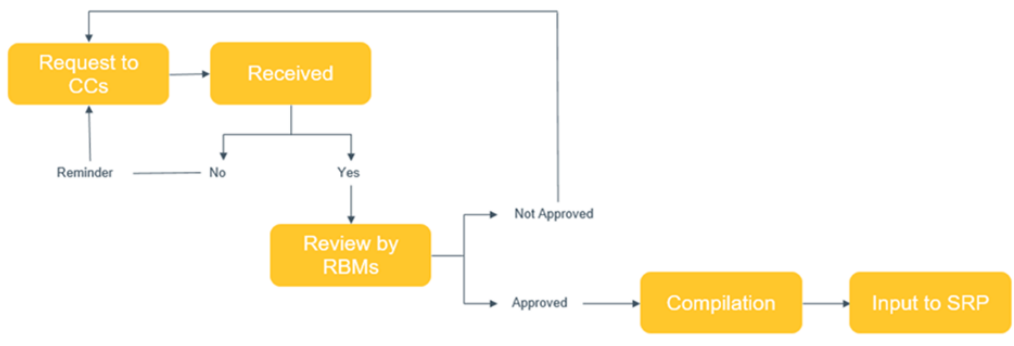


Figure 5.8: Forecasting Process Steps

CC requests
In this stage, the files for each quarter are updated, and the instructions and deadlines are given to the CCs. The cc's have 10 days to provide the reports after receiving the request.

RBM review
It is critical to ensure that the reports are received on time at this stage. Check and double-check with each cc that the figures are right and make any necessary revisions.

Compilation
During this process, all the information acquired is saved in the URE global business team.

Input to SRP
Finally, the forecast values are updated in the SRP system quarterly in this stage.

5.4.2 SRP Planning Process

The goal of this process is to produce a product based on a forecast, information from customer centers, and market trends. The sales requirement prognosis is the process's outcome (SRP). Forecast compilation, SRP meeting, GBM review, compilation, sharing with production, and lastly update in the M3 system are all processes in this process. The SRP planning step is shown in the figure 5.9

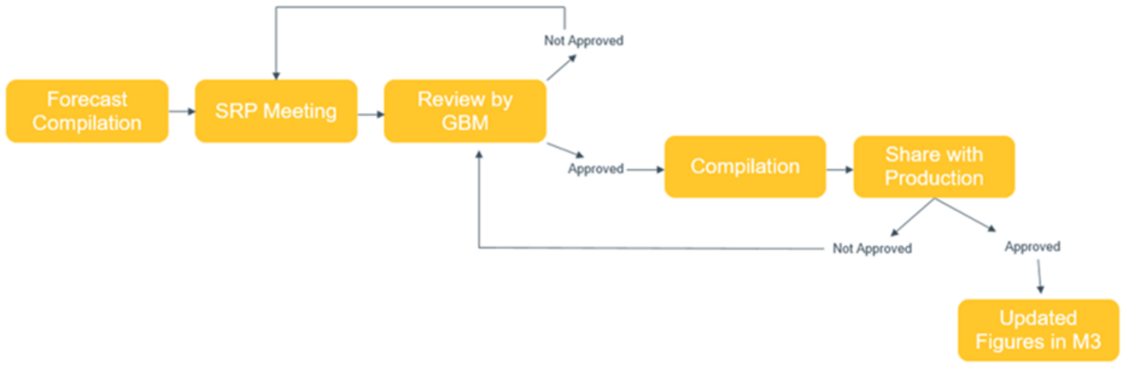


Figure 5.9: SRP Planning Process Step

Forecast compilation
Each RBM is participating in this process, which involves reviewing the forecast compilation data and finalizing the business cooking for each region.

SRP meeting
Agenda for this stage covers topics such as confirmation of production slots, MO confirmation, and manually updated lists that are not in the M3.

GBM review
GBM is involved in this stage to review the modifications. It has been passed to the next phase for compilation after the changes have been authorized; otherwise, a fresh review is required.

Compilation
In this phase, the GBMs and spreadsheet file have completed all necessary reviews, and a presentation has been included to show the changes.

Share with production
It is critical to secure production and buying capacity at this stage. If the product meets the criterion, it has been updated in the M3 system; otherwise, it must return

to the previous phase and examine.

Updated in M3
After the SRP has been accepted, the production team has one week to update the M3 with the new values, and an email confirmation is required.

5.5 Summary of M-Phase

The measurement phase acquired detailed information on process variations as well as some quantitative data to back it up. In the analysis phase, the qualitative data collected through semi-structured interviews will be addressed. The major goal of this step is to comprehend the mechanism underlying the little y and its importance in it. Similarly, using value stream mapping to uncover the sub-processes of the processes and identify the regions with the most improvement potential made it feasible to eliminate some of the noise in the process. Apart from the constraints indicated in the define phase, other possible improvement areas that cause the small y have been found.

Forecasting, machine structure specification, sourcing, and order preparation are some of the processes that are studied further in the value stream mapping. With this, complete knowledge of the process concerning forecasting, machine structure specification, sourcing, and order preparation has been explored to gain a better understanding of the small y process and to identify the essential X components involved. The time spent measuring was crucial since it allowed the author to obtain a better knowledge of the small y and discover the X components. All of this served as a basis for further data analysis in the following phase, which included the use of lean and six sigma tools. To analyze the data obtained and prepare for changes to decrease or eliminate process deviations such as material delays, 90-kits, and lack of quality, methods such as the fishbone diagram, 5Why's, text mining, matrix analysis, and P-FMEA are utilized.

6

Analyze

Data is being used in the Analyse phase to identify the major process inputs that influence the process outputs (Carleton, 2016).

6.1 Text Mining

In this section, the authors used the text mining software in JMP to analyse the pattern of correlation and contradiction in the findings which have been listed below.

6.1.1 Change Forecast

The words and phrases lists, as well as a visualization in the form of a word cloud at a centered angle about the number of times the terms were used in the data, may be seen in figure 6.1.

The terms forecast, need, material, production, change, machine, 90,kits, and customer are the most used terms, while the phrases 90-kits, forecast changes, bill of materials, need to change, need to update, air freight, delivery mode optimization, new material, and lead time are the most used phrases. The most significant issues, according to questions about change forecast, new customer requests, and changes in connection to the bill of materials, are the most significant challenges, resulting in 90-kits. As a result, the lead time of the material rises, causing delays in the assembly process as well as delivery to the clients. As a result, air freight is employed as a form of transportation to deliver parts as quickly as possible.

Changes in the forecast or a new client request have an impact on every department in the value chain. Production, marketing, and R&D are among the first departments to be affected. Finally, several of the methods and strategies mentioned in the phrases and list, such as standardized procedures, delivery mode optimization, and accurate bill of materials, are fewer approaches to effectively manage change forecasts and limit or eliminate process deviations.

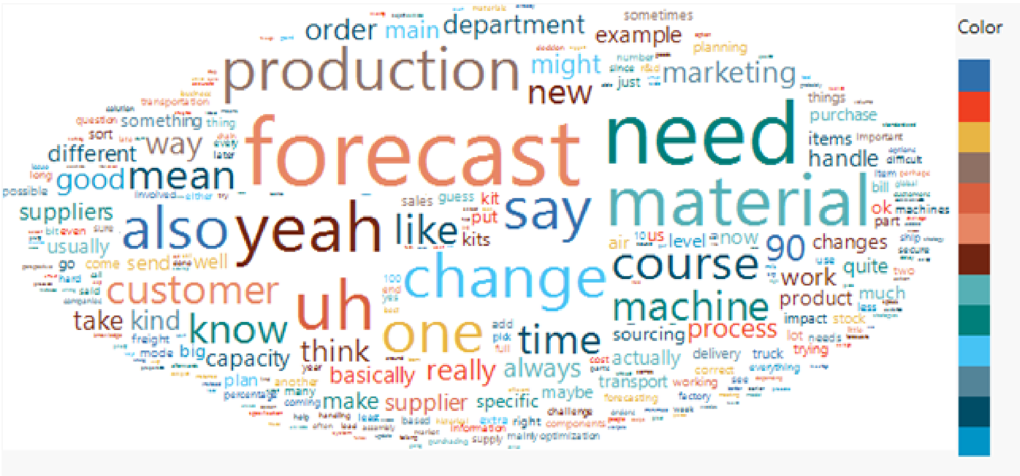


Figure 6.1: Change Forecast Word Cloud

6.1.2 Machine Structure Specification

The words and phrases lists, as well as a visualization in the form of a word cloud at a centered angle about the number of times the terms were used in the data, may be seen in figure 6.2.

The terms machines, change, production, client, material, specification, time, BOM, difference, and 90 are the most often used terms in the figures. 90-kits, machine BOM, bill of materials, late changes, delivery time, machine order, incorrect materials, lead time, various choices, machine order, machine specifications, many different, sales company, material availability, and specifications modifications are all phrases used in this document. According to machine structure specification questions, the most significant obstacles in terms of process deviations might be attributed to specification modifications, sales business requests, and the many alternatives available. It also has an impact on material lead times, shipping times, and material availability, all of which cause delays in the process and, in some cases, result in 90-kits. Standardizing the process, minimizing the complexity of components, and increasing the number of modularized parts are some of the strategies that might be employed to prevent issues in machine structure requirements.

Finally, the machine structure specifications are being updated owing to new modification requests from the sales organization, production-related concerns, and market demand. Furthermore, it is assumed that the modifications can take place at both the module and small component levels.

Number of Terms	Number of Cases	Total Tokens	Tokens per Case	Number of Non-Empty Cases	Portion of Non-Empty Cases
855	11	7958	723.455	11	1.0000

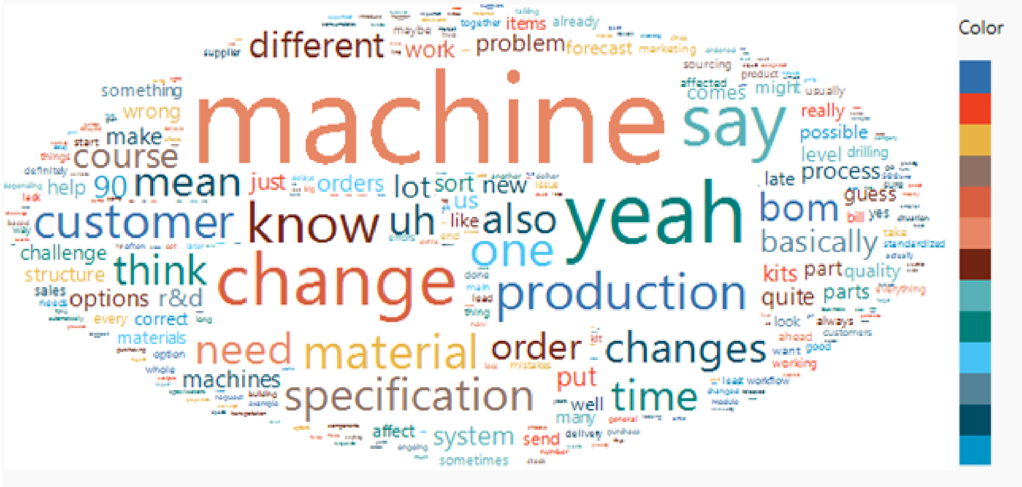


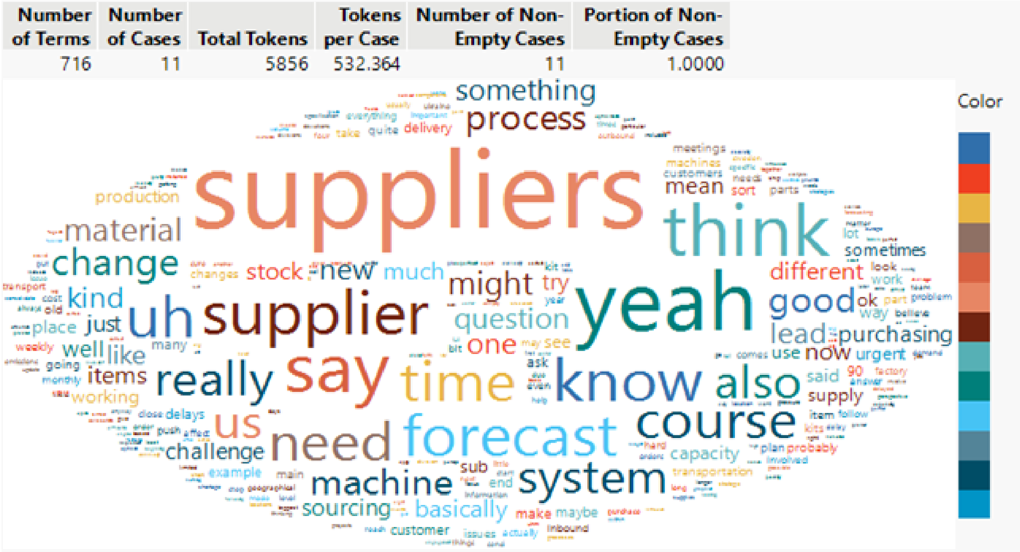
Figure 6.2: Machine Structure Specification Word Cloud

6.1.3 Suppliers

The words and phrases lists, as well as a visualization in the form of a word cloud at a centered angle about the number of times the terms were used in the data, may be seen in figure 6.3.

The most used terms are suppliers, time, forecast, need, system, change, machine, process, materials, and lead. 90-kits, new system, placing pressure, supply shortage, hard to access, old system, long lead time, pick-up days, air transport, and cost are all the phrases. According to supplier issue questions, Epiroc's primary problems with their suppliers include supply shortages, forecast changes at the end of the process, and longer material lead times. All these factors cause process irregularities, resulting in extra transportation in the form of air freight owing to material delays.

Furthermore, delivery mode optimizations, set pick-up days, commodity-specific sourcing methods, and regular updates are some of the improvement techniques that might be implemented to overcome these obstacles and lessen or eliminate the Big Y. Finally, in the event of a covid pandemic, the geographic location might be a major element to consider. As a result, it is critical to have continuous updates and information on suppliers to avoid discrepancies.



Number of Terms	Number of Cases	Total Tokens	Tokens per Case	Number of Non-Empty Cases	Portion of Non-Empty Cases
716	11	5856	532.364	11	1.0000

Figure 6.3: Supplier Word Cloud

6.1.4 90-Kits

The words and phrases lists, as well as a visualization in the form of a word cloud at a centered angle about the number of times the terms were used in the data, may be seen in figure 6.4.

The terms 90, machine, kits, sales, business, customer, cost, priority, need, production, process, material, and components are commonly employed because of this. 90-kits, sales firm, generating 90-kits, consignment order, client desires, keep track, alter the specification, and need to manage are examples of phrases. The biggest obstacles noted in the 90-Kits questions are increased expense, prioritization over other components, communication concerns, and a lack of preparation. All of this contributes to a distinct process, resulting in increased costs, emissions, and effort. The 90-kits will be handled by the production planning and material handling departments.

Finally, understanding what the client wants from the start and not having to modify requirements at the end of the process reduces or eliminates the 90-kit process. Because the 90-kits are an overhead process of the deviations that occur, they are not a key procedure. Additionally, standardizing the 90-kit procedure would assist all departments in having clear communication of the process and avoiding delays in the process.

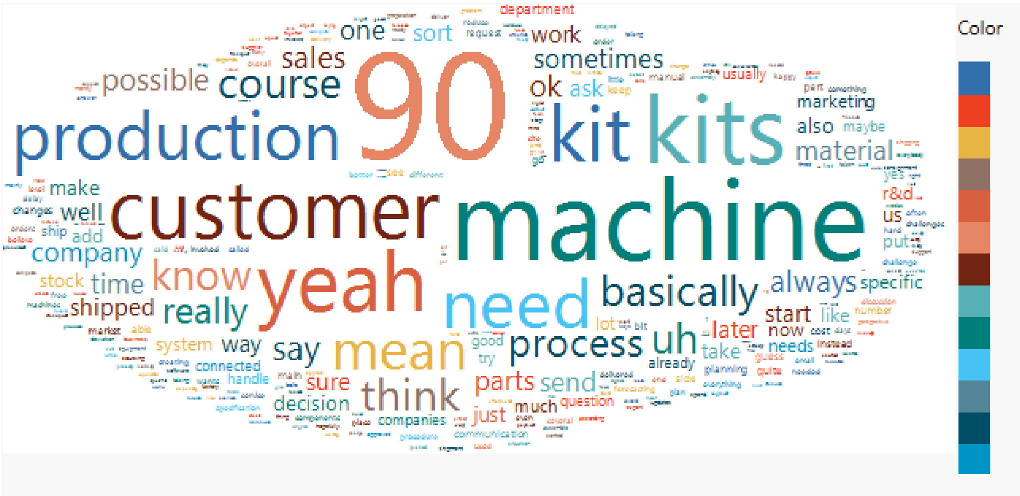


Figure 6.4: 90-Kits Word Cloud

6.1.5 Green Lean Six Sigma

The words and phrases lists, as well as a visualization in the form of a word cloud at a centered angle about the number of times the terms were used in the data, may be seen in figure 6.5.

The phrases "green," "good," "process," "R&D," "cost," "lean," "reduction," "start," and "need" are frequently used in this context. Six sigma, green design, part numbers, the best way, green lean six sigma, emission decrease, R&D stage, practicable to start, start working on the green, KPI's, and best way are all phrases used in this research. According to the green lean six sigma questions, the approach would provide the organization a fresh start in terms of reducing emissions or eliminating process defects in this thesis. It can also be observed that if the technique is implemented from the R&D stage, it will be practicable since the R&D department will be able to consider the green way of thinking and the materials that will be obtained in an environmentally friendly manner.

Finally, it became evident that further education is required on the technique, including how it benefits the firm and how individuals of the organization may begin using it and performing green kaizen projects to reduce costs and emissions. Furthermore, KPIs should be assessed at each level to keep track of progress and take appropriate action when necessary.

Figure 6.5: Green lean six sigma Word Cloud

6.1.6 Material Handling

The words and phrases lists, as well as a visualization in the form of a word cloud at a centered angle about the number of times the terms were used in the data, may be seen in figure 6.6.

The phrases "need," "material," "quality," "time," "production," "system," "lead," "suppliers," "90," "transport," "air," and "problems" are regularly used in this context. Lead time, material handling, 90-kits, quality issues, manufacturing floor, supplier quality, ERP system, stocked goods, machine materials, time in our system, bill of materials, and non-stocked products are among the words. According to material handling issues, problems include a very short lead time for materials in the ERP system, which creates material delays as well as late information to suppliers. Other problems include obtaining the right bill of materials from the start to prevent process delays and material availability. It increases the process's cost, resources, and time commitment. Furthermore, receiving high-quality items from suppliers is critical since inappropriate material handling leads to rework and delays.

Finally, to maintain an effective flow in operations, it is necessary to have an alert system, sourcing strategies with suppliers, and other capabilities with suppliers to monitor and keep track of their stocks. Epiroc employs the milk run delivery idea to convey a mixed load of different providers to its location.

Figure 6.6: Material Handling Word Cloud

6.1.7 Order Preparation

The words and phrases lists, as well as a visualization in the form of a word cloud at a centered angle about the number of times the terms were used in the data, may be seen in figure 6.7.

Order, machine, system, customer, 90, changes, production, sales, preparation, planning, information, and marketing are all terms that appear often in the data. Machine order, 90-kits, lead time, sales portal, business system, buy order, client order, information flow, order preparation, planning department, production planner, sales firm, and marketing department are some of the phrases specified. Information flow is crucial to minimize delays and confusion in the order preparation and information flow process, according to the inquiry. Because failing to recall who to contact at the next stage might result in failure and delays, one of the significant challenges is to remember who to contact at the next phase.

Finally, because order preparation is a simple procedure, most respondents have no problems or obstacles with it. However, because much of the work in the order preparation team is done manually, the errors in the process are caused by human error. Furthermore, because of the great complexity of the parts, quality checking the structures is difficult, and there is a possibility of selecting the incorrect parts, resulting in delays, 90-kits, and a loss of quality at a later stage in the process.

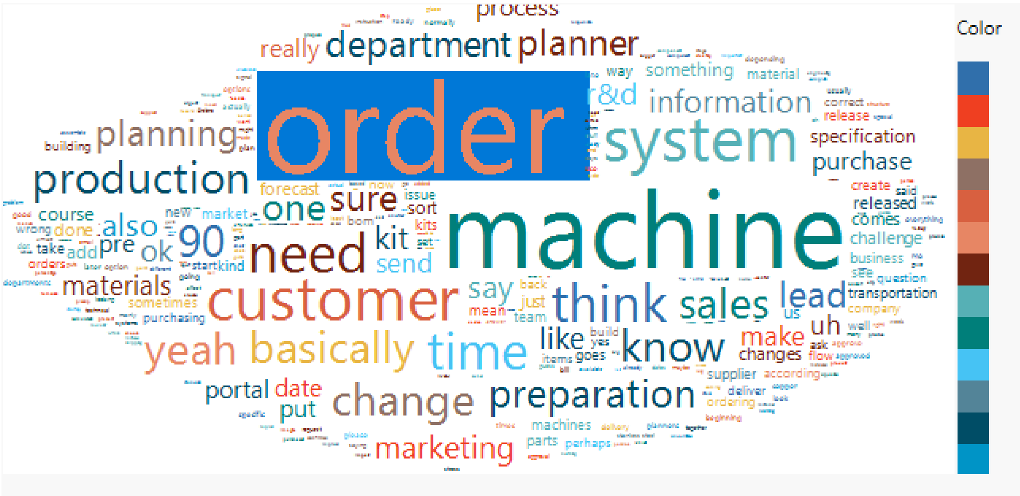


Figure 6.7: Order Preparation Word Cloud

6.2 Matrix Analysis

The massive amount of data was analyzed using text mining tools and manually in the form of matrix analysis based on the actual findings from the interviews. The matrix analysis was used to analyze the interviews by allocating codes and themes for interviews. The primary agenda behind this analysis is to improve the research's reliability and validity by identifying the essential X factors for change. From the interviews, the author established many codes, and thematic analysis was used to observe and grasp the common understanding, meaning, and experiences. The codes and topics that were investigated are detailed below.

Change forecast challenges

The influence of change forecast on most of the process, which results in process deviations of delayed material and 90-Kits, was extremely obvious to note. One major issue, though, is that the forecast is based on speculation and the bill of materials is created using past data. Due to this, the forecast BOM must be adjusted and updated manually. As a result, delays occur since the supplier forecast must be modified with less lead time. Additionally, because of the revised forecast, constraint material accumulates because the original material was not canceled, and additional material is added, increasing costs, and causing delays in the process. Additionally, it adds to the value chain's workload, lengthens the project's lead time, and raises the risk of major delays. Additionally, the transportation department has trouble allocating the raw materials since difficult-to-manage late changes result in air freight.

Impact due to change in forecast
The difficulties influence every department in the value chain. A later change forecast has an impact on departments starting with marketing, research and development, order preparation, sourcing, purchasing, production planning, and assembly.

Strategies for change forecast
One of the crucial points that have been observed for taking an early step to managing the change forecast is to freeze the MO (Manufacturing order) since modifications cannot be introduced later in the process, which helps to prevent triggering the small y. Additionally, if the SRP prediction has been established without variation and if the bill of materials is based on future-focused information in addition to historical data, this would help to remove the difficulties associated with change forecasting.

Machine structure specification challenges
There are several difficulties associated with machine structure specification, which is a crucial step to comprehend. First, because the process is not standardized, it is challenging to incorporate all the stakeholders and standardize a quality procedure for each machine based on its complexity. Second, vendors at the module level purchase materials directly, which denies Epiroc the authority, visibility, and transparency necessary to conduct material analyses and offer high-quality parts. Finally, because there are so many different pieces, there is no system flag in the process to halt or notify if the wrong parts have been selected. Since this causes delays, which in turn creates a 90-Kits.

Strategies for machine structure specification
It is important to establish a standard workflow with a more rule-based configuration and utilize more digital transformation technologies where all stakeholders are informed if a change has been made to regulate the variance and avoid issues about machine structure requirements. To prevent delays in the process later, it is essential to construct a configurator to determine whether the machine design is feasible and can be physically installed. Additionally, because there are so many different parts, it is important to simplify each machine and use fewer parts, which may be modularized and make forecasting easier.

Frequency of updates and changes
New client requests, market demands, and production-related concerns are the major causes of modifications in the machine structure specification. Additionally, the modifications may affect both components at the module level and those at the small level.

Supplier challenges
Suppliers are important because they must supply the materials for production and assembly on schedule. Due to a change in the forecast or BOM, Epiroc is facing difficulties with capacity limitations and a lack of supplies from the supplier. The main hurdle is getting the new material in time for production planning. It is also challenging to reprioritize orders and optimize production because of unforeseen changes and capacity issues. While delivering it to the clients, any of these might result in a quality problem.

Collaboration between suppliers
To work with its suppliers as effectively as possible, Epiroc. On a weekly and monthly basis, meetings are held with the suppliers. The agenda for the meeting includes updates on the forecast, modifications, and being ready for them. Suppliers are informed of the change in advance if Epiroc is aware of it; otherwise, the affected suppliers must take the appropriate measures.

Strategies for supplier enhancement
Certain tactics may help to boost dependability to improve supplier collaboration and prevent process variances. First, delivery mode optimization (DMO) may be described as a technique that aids in both the prevention of delays and the identification of their causes. To improve collaboration and deal effectively with the suppliers, it is also necessary to design sourcing methods for each commodity, such as the Kanban system. To plan the modifications appropriately, for instance employing digital technologies and features, it is important to understand how much stock the suppliers still have accessible. Finally, a gate model to create and predict the machine order may aid in improving machine forecasting.

90-Kits challenges
Regarding this code, there are drawbacks as well as advantages. The difficulties would be that the 90-Kits would take precedence over the components, delaying the machine's construction. There is no system to support it, which results in more costs for R&D and imports as well as more manual labor. It also demonstrates how poor planning may be considered a key element in the creation of a 90-Kit and how the components of a 90-Kit are unable to test the parts over a machine, which may subsequently cause issues with quality and safety. Contrarily, it is viewed to resolve problems and provide a way to deliver the delayed material.

A standardized procedure for 90-kits
90-Kits are viewed as a large contributor to carbon emissions, and it is crucial to establish if the process has been standardized. There is a definite technique to construct a 90-Kit and how it should be sent. However, because the process for doing so has not been fully understood, it is essential to educate everyone on the

initial motivation of creating a 90-Kit. For instance, is it related to a new customer request, a delay, or material restrictions to avoid it in the long run.

Green lean six sigma usefulness
This approach is thought to help Epiroc achieve its goals and to lessen or eliminate the process deviations associated with material delays, 90-Kits, and poor quality in this thesis. Additionally, most people think it removes the process' non-value-added operations, further optimizing it. Additionally, it stimulates the implementation of green kaizen and the beginning of circularity implementation at the R&D stage. Finally, it serves as a springboard for integrating sustainable practices across the supply chain, broadening the sustainability viewpoint.

Material handling challenges
Material handling is one of the crucial departments to maintain a closer check as it may have a direct influence on the process irregularities. For instance, material delays. One major issue is that there is not enough system support to track the materials accurately, which results in delays when the materials are finally received for assembly. The ERP system is quickly updated on short notice regarding the lead time of the materials. As a result, suppliers are quickly alerted, which causes a delay in the delivery of the devices. All of this results in increased expenses and demands on resources.

Sourcing strategies & other functionalities
The milk run idea is one of Epiroc's primary procurement strategies with its suppliers. Additionally, one of the Eprioc units in Fogesta features an intriguing alarm system known as 01S275. This alert system helps to keep track of the client order and the forecast. For instance, if a target of 1000 orders has been set for a month, and the limit is exceeded for the month, it will notify every department along the value chain. Planning by consumer demands and preparing for them is beneficial.

Order preparation & Information flow challenges
The challenges in this area are minimal, yet the information that is flown is viewed as essential to this department. It is important to have a smooth information flow rather than having to remember who to call next. Additionally, the only difficulties encountered are manual ones, which might be fixed by reviewing them.

6.3 Cause and Effect Diagram

In this section, the authors have explained the causes by analyzing the semi-structured interviews. The 6M's considered by the authors to examine the causes for the process deviations in the cause & effect diagram are as follows: measurement, method, man, and machine order type, material, and management. The authors have thoroughly scrutinized the semi-structured interviews to obtain the cause-and-effect diagram as shown in the figure 6.8.

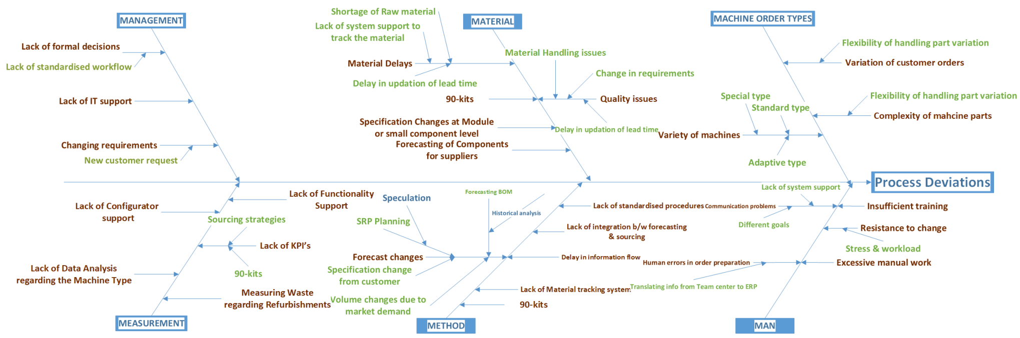


Figure 6.8: Cause and Effect Diagram for the causes & sub-causes identified from the interviews

6.3.1 Man

The causes affected by the employee or workforce fall under this section. As shown in the FIG, the main causes originated by Man can be credited to:

Excessive manual work:
Due to continuous and regular manual work, there is a high possibility that the employees can lose their concentration and cause a few problems while updating or transferring the data from one system to other. The amount of manual work concerning preparing SRP can be seen as one of the potential examples.

Human errors in Order Preparation:
As discussed in previous sections, the order preparation team plays a major role in translating data from SRP into the M3 or the ERP. Since it possesses a chunk of information, there can be few human errors in terms of numbers and types of components required. Also, changes from the R&D need to plug into the ERP system which can be a tedious job.

Resistance to Change:
In some scenarios, the workforce may be reluctant to make a few changes in the organization or the way they work due to excessive workload and fatigue. This resistance to change may lead to errors while working.

Communication Problems:
According to the authors, there are many scenarios in the process in which a void is created due to miscommunications and lack of information flow. This can be due to

two major reasons, i.e., lack of system support and the employees having individual goals and ambitions.

6.3.2 Machine Order Types

The authors improvised the second 'M' to machine order type to make it clearer for the readers to understand that, since there was no physical product, it was not possible to segregate this into a cause occurred by 'Machine'. As discussed previously there are three major types: Standard, Adaptive and Special machine order types.

Variation of Customer Orders:
Since there are three machine order types there is a variation of requirements from customer to customer. This results in the new development in R&D and a high amount of work on the supplier end. A variation in module level and component level may lead to quality issues. In some scenarios, the variation in customer orders leads to changes in the processes which results in a delay of material from the supplier end.

Variety of Machines:
The variety of machine orders leads to different scenarios concerning design hours. The standard machine order type may require around 1-2 days of design hours to publish the BOM. The adaptive machine order types require around 160 design hours to make changes to the components and module level to publish the BOM. Lastly, the special-order type requires more than 600 design hours to develop the machine based on requirements and publish BOM.

6.3.3 Material

The third 'M' in the cause-and-effect diagram is Material. The researchers have sorted out five main causes which are associated with the material. Since the suppliers are the main actors for material, this section covers a wide range of sub-causes as well.

Forecasting of Components for Suppliers:
As discussed previously, once the forecast BOM is released, the purchasing team proceeds with a component order confirmation for procurement. This forecast BOM may be accurate or vary depending upon the order type, customer requirement, and raw-material availability.

Specifications changes at the module or small component level:
According to the analysis based on semi-structured interviews, 'specification change' is the major cause that was highlighted by many of the interviewees. The changes in the specification at the module or small component level lead to quality issues in

the functionality of the module when coupled. The late changes may require time for production in the supply end which leads to material delays and 90-kits.

Material Delays:
The causes for the material delays are a lack of support system to track the movement of the material after being shipped from the supplier, delay in updating the lead time to produce it, and sometimes the shortage of raw materials, for example, shortage of semiconductors.

6.3.4 Method

The fourth 'M' in the cause-and-effect diagram is the Method utilized for the processes. The authors have recognized a lot of causes when it comes to 'method' since the research is primarily focused on process improvements.

Lack of Standardized Procedures:
After the interviews, the researchers analyzed there are a few processes that are not standardized. For example, the process of 90-kits lacks standardization since the process is a deviation under certain circumstances.

Forecast Changes:
One of the major causes for the process deviations to occur. As shown in the figure, it is linked with many sub-causes which enforce changes to be made to the forecast. Due to the various changes in market demand depending on the requirement of the work, the specification or customer need is highly likely to change, leading to changes in the forecast. The volume changes due to market fluctuation and forecast BOM changes can also enforce the changes to the forecast. Since the forecast BOM is based on historical data, there can be variations when compared to market demand in the future. Hence, a change in forecast is very likely in these cases.

Other Causes:
Lack of integration between forecast/marketing and sourcing has been identified due to delay in information flow, and transfer of data from one system to other. Lack of material tracking can also be placed under the 'Method' cause of the absence of a system in case tracking and tracing of the inbound and outbound components or machines.

6.3.5 Measurement

The fifth 'M' that covers the causes for the process deviations is the cause-and-effect diagram is 'Measurement'. In the case of measurement, the sub-causes can correspond to a lack of KPIs in certain processes, analysis of the data captured, and sometimes support from the system. The major causes in the case of the measurement are lack of data analysis regarding the machine type, measuring waste regarding refurbishments, lack of KPI in case of 90-kits and sourcing strategies, and finally the lack of functionality support to measure the required parameter. Changes in specifications or demand might lead to wastage due to refurbishments in the products. These wastages are not measured which results in less transparency for neighboring departments. The researchers also recognized that in the case of sourcing strategy and forecasting accuracy there is a lack of measurement systems or parameters.

6.3.6 Management

The last 'M' that is relevant to explaining the causes is 'management'. The authors have used management as one of the 'M' because the research is based on the strategic decisions taken by higher-level management. For example, the decision to make changes to the forecast or the change of machine order type to a particular customer must be decided from the management perspective. The causes affecting the decisions are remarkably like the ones discussed in previous sections. Refer to the FIG to have clarity on the classification of causes and sub-causes.

6.4 P-FMEA

FMEA (Failure Mode and Effect Analysis) is a methodical approach for locating and stopping issues with products and processes before they arise. The goals of FMEAs (Failure Mode Effect Analysis) are to reduce defects, improve safety, and boost customer happiness (McDermott, Mikulak, & Beauregard, 2009). FMEA is usually utilized for product design and process development activities, but it can also be conducted for analyzing existing processes and products (McDermott et al., 2009). The P-Fmea table can be found in appendix A.3.

The authors in this research have used a standard academic FMEA template to represent the failure modes and their occurrences as shown in the TABLE. The first column of the table 'Process Step' indicates the steps or sub-processes involved to finish tasks. The column 'Input' consists of the inputs or the supplier to the corresponding process steps. The next column 'Potential Failure Mode' indicates the possible failures of the input or symptom. The fourth column 'Potential Effects of Failure' explains the possible impacts on the customer requirements which can lead to non-fulfillment of tasks. The next column 'Severity' indicates how severe the effect is to the customer receiving the inputs and the rating chosen by the authors is from 1 to 10, which means the higher the rating higher is the severity. The sixth column in the table 'Potential Cause/Mechanisms of failure', indicates the causes of the possible failure modes for individual failures. The next rating column 'Occurrence' shows how often the cause of failure mode occurs. This is indicated by the range 1 to 10. The next column 'Detection' indicates the range from 1 to 10, which means how well the processes can detect the occurring failure modes. Finally, the last column conducted in the FMEA is the RPN which is given by the product of the 'Severity,' 'Occurrence,' and 'Detection.' The process steps and the corresponding inputs to the individual process steps are conducted and recorded as shown in the TABLE.

6.5 Identified X-Factors

The essential X-factors have been found based on the empirical data from the semi-structured interview, observations, reports, fishbone diagram, p-fmea, and analysis performed using text mining tools and a matrix analysis done manually. It is shown in the figure 6.9. The X-factors that have been chosen are

X1 Part variation complexity
All Orebro machines have n number of pieces that fit together, and there are no modularized parts, making it impossible for the company to estimate properly. It wastes materials, causes delays, and generates problems in the forecasting process.

X2 forecasting process
It can be considered a consequence of X1, but it occurs for a variety of reasons, including new client requests, late revisions, and a lack of a standardized model. Late modifications, for example, influence other departments in the supply chain, resulting in delays and 90-kits. The sourcing process is one of the departments that is immediately impacted.

X3 sourcing process
It can be regarded because of X2, but it can also occur for other reasons, such as late adjustments that create a change in the predicted BOM. Furthermore, makes modifications to the firm order, loses track of the material owing to a lack of IT assistance, resulting in delays and a longer lead time, and finally, supplier issues due to changing forecasts, capacity constraints, and allocation concerns. To have an effective and optimized process, it is critical to have a better sourcing strategy with suppliers.

X4 KPIs
They are important to track to take remedial action, however, Epiroc fails to catch several KPIs related to process deviations such as material delays, 90-kits, and poor quality. For example, because Epiroc lacks KPIs for inbound supplier quality and time to make adjustments, they have no idea how much time this process takes, resulting in unnecessary shipping, additional costs, and rework.

These critical-to-quality X-factors were chosen because they are thought to have the greatest influence on the thesis. Furthermore, reducing these elements would result in a more stable process as well as cost and environmental savings.

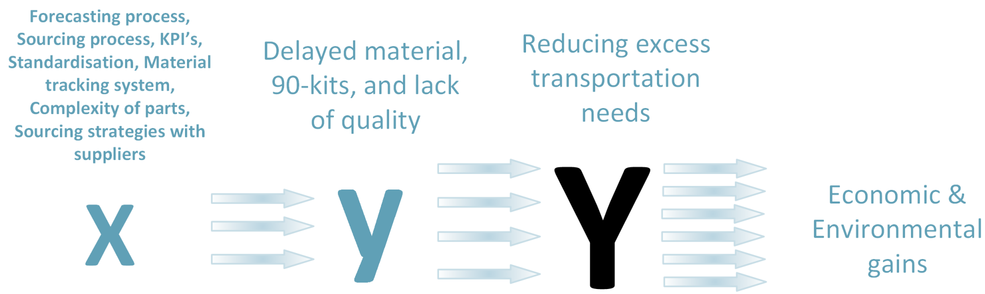


Figure 6.9: Identified X-Factors

6.6 Summary of A-Phase

The crucial X variables that impact the process were identified and further explored during the analysis phase and the underlying reason for difficulties was discovered. Problem formulation, model building, improvement plan, and suggestions might all be started by identifying elements that impact the process.

The text mining software was used to analyze the enormous quantity of data collected by the interviews to gain a better understanding of the issues and to identify and research them more. To evaluate the qualitative data from the interviews and compare the reliability with the computerized analysis, matrix analysis was done manually. The root cause of the difficulties was then determined using a fishbone diagram, 5-Why analysis, and P-Fmea.

Finally, an improvement plan with the critical X factors that contribute to the causes of most of the problems has been sorted out, and a model has been developed to reduce and eliminate the problems, with the expected outcome of reducing process deviations and maintaining the gains in the long run to achieve economic and environmental profits.

7

Improve

During the Improve stage, the original thought can be considered to modify particular processes and other potential courses of action to have the intended effect on process performance (Montgomery & Woodall, 2008).

7.1 Brainstorming

The members of the thesis team and the firm participants in the thesis met to brainstorm ideas. The company's members came up with a variety of themes and ideas, all of which pointed toward creating a model that has the best chance of minimizing process deviations. During the brainstorming meetings, the ideas were debated and eliminated after discussion. Then, in the improvement phase, the ideas that benefit the firm and suit the thesis were chosen and developed further to achieve economic and environmental advantages.

7.2 KPI Dashboard

The major goal of creating a KPI dashboard is to make it simpler for management to see how the process is doing and to take the appropriate corrective action when required. The master data excel file for the KPI dashboard contains the current year's actual data, the current year's goal data, and the previous year's actual data for the KPI measurements that have been mentioned for the process. You can arrange this master data according to month. The dashboard is shown as charts, which will assist the business in understanding the relationships between various KPI metrics and monthly trends. The management team will be able to increase process efficiency with the aid of this KPI dashboard, which will enhance process performance. Additionally, it aids in maintaining alignment with the organization's overarching mission and objective. To learn more about the KPI dashboard shown, please refer to the appendix A.4.

7.2.1 KPI's

The authors have created seven key performance indicators (KPIs) to track to monitor process performance and lessen or eliminate process variations. Four categories were established for the KPIs: quality, rework, on-time delivery, and forecasting accuracy. To distinguish between each KPI criterion, a KPI code has been assigned to each one. Below is a detailed explanation of the many KPI categories as well as the standards by which they will be measured and why.

Firstly, the KPI group for Quality is measuring three KPI criteria.

Yield (101)
This KPI is used to track how many machines are produced by specifications without any scrap or rework at the outset. Reworking results in delays, poor quality, and 90-kit as a result. As a result, this KPI would help the organization determine where to exert control in response to a problem. It is calculated as a percentage (percent).

Incoming supplier quality (102)
This KPI counts how many parts are procured from vendors and brought in-house complying with the requirements. It helps to determine which suppliers and which components have the greatest flaws and aids in the development of an avoidance plan. Since every variation raises the small y, this KPI may be used to gauge how well the process is working. It is calculated as a percentage (percent).

Production Defects (103)
This KPI counts the number of production-line components that do not meet specifications. Understanding the fundamental causes of the flaws that the manufacturing department and other departments have created allows one to take the required steps to prevent them in the future, minimizing delays, 90-kits, and the manufacture of low-quality products. It is calculated as a percentage (percent).

Secondly, the KPI group for Rework is measuring two KPI criteria.

Time to make changes (201)
This KPI (Key Performance Indicators) is targeted as a criterion to understand how long it takes to make changes, which in turn causes delays, and schedule modifications. It would be useful to monitor and take the appropriate steps to stop additional issues if we could record this KPI. By removing the process bottlenecks that lead to process deviations, this KPI will assist in preventing delays and 90-kits in the process. Days are used as a unit of measurement.

Forecast BOM changes (202)
This KPI is only concerned with the time it takes and the forecast BOM changes. This criterion aids in understanding why the forecast BOM is regularly modified and whether it contributes to process delays. Taking the appropriate steps to remove, helps to identify bottlenecks and strive to lessen or eliminate them throughout the process. By reducing or eliminating forecast BOM bottlenecks that are the source of variances, this KPI would assist in lowering carbon emissions. Days are used as a unit of measurement.

Thirdly, the KPI group for On-time delivery measures two KPI parameters.

Machines shipped on time (301)
The goal of this KPI is to track how many machines are built and delivered to customers on time, without any delays. It is useful to keep track of how many machines are experiencing delays and the most common causes of such delays. This will also assist in eliminating the core problem and preventing process variations like material delays and 90-Kits. Limiting emissions has a good impact on the sustainability of the environment. It is calculated as a percentage (percent).

Material handling (302)
The goal of this KPI is to track and monitor the material (components/modules) utilized in the production of the machines. It is useful to know whether there is a delay in the availability of the materials needed to create it or whether they are easily accessible. This KPI aids in determining if delays are the result of random fluctuation or specific materials or modules. Overall, this KPI would strive to prevent material supply delays, which in turn contribute to an issue of delays, resulting in carbon emissions from 90-kits. This would make it easier to retain enough material on hand for manufacturing without any delays, which in turn would reduce process deviations. It is calculated as a percentage (percent).

Finally, the KPI group for forecasting accuracy is measuring one KPI criterion in total.

Predicted forecast vs actual forecast (401)
This KPI calculates the difference between the forecast's projected and actual accuracy. This KPI aids the marketing team in developing a solid plan or model to prevent forecasting errors. Because it causes delays, 90-Kit, and a lack of quality, which are the biggest problems with the thesis, this will make it easier to create plans if there is a significant departure from the prediction that has been planned, forcing the team to review the strategy and come up with a fresh approach to prevent forecast mistakes. It is calculated as a percentage (percent).

7.3 Process Models

The competition of today and tomorrow is centered around processes. Organizations have concluded that processes must be able to offer efficiency in addition to quality and service (Alonso, Dadam, & Rosemann, 2007). After analyzing the interviews and the documents, the authors considered two of the main processes which can be improved, the Machine forecast process and the Sourcing process. Firstly, the current scenario in these processes is explained for the readers to have a better understanding.

7.3.1 Present - Machine Forecast Process

The current machine forecast process consists of various activities which involve more than three departments to complete the entire task as shown in the figure 7.1. The process starts with the machine forecasts from CCs which include uncovering customers' needs and volume demand for the next five quarters. Once the machine forecast is received; the marketing team prepares an SRP proposal which is named Pre-SRP. A review of this Pre-SRP is done by three departments, i.e., production, purchasing, and design for the upcoming eighteen months. After reviewing the SRP, it is released, and production slots are created. In the next step, the production and sourcing department confirms the production slots, and temporary delivery dates are issued. Once the dates are confirmed then, the SRP is transferred into ERP systems for purchasing the components. In the final step, the Manufacturing order is confirmed and M3 is updated in the system for transparency.

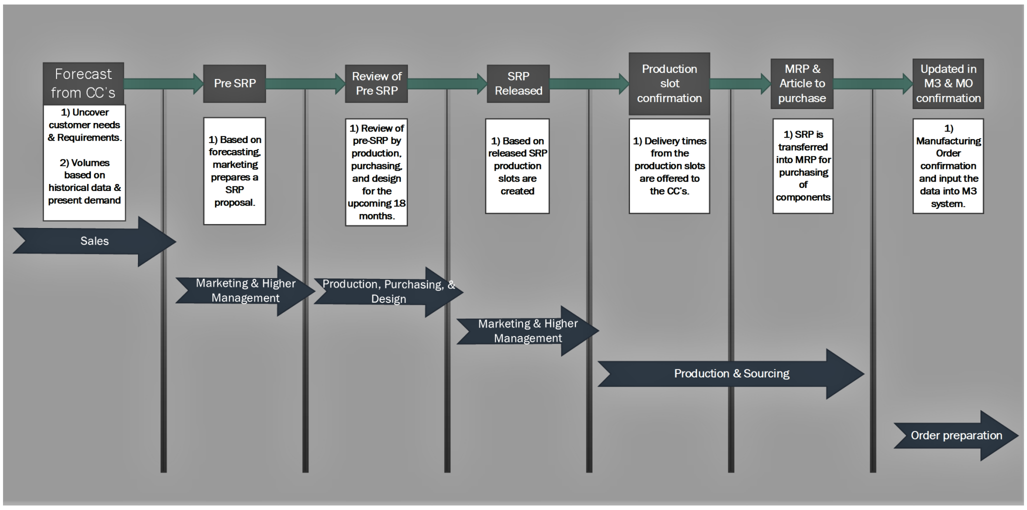


Figure 7.1: Present Forecasting Model

7.3.2 Present - Sourcing Process

The next critical process is purchasing or sourcing activity. The sourcing process involves several departments and their activities step-by-step to finish the task of component procurement. As discussed previously, the market needs are received through machine forecast details every month which incorporates market needs for the next five quarters. This document is provided to the Research and development team to prepare a forecast bill of materials (BOM) which is based on historical data. The forecast BOM is sent to the suppliers for review regarding the raw material availability. The next step in the process is an iterative step of releasing the SRP every sixth week based on the market demand. After receiving the SRP, the production plan is pushed along with the simultaneous activity involving the order placement for component procurement. The firm customer order is confirmed and the final BOM is released by the order preparation and R&D department, respectively. The detailed process step is shown in the figure 7.2 below.

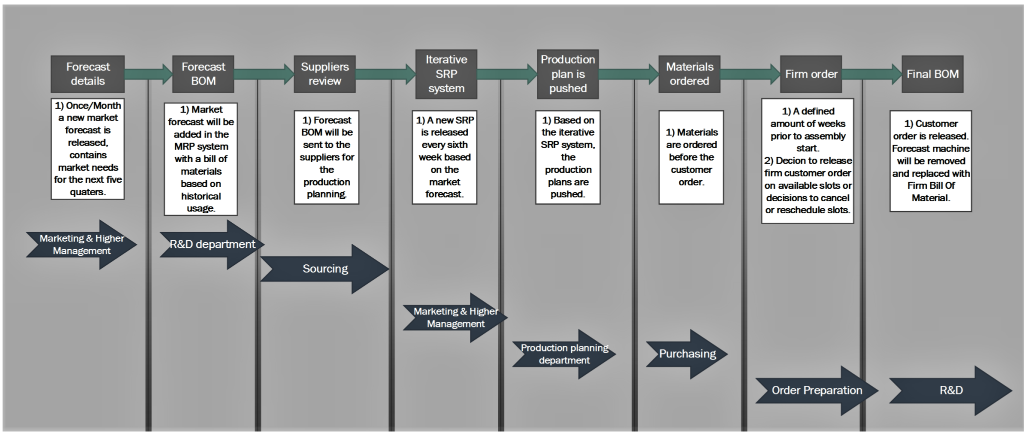


Figure 7.2: Present Sourcing Model

The following two sub-sections involve a detailed explanation of the new model developed by the researchers for forecasting and sourcing.

7.3.3 Machine Forecast Model

The authors have utilized the Stage-Gate model to build a new process model for the machine forecast process. The machine forecast model involves ten stages where the activities of the process occur, and four gates are the criteria for the decision to be confirmed from the previous stage to the next. The arrows below the stages indicate the responsibility of the individual and dual departments for the tasks mentioned in each stage as shown in the figure 7.3.

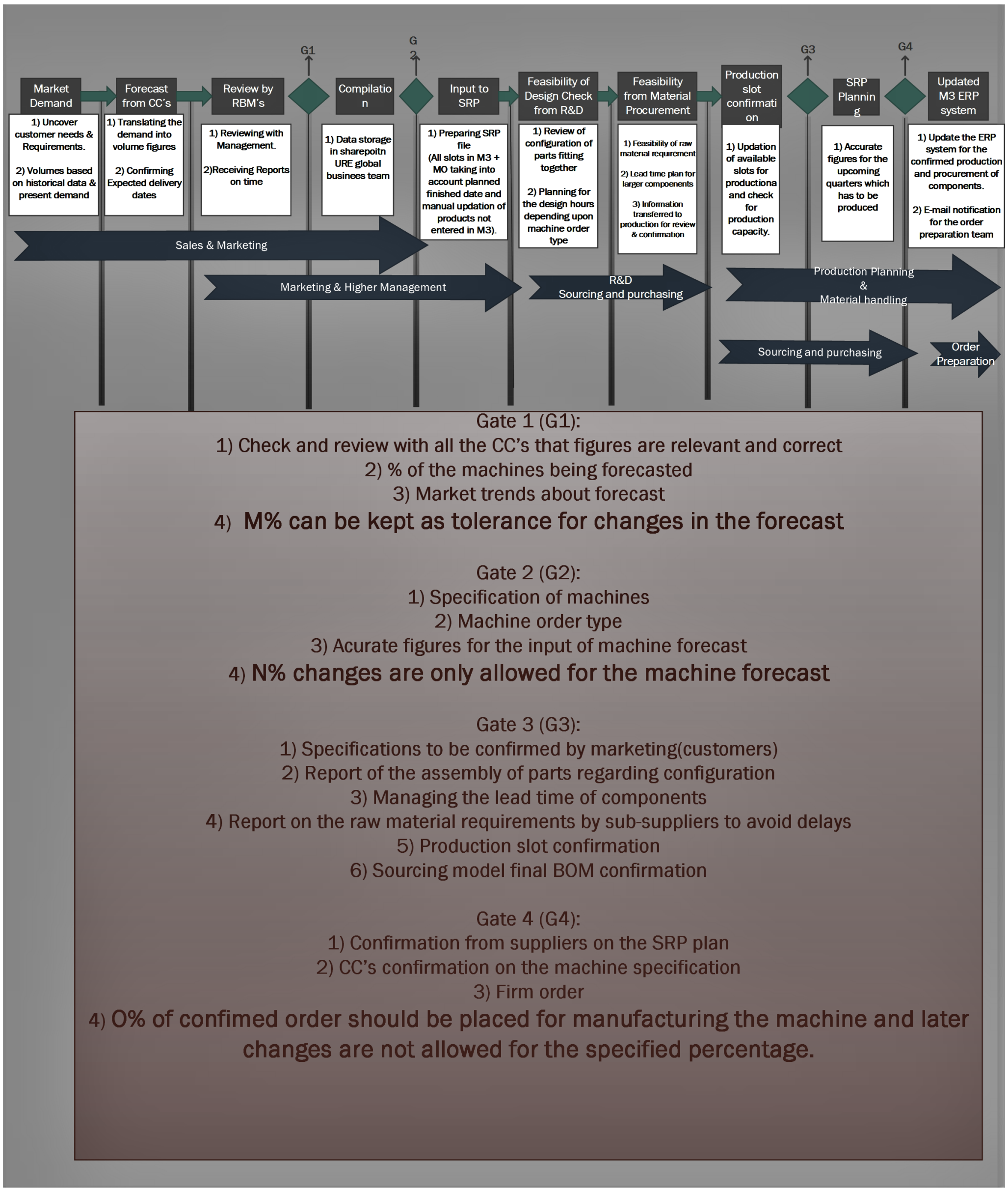


Figure 7.3: Forecasting Model

Stage 1
The first stage should involve uncovering customer needs and requirements. The volumes predicted should be based on the market demand and a few numbers should be added based on historical production.

Stage 2
The forecasts from CCs should be translated to numbers and estimated delivery dates should be presented.

Stage 3
The volumes and the delivery dates should be reviewed by the RBM along with the higher management.

Gate 1
After the third stage, the decision-making criteria must be utilized. The first point in Gate 1 is checking and reviewing with all the CCs that the figures are relevant and precise. The second point N% of machines being forecasted must be intact which leads to the last criterion, i.e., M% of machines can be changed with changes in the forecast.

Stage 4
This step involves the compilation of the forecast by storing the data in SharePoint URE global business team for transparency. The first four stages require extensive involvement in sales and marketing.

Gate 2
Specifications of machines need to be analyzed, machine order type should be finalized for allocating design hours, and only X% changes are allowed till this phase. The changes include specifications, volumes, and delivery dates.

Stage 5
This step involves preparing the SRP file which incorporates filling up the M3 and manufacturing order considering the planned delivery dates and completing SRP manually. Stages three and four are managed by marketing along with sales and stage five is supervised by higher management.

Stage 6
The feasibility of the design check is done by the research and development team. The work should revolve around reviewing the configuration of parts fitting together and planning the design hours depending on the machine order type.

Stage 7
This step involves the feasibility decision from the material procurement department. The feasibility of raw material availability should be checked, and the lead time should be planned for larger components. The information captured through this investigation must be transferred to production for review and confirmation.

Stage 8
After reviewing the previous steps, the production planning department should confirm the production slots.

Gate 3
The criteria in this gate can be assumed to be the confirmation gate, where several tasks and decisions need to be taken. Confirmations such as machine structure specifications, production slot, and BOM confirmation by sourcing. The departments responsible should also plan to receive a report on the raw material requirements by sub-suppliers to avoid delays.

Stage 9
The accurate figures for the upcoming quarters which are named as confirmed orders must be uploaded to the SRP system for transparency.

Gate 4
The last gate involves confirmation from suppliers on the SRP plan, CC's confirmation on the machine specifications, a firm order release from the production department, and Y% of machines cannot be allowed for the changes.

Stage 10
The final stage of the machine forecast process is handled by the order preparation department to update the ERP system for confirmed production and procurement of components. The final three stages are supervised and performed by production planning, material handling and decisions must be taken by the sourcing and purchasing team.

The complete process flow, the stage-gate model along with the departments are shown in the figure 7.3. The criteria for the gate are also mentioned in the figure 7.3.

7.3.4 Purchasing and Sourcing Model

In this section, the authors explain the sourcing model which has a similar approach to the stage-gate model with the departments mentioned in the arrows as shown in the figure 7.4. It consists of seven stages as process steps and four gates which act as criteria as discussed in the previous section. The major responsibilities and tasks should be managed by the purchasing and sourcing team with effective assistance from other departments for efficient processes. The scope of the model was to integrate the machine forecast model and sourcing model. Hence, the starting point of the sourcing model is to receive the forecasting details. The integration of both models can be noticed in the first two stages of the sourcing model, which means there is a high level of transparency between the marketing and sourcing division.

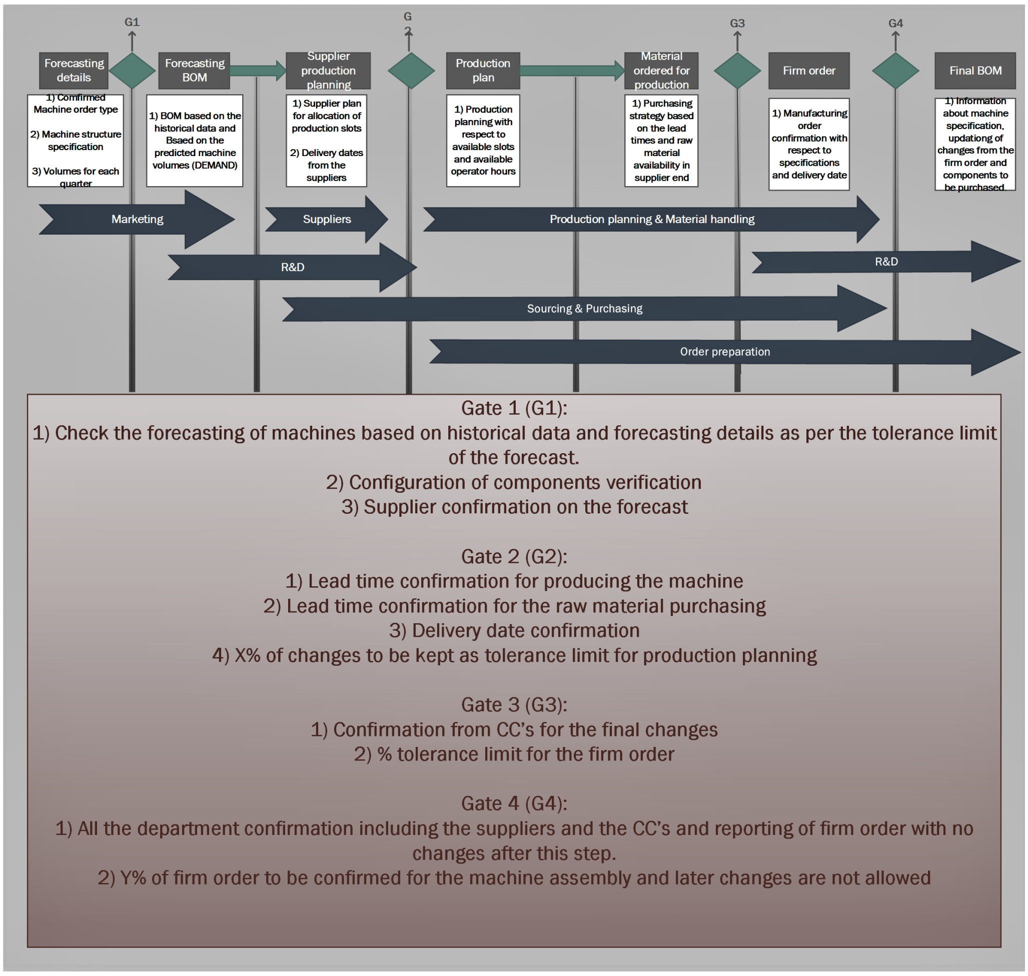


Figure 7.4: Sourcing Model

Stage 1
The forecasting details are confirmed by the marketing department which includes machine order type, machine structure specification, and volumes for each one-fourth.

Gate 1
The decision-making criteria involve checking the forecasting of machines based on historical data and other forecasting details. Also, the other criteria incorporate inputs from the suppliers about the confirmation of the machine forecast.

Stage 2
The next stage is publishing the forecast BOM based on the historical data and machine volumes predicted (market demand).

Stage 3
The authors have incorporated one step related to suppliers as well. In this step, the suppliers plan for the production slots and should confirm the delivery dates based on the requests from the sourcing department.

Gate 2
As shown in the FIG, this gate consists of criteria related to confirmation of lead time for producing the machine, lead time for the raw material purchasing, and delivery date confirmation. Lastly, X% of changes can be allowed in the production planning phase.

Stage 4
Based on the availability of slots and available operator hours the production planning must be completed.

Stage 5
A purchasing strategy can be incorporated based on the lead time and raw material availability in the supplier which accounts for placing the order for procuring the components.

Gate 3
The confirmation from CCs for final changes can be considered here, and if there are any changes, Y% can be accepted since the firm order has to be published.

Stage 6
The manufacturing order needs to be confirmed while taking into account the specifications and delivery date.

Gate 4
The final decision-making criteria involve confirmation from all departments including suppliers, CC, and reporting of firm orders with no changes beyond this stage.

Stage 7
The final BOM is published in the system.

The complete process flow and the stage-gate model along with the departments are shown in the figure 7.4. The criteria for the gate are also mentioned in the figure 7.4.

7.4 Recommendations

In this section, certain significant recommendations are provided that help to reduce carbon emissions and improve the processes.

7.4.1 Modularisation

One of the crucial suggestions for Epiroc is to modularize its component pieces. Since the process variation is significantly impacted by the complexity of machine variants. To decrease the number of pieces, Epiroc must begin undertaking a modularization initiative. It facilitates forecasting, decision-making, a shorter lead time, and cost savings. It was thought that when designing modularly, various machines that are put together at Orebro should be considered.

The advantages of this technology include reducing the complexity of machine parts; making forecasting easier; lowering component costs; reducing lead times; lowering costs; expediting construction; reusing the module across machines; simplifying development; and enabling on-demand stock. This improvement plan's shortcomings include its lack of flexibility for modification and the difficulty and expense of replacing a failed modular component. For instance, if a machine drill rig is modularized for n machines and a client needs a new-spec drill rig, it will be expensive and difficult to alter.

7.4.2 Standardisation of 90-Kits

Standardizing their procedure is one of the most important suggestions for Epiroc. The management of 90-Kits is viewed in this thesis as a serious issue for the firm. It is challenging for everyone to comprehend why a 90-Kit is prepared in the first place since there is not a standardized process in place for 90-Kits, which leads to misunderstandings amongst departments. Therefore, a model of how a 90-Kit may be built has been created, leading to a shared knowledge of its process flow including all the value chain departments. The model is shown in the figure 7.5.

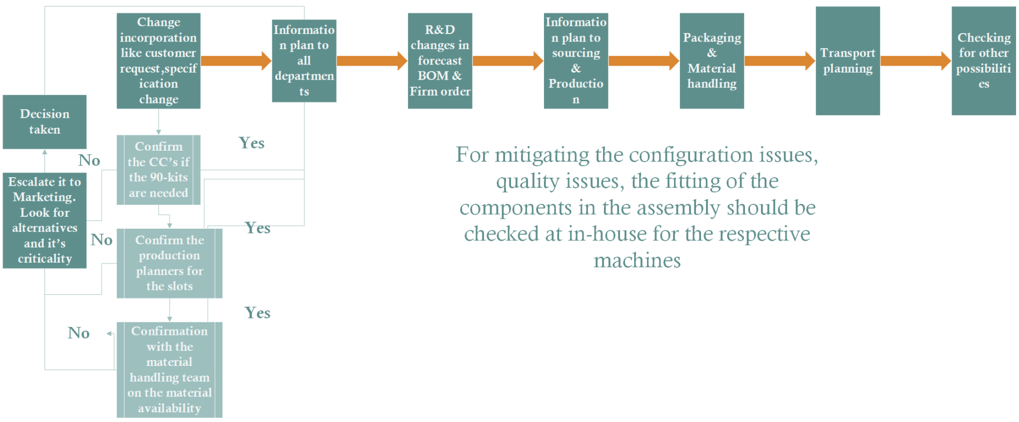


Figure 7.5: 90-kits Standardisation Model

Change incorporation's
First phase determines if the adjustments are a result of a client request, a change in the specification, or a demand in the market. The first stage in determining whether a part is still needed is to confirm the cc's, after which the manufacturing slot is confirmed. Additionally, the availability of materials is examined to prevent any effects on the other machines in the assembly.

Flow of information
After the preceding stage is finished, the subsequent departments are receiving the essential information to get ready to create a 90-kit.

Modifications connected to R&D
The appropriate adjustments are made to the firm order when the 90-kits are produced, and it is then sent to the production planning department to be adapted.

Information on sourcing and production
The 90-Kits are being created and sent to the following department for packing and mailing once the relevant information is made available from R&D.

Material handling and packaging
The components are properly wrapped to prevent damage once the 90-Kits have been entirely manufactured before being sent to the transport department for delivery to the consumers.

Planned transportation
Finally, the packaged items are air freighted to the client based on their priority, and the transit arrangements are optimized based on their significance.

Clear departmental communication, a standardized model, greater flexibility, decreased waste, and consistent quality is among the advantages of this system. Due to the 90-kits being viewed as an overhead procedure, it is regarded as a waste, which is one of the disadvantages of this improved method. Therefore, standardizing 90-Kits does not appear like a good answer; rather, it is considered to somewhat minimize waste because of their implementation.

7.4.3 Material Tracking System

For manufacturing companies, tracking, and tracing shipments is critical for providing excellent customer service and for effectively managing logistics networks (Shamsuzzoha & Helo, 2011). Global companies are experiencing issues with tracking and tracing in their logistics supply networks, which causes significant coordination issues at product development sites (Shamsuzzoha & Helo, 2011). The tracking system assists in determining the location of the shipment and notifies the customer in advance and tracing the items can be useful to trace and quantity of the products (Shamsuzzoha & Helo, 2011). The material tracking system model is shown in the figure 7.6.

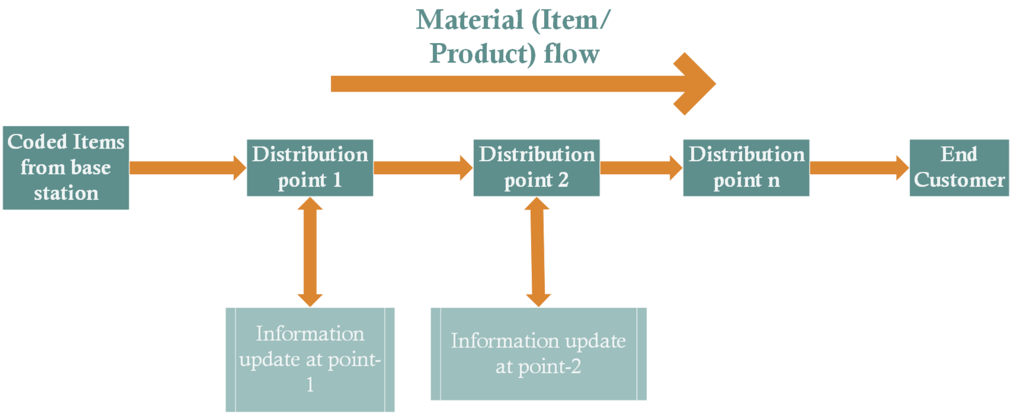


Figure 7.6: Material Tracking and Tracing Model

The tracking and tracing system is thought to be a very beneficial service in industrial logistics and for meeting increased client demands (Shamsuzzoha & Helo, 2011). The tracking technique is identified by organizational management to boost their market position by improving customer happiness and implementing information technology. In today's shifting market settings, this technology provides more transparency to both physical and information logistics networks, allowing them to operate more effectively and efficiently (Shamsuzzoha & Helo, 2011). Product tracking begins with the idea of a thing's value or associated risk, and the need to locate the product whereas product tracing, on the other hand, begins with exception handling, in which an individual seeks to determine the source of quantity and quality (Shamsuzzoha & Helo, 2011). According to Shamsuzzoha and Helo (2011), the tracking and tracing system is not only limited to manufacturers, but also to entire supply chain networks that are divided by market forces. Supply chain networks can be thought of as an integrative strategy to deal with material planning and control from suppliers to end-users in terms of tracking and tracing systems.

7.5 Discarded Factors

The most significant aspects with the most room for development were considered for improvement, and the other ones were disregarded. Based on the RPN value from the FMEA study, the improvement areas were selected. The same was also addressed with the staff members of the firm to get their opinions. Since the machine forecasting process, sourcing process, KPI, and part variation complexity have the biggest influence on process deviations, the improvement plan for these aspects was considered critical. Since these are the elements that are more in line with the objectives of the thesis.

The criteria were used to create a concrete model, and the remaining aspects were chosen for future improvement projects based on their importance as determined by the FMEA RPN number. As a result, it is decided that the authors' and company members' discussions have recommended and confirmed the order of importance for the improvement plans.

7.6 Summary of I-Phase

The solution to the problem was proposed during the improvement phase. These improvement plans were created using the thorough analysis from the previous phase (Analyze), as well as ideas generated during a brainstorming session between the authors and company members. The elements with the greatest potential for improvement were chosen and put into practice; the other factors, which would take more time to execute, were recommended to the firm.

To better understand the forecasting and sourcing processes, which are the processes that have the most impact and influence on most of the problems, two models and a KPI dashboard were established. Since Epiroc lacks specific KPIs to track and monitor process deviations that would enable them to take the appropriate steps as needed, the KPI dashboard was also provided. The goal is to include everyone in the process so that it can be standardized and there is a rapid approach to identify potential changes.

8

Control

To ensure that the project's advantages are institutionalized, the Control step's objectives are to complete the project's remaining activities, and hand over the improved process to the process owner, along with a process control plan and other suitable processes (Montgomery & Woodall, 2008).

Issue	Frequency of update	Measure	Trigger	Owner	Corrective action (CA)	Process adjustment
Forecasting deviations	14 days	401 (KPI dashboard)	Deviations from the target value in the KPI dashboard	Marketing department	Identify the reasons behind the trigger and develop a plan to mitigate it. Root causes analysis are made, and corrective actions (CA) are taken.	Communicate the CA to the respective departments and the people involved. Provide education and trainings on the causes of the trigger. Enforce standard and make sure CA are taken.
90-Kits	14 days	202 (KPI dashboard)	Deviations from the target value in the KPI dashboard	Cross-functional departments	Identify the reasons behind the trigger and develop a plan to mitigate it. Root causes analysis are made, and corrective actions (CA) are taken.	Communicate the CA to the respective departments and the people involved. Provide education and trainings on the causes of the trigger. Enforce standard and make sure CA are taken.
Lack of quality	14 days	101 (KPI dashboard)	Deviations from the target value in the KPI dashboard	Quality department	Identify the reasons behind the trigger and develop a plan to mitigate it. Root causes analysis are made, and corrective actions (CA) are taken.	Communicate the CA to the respective departments and the people involved. Provide education and trainings on the causes of the trigger. Enforce standard and make sure CA are taken.

Figure 8.1: Control Plan

8.1 Control Plan

In this section, the control plan has been developed to mitigate or reduce the carbon emissions for the process deviations of delayed materials, 90-Kits, and lack of quality. The control plan can be seen in the figure 8.1.

8.1.1 Forecasting deviations

In a manner, the mining industry is quite dynamic. As a result, it is extremely difficult to foresee for machines. Additionally, other procedures go into a machine's forecasting. The other departments in the value chain are impacted if a machine's forecasting is altered or delayed because of the ensuing air freight of that equipment. Certain elements affect forecasting, generating changes in the value chain that cause delays in the process. As a result, the research shows that the forecasting process must be improved to lessen or eliminate process deviations. The measurement in place today and the model do not mitigate this problem.

Action Strategy
To provide a standardized process, a gate model integrating forecasting and sourcing has been designed. It aids both departments in determining what steps and demands are necessary at the process and gate. As a result, there are no new client requests, late revisions, or last-minute specification adjustments that mitigate delays, quality problems, or 90-Kits. To iterate the model and make it resilient and insensitive to change, a short-term PDCA model has also been supplied. Additionally, the KPI dashboard displays the forecasting accuracy%, prompting the team to take appropriate action on the generated charts.

8.1.2 90-Kits

Sending the clients, the missing parts are done using the 90-Kits method. Most of the time, 90-Kits is shipped by air freight since it is seen as an overhead process. The process itself is viewed as a non-value-added activity that generates emissions and unnecessary transportation since it is an overhead procedure. Furthermore, there is no established procedure to adhere to that ensures clear communication and prevents negative effects on the subsequent department. As a result, there are issues with measurement and process today, including a lack of clear communication with other departments and general ignorance of the rationale behind the creation of 90-Kits.

Action Strategy
A 90-Kit model has been designed to have clear communication across different departments in the value chain and for the process to be harmonized. The approach aids in establishing standardized procedures and provides a shared understanding for all parties involved.

8.1.3 Deficit in quality

The second big issue is regarded to be a lack of quality, which affects the other departments and causes a 90-Kits or a significant delay. Suppliers provide the materials, and quality issues including geometry, functioning, assembly, and delivery are considered the biggest concern influencing the Big Y and contributing to excessive transportation. A stronger procurement strategy is required to avoid these issues, which in turn cause process deviations such as material delays, 90-Kits, and a lack of quality. In addition, the suppliers' shared sourcing strategies are poor. Finally, the mitigation approach in place is not particularly successful, therefore this divergence is seen as a critical one to bring about beneficial improvements to Big Y.

Action Strategy
A key element to improving product delivery, timeliness, and efficiency is the sourcing strategy for suppliers. To supply the product on schedule and with high-quality goods, a sourcing strategy has been recommended. All of this results in the process deviations of poor quality, 90-Kits, and material delays being eliminated or reduced. Additionally, the KPI dashboard aids the business in understanding how long it takes to implement changes and the level of supplier quality. When there are any deviations from the objective, it helps to keep the process on track and take the required steps when necessary.

8.2 Plan-Do-Check-Act Cycle (PDCA)

The Plan-Do-Check-Act cycle gives the readers a holistic approach to the short-term plan to control and utilize the process models which were presented in the previous part. The PDCA cycle involves four stages. The authors have formulated a PDCA cycle as shown in the figure 8.2 below.

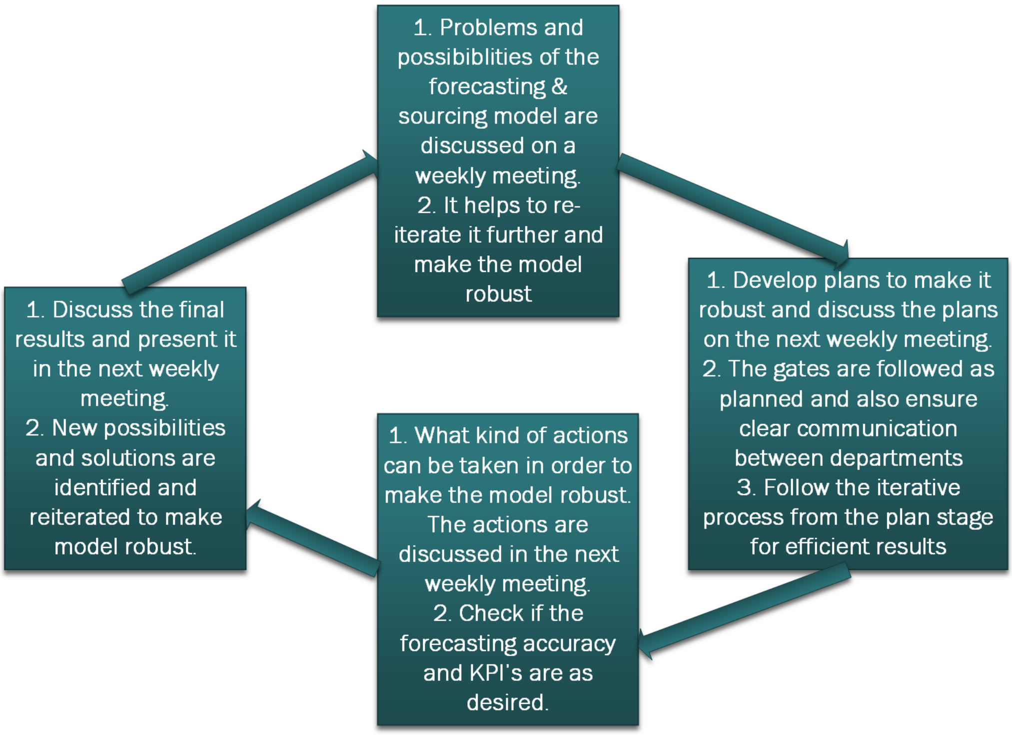


Figure 8.2: Plan-Do-Check-Act Cycle

Plan

First, the model implementations remain the main challenge. The model can be planned to be implemented phase by phase within the department. Potential problems and challenges of the forecasting and sourcing model can be discussed weekly. This makes the implementation and sustaining of the model change easier for the organization.

Do

The authors suggest that developing plans to make the process model robust can increase the efficiency of the process. The organization needs to ensure clear communication between the various departments.

Check

In this phase, always keep a check on the implementation of the plans. KPIs play an important role in checking the efficiency of the model and other factors related to it. Also, the organization can focus on actions that can be engaged to Mould the process model to robustness.

Act
It is always important for the organization to discuss the outcomes and reflect upon the actions being implemented. Also, new possibilities and solutions can be identified to reiterate the process model for efficient results.

8.3 Updated FMEA

In this section, the authors focus on modified FMEA when compared to the previous FMEA conducted in the analysis phase. The FMEA described in the analysis phase was created to analyze the potential failures and allocate the 'Risk Priority number' (RPN). In the control phase, based on the RPN the researchers have recommended actions to mitigate the potential failures in the process. Please refer to the appendix A.5 for the updated P-Fmea.

The recommendation for all three process steps was suggested to reduce risk factors. The major reduction in the RPN as shown in FIG is for the supplier forecast. Since the authors have focused on the integration process model explained previously in the report, the recommendation action is to implementation of the model along with the rule-based approach. These actions can be seen as the potential improvement aspects to reduce the RPN. Another example of recommendation action is the material tracking system, where the authors have developed a new model to track the materials for better transparency. Lastly, the complexity of components can be mitigated by modularization projects right from the R&D phase to reduce the number of components and increase the commonality between the several types of machines. The new PRN values for the corresponding process steps can be witnessed in the FIG for a better understanding of readers.

8.4 Summary of C-Phase

Different control criteria for the forecasted deviations, poor quality, material delays, and 90-Kits were offered during the control phase. The control parameters listed give specifics on how the process is performing and what, when, and how actions should be done in the event of a significant process deviation. To make the forecasting and sourcing model more durable over time and to repeat it as necessary, a short-term model in the form of a PDCA cycle has also been built. To decrease non-value-added operations and increase efficiency, the value stream mapping has also been modified to explain how a future state process for forecasting and sourcing should be. Finally, an updated FMEA was created to show how the process of RPN has changed because of the suggested action that has been put forth and what the priority next steps are to take to sustain it over the long term.

The control plan is created to avoid debating the appropriate course of action and to be utilized for actual improvement activities. 8.1, 8.2, 8.3, and 8.4 show the control plan, short-term model, value stream mapping, and FMEA. Table 8.5 provides a summary of the procedure and the metrics that will be used to evaluate it.

9

Results

The reader can access a variety of data from various interviewees through the empirical findings offered in this section. In this part, the empirical results will be summarized as a topic and presented.

9.1 Change Forecast

In this section, the findings from the interviewee stress the relationship and problems related to challenges in change forecast, how the new customer request influences it, the impact it has on the other departments, and finally pinpoints certain improvement strategies to overcome the challenges.

Interestingly, most of the interviewee has a common perception related to the challenges in change forecast. According to interviewee B, due to a change forecast, the material is delayed leading to a new material being added where the previous material is seen as a constraint material. This could lead to securing the space correctly and planning the right capacity. According to interviewee F, it is seen as extra work due to changes in the forecast which has an impact on other departments leading to delays. The statement from interviewee F was agreed upon by almost all the interviewees.

"The main challenges caused by change forecast, it causes material delays because we have the long lead time on the material and if we need to change something and this causes extra work for the purchasing department, and it is ultimately causing delays in production"

- IN F

One of the interviewees mentioned a significant major challenge influencing the change forecast is SRP is built on speculation. Secondly, forecast bill of material is not future predicted and more from a historical usage are the major challenges pointed by the interviewee, which is agreed upon by three of the interviewees, and that is

"The main thing is of course that the SRP is built on speculation and the forecast bill of material is based on historical usage. So, we have speculation and historical usage that will never be a reality"

-IN G

Importantly, new customer request is seen as a major challenge that is leading to a change in the forecast. This has been agreed upon by most of the interviewees. According to interviewee C, due to it, transport planning is affected, and pushing it out early sometimes ends in sending out the wrong materials leading to delays. Furthermore, it is critical to communicate the change appropriately with everyone in the value chain and is aware of the change that is coming. Since the suppliers get affected by it to a larger extent. The interviewee J & K states that,

"It is important to communicate with the suppliers regarding updated forecast and plan accordingly to produce more in a short time and make sure everyone is aware of changes that are coming"

- IN J & K

Due to the challenges in change forecast and new customer requests, the departments involved in the entire process are getting affected. The changes have an impact on the entire value chain process. All the interviewees agree on it and the interviewee B, C, D, I, & J states that,

"I would say Marketing, planning department, Purchasing department, R&D, Production, Sourcing, Material handling, & Transport. All departments have an impact on the changes, and everyone is impacted due to it"

- IN B, C, D, I, & J

Finally, various improvement strategies have been determined that might mitigate this and avoid leading to 90-Kits, delays, and a lack of quality. According to Interviewee A, delivery mode optimization (DMO) is seen as a significant methodology to optimize the process. Another interviewee pointed out that freezing the manufacturing order (MO) might help to avoid late changes or new customer requests later in the process and avoid delays.

"Process delivery mode optimization is done only on the outbound process and that is a weakness. We do not have delivery mode optimization for the inbound process. We do not have any tool to do the optimization to the best of my knowledge"

-IN A

"We are trying to freeze the MO once it has been released, but that is difficult because we need to have a measure of flexibility. So that is one thing we are trying to push a policy that we do change things so late in the process, but it is not always possible"

-IN F

Furthermore, according to interviewee G, three main strategies might be beneficial to overcome the challenges in the change forecast. One is to have the SRP without fluctuations, the second is to have the correct bill of materials, and lastly is to have an effective sourcing strategy. It has been agreed upon by almost all the interviewees, that the authors could find a common perception among it.

"Realistic forecast from our sales companies and having a correct bill of materials would be next steps which could have a major impact if it is not correct"

-IN K

9.2 Machine Structure Specification

In this section, the empirical findings emphasize the challenges they face regarding machine structure specification, how frequently it occurs and by whom, and finally propose certain improvement strategies to overcome to mitigate the process deviation of material delays, 90-Kits, and lack of quality.

It was evident to see that, most of the interviewees have a common perception of the challenges regarding machine structure specification. Due to a lot of variations of different specifications in the machine's assembly making it is harder to develop a standardized process that has been supported by four of the interviewees. Furthermore, they do not have any system flag to alert if they have made a wrong choice of parts. All of this leads to further delays in the process leading to 90-Kits and air freight for instance. In addition to that, including wrong parts in the BOM makes it difficult to produce the parts on time and adds further delays in the ordering of the new parts. This has been agreed upon by most of the interviewees

"We have so many variations of different specifications that it is difficult to get a standardized process for these. And it is difficult to set a standardized quality process for this"

-IN F

One of the significant challenges that have an impact is the late changes in the machine's specification process. This happens due to less accurate forecast from the marketing leading to the possibility of including wrong material parts in the forecast BOM from the R&D due to the complexity of part variation. This leads to delays in the process further down the line impacting the process deviation of material delays, and 90-Kits. Five of the interviewees support this and see this as a significant challenge.

"Is all about the late changes in the machine structure specification putting wrong materials on the forecast BOM affecting the lead time of the materials"

-IN H

Furthermore, interviewees B and J say another challenge is the lack the visibility of the material to perform the analysis leading to quality issues. In addition to that, they feel it is difficult to say if the parts fit together or not leading to configuration issues from the R&D. Also, due to changes involved making it difficult to plan the materials since certain material has a longer lead time.

"We lack visibility and the possibility to perform analysis on the material availability, and review if the change is possible or not for the other parts"

-IN B

New customer requests, material updates, late changes, production issues, and market demand are the most said terms that have a frequent impact on its updates. Further, the updates occur in both small and in module-level components. It has been agreed upon by all the interviewees. Further, consider the improvement strategies to overcome the challenges regarding machine structure specification. Two major improvement strategies have been mentioned which have been commonly said amongst all of them. Firstly, standardizing the workflow would help to avoid delays, secondly, it to modularise the part components and reduce the complexity thus reducing the number of parts making it easier to forecast and avoid delays, quality issues, and 90-Kits. Lastly, one of the interviewees pointed out that there is not much flexibility making it too difficult for an accurate forecast to support the argument regarding modularisation.

"Creating a standardized process and workflow would help to get the right message at the right time. Further rule-based configuration approach would help to have correct BOM and avoid the wrong parts choice. Finally, it would be easier to standardize the machines to have less of an option to be correct"

-IN A, H, K

"One is to refurbish, recycle and reuse from the R&D stage would help us avoid delayed materials. Further, modularisation is one important thing that can help us a lot. Finally, we do not have much room for option flexibility on the machine or the specification changes"

-IN E, G, J

9.3 Suppliers

In this section, the empirical findings highlight the challenges related to suppliers how it impacts the process deviations, and what kind of improvement strategies can be followed to reduce or eliminate them.

The common challenges that Epiroc faces with its suppliers have been mentioned by eight interviewees. Firstly, it is due to the capacity constraint when the ramp-up is planned very quickly. Secondly, there is a supply shortage causing time delays due to uncertain times like the pandemic Covid-19. Furthermore, due to low volume production and if there is a deviation from the standard schedule it is difficult to cope with the changes in a short lead time. It increases the lead time to deliver the material and it also influences allocating their production schedule. Finally, a significant challenge is it is difficult for Epiroc to foresee what happens if we prioritize this and what impact it has on the next steps later in the process. Due to this, it leads to new material issues, and it is difficult for the suppliers to optimize the production, as a result, lose their capacity causing delays in their next steps.

"I would say when we try to ramp up very quickly and then we end up in a capacity constraint with the suppliers. The low volume I would say and the deviations from standard assortment adapted materials and things like that. It is difficult to reprioritize and tell them what needs to come first and we cannot foresee what if we prioritize this, what will we lose in the second or third step, and in the end, we lose capacity and that will most likely affect us in the next step"

-IN B, F, G

To overcome the supplier challenges and to develop an effective strategy with the suppliers, two improvement plans have been suggested by the interviewees. But most of the interviewee does not have anything to comment on since they are not directly involved in the process and does not know what strategies would be efficient to break free of the challenges. According to interviewees A & G, there are delays with the suppliers due to many reasons, hence a delivery mode optimization for the inbound process would be effective which helps to track delays and to find out the root cause of the delays. Secondly, following a strategy for each commodity with the suppliers would be beneficial.

"I was thinking about one thing because in the delivery mode optimization process there is actually a follow-up on delays they would dig deep into, and they would look at each delay and then see what has caused this delay"

-IN A

"I should say that the sourcing strategies are more important than we have for each commodity and we have never been able to reach that point where we can sit down and try to focus on this strategy. How can the suppliers be most effective and how we can help them with that and what can they do for us and what we can do for them? So, we have never had time to start to dig into our strategies and work with the suppliers based on the real strategic level and that is more important that to add another system"

-IN G

9.4 90-Kits

In this subsection, the empirical findings highlight the challenges that are being faced regarding 90-Kits, standardization of 90-kits and how it has been understood by the departments involved in it, and finally the supporting business process that would help avoid or reduce the challenges that are involved.

In 90-kits different department faces various challenges. Due to material delays, or a late charge from the customer the 90-kits are created where they put the material in stock to deliver the Kits. But sometimes the customer does not require the 90-Kits since they can manage without them which causes the material to be added and considered a waste. Secondly, some interviewee sees 90-Kits are already a delayed material that takes the priority over the components which was meant to be used in the production assembly for one of the machines. But in contradiction, three of the interviewees see 90-Kits as a solution to a delayed material and an efficient process to deal in case of a deviation that affects the delivery date.

"We create 90-Kits and put them into stock and then they are never leaving for our customer because they can manage without them is one of the challenges"

-IN B

"I will say 90-Kits is already delayed material, it will need to take priority over components that were meant to be used in the production for the next machines"

-IN F

"90-Kits, I should say it is a solution of that, we do not have the material in time for production"

-IN G

Most of the interviewees are not aware of this segment since they are not involved in it and do not know what happens in there. One of the interviewees confirms that there is a standardized procedure on how 90-Kits should be created but does not have a process on an overall level. But in contradiction to this, another interviewee mentioned that there is no standardized procedure available regarding 90-kits showing there is no clear communication of the process that is been understood by the departments involved in the 90-Kits. In addition to that, four of the interviewees say that there is no specific business process that can help them to reduce or avoid it, but it is a collaborative effort between all the departments involved to reduce or eliminate it. Further, it has been mentioned that it is significant to understand why the 90-Kits have been created in the first instance to eliminate the process and to avoid non-value-added activities.

"Not on an overall level when it comes to taking a decision. The delivery deviation is a process of course, and it is done but this is a final step of the 90-Kits, I mean we maybe should have something in the

start as well"

-IN G

"I am sure if there is a process on how we should do it"

-IN H

"I think it is a company effort to try to make these deviations go away"

-IN I

9.5 Green Lean Six Sigma

In this section, the authors highlight the empirical findings that are related to the methodology and green design. The questionnaire consisted of what the interviewees reflected on the methodology. Out of the eleven interviewees, it is evident that four interviewees were new to the concept of green lean six sigma. They showed some willingness to understand the methodology and utilize it shortly if it can be beneficial to the organization.

Other interviewees in general were keen on implementing the methodology in different sectors of the organization with the acceptance of higher-level management. They believe that it will have a positive impact on the environment and can be a major step toward reducing emissions. Interviewee B thinks that it might increase the standardization of components which will lead to the standardized procedure in procurement and less transportation with higher flexibility. Interviewee E plans to start implementing green Kaizen in the operations and believes it can account for great reductions in emissions.

"Very good but to be able to start to work with it, first, we always need to have a green light from the management. I think it will have a positive impact on the environment. I think it will at least increase the market share. But I am of course Very keen on having emissions reduction."

-IN A

In the case of green design and implementation of this concept, many interviewees were not aware of it, or they were associated with development research. But interviewee E, being associated with the R&D department, admits that there is a constant push from the higher management for introducing circularity in the process. The interviewees also believe that the main challenge is there are a lot of boxes to be ticked to pursue this concept in R&D. Few interviewees also think that it is a requirement for the designers and entire team to start thinking about green when the products are designed. Finally, interview G thinks that introducing modularity in the machines can be a way to start in terms of green design because it leads to a reduction of the total number of parts that are active in the system.

"We are trying to introduce Circular ways of thinking within R&D."

-IN E

9.6 Material Handling

In this section, the empirical findings highlight the challenges related to material handling in Epiroc. The familiar challenges that organizations face with material handling are that late changes in the specifications can result in delays. This results in delivering excess material in a limited period. The interviewees think that the specifications must be locked in in the early stage to avoid transportation of excess material which can lead to damaged components.

"I would say it is late changes in the Machine specification is the main issue."

-IN I

A few interviewees also agree that the lead time for different suppliers must be updated in the ERP system. The wrong error in the system can result in miscommunication and excess procurement of material leading to high inventory.

"I think that this is a key neighborhood where we have the correct lead time in our ERP system that is reflecting the production time at the supplier."

-IN A

Interviewee B spotted one of the problems or challenges concerning tracking the material. In the case of Epiroc, having several transportation hubs, an in-house warehouse, and an external warehouse can be challenging to track where the required materials are located. It can be accredited to the lack of system support as indicated. The respondent also believes that excess movement of materials involves the risk of quality issues.

9.7 Order Preparation and Information Flow

In this section, the authors have covered the empirical findings related to challenges in order preparation and flow of information within various departments. Few interviewees think that the process is straightforward and feel there might be no issues. Interviewee A believes it is especially important for having a transparent type of information flow because miscommunication can lead to negative results. Two interviewees think that the preparation of 90-kits is a challenging task when it comes to the order preparation department because in critical situations the customer might require the materials as early as possible but lead times may vary.

10

Discussion

The empirical findings based on the literature that is presented are discussed in this part. By connecting it to the literature, this part clarifies how the research questions are addressed further.

10.1 Six Sigma and Lean Production

Reducing deviations within a service performance specification limit is said to be six sigma's main objective, according to the literature (Antony, 2006). Empirical data outlining issues involved in various processes and devising an improvement approach to solve it has been used to support this. Additionally, process improvement teams define the crucial X's that lead to failures (Y's) in six sigma terms (Pojasek, 2003). According to empirical findings, the small (Y's) that cause failures (Y) include change forecast, machine structure specification, 90-Kits, suppliers, and material handling concerns. Additionally, the critical (X's) causes of process deviations (y's) are mentioned. All those who participated in the interview concur that reducing variations requires quantifying variance to enhance quality (Antony, 2006). The empirical data indicate that some of the major X's impacting the process deviations of delayed materials include forecast BOM changes, new customer requests, late modifications, and SRP that is based on speculation.

The crucial (X's) are seen by the empirics as a critical difficulty because there are many possibilities in machine structure specifications, there is a lack of standardization, there are problems with configurators, and there is a lack of visibility. This is supported by (Antony et al., 2007) conclusion that it is important to comprehend how errors occur and develop process improvements to reduce the frequency of defects and hence enhance customer fulfillment. The significant (X's) associated with supplier issues include capacity limitations, supply shortages, schedule changes, and a lack of transparency, which result in substandard products and a failure to meet customer demand on time. This directly reflects the findings of (De Koning et al., 2006), who identified waste removal and resource management as key lean tasks.

However, a small percentage of the respondents said that 90-Kits were a non-value-added activity and already an overhead operation. However, other interviewers disagree and think that 90-Kits is a good way to catch up on missed material. Therefore, one of the main problems with 90-Kits is that customers do not think they are necessary and think they can get by without them. Another important (X) is that the 90-Kits prioritize the component above the original assembly operation and create delays. According to De Koning et al. (2006), who discuss the distinction between value-added and non-value-added activities, this is directly accurate. He says that value-added activities are those that assist customers in getting the results they want from a good or service. The remainder is viewed as financial waste. Lean manufacturing has advantages, according to (Andersson et al., 2006), including reduced work-in-process, higher inventory returns, and shorter cycle times. Empirical evidence shows that avoiding unnecessary effort, maintaining high inventories, using an effective system for tracking materials, and having short lead times are all advantageous for preventing delays and other process deviations. Quality problems, such as improper or damaged materials, are some of the important (X's) in connection to material handling. The other important (X's) are longer lead times for materials because of inadequate system support for tracking the materials. Additionally, there are delays caused by the short lead time for updating the supplies in the ERP system.

10.2 Process Improvements and Measurements

According to Dalrymple (1987), strategic planning, and determining actual data patterns for forecasting using the most recent limited data can improve management efficiency and improve the organization's advantages over the competitors. Additionally, the empirical findings show that few processes involved in forecasting and sourcing cause process deviations that need to be improved. Additionally, the challenges faced by the machine forecast changes can result in excess transportation or an increase of 90-kits. Hence, the authors have built a process model which can mitigate or lower the risks involved. According to Grönlund et al. (2010), stage-gate techniques can be utilized by the business model to improve the process. Through the implementation, it can prove that it is a conceptual and operational model which can bring in a lot of results in the value chain. The empirical evidence demonstrates how important it is to have effective measurements to analyze the machine forecast accuracy, the quality criteria, and material handling issues to improve the process continually.

The literature by (Marr, 2012) asserts that KPIs are important instruments that can be utilized by organizations to understand whether the processes being followed are on the right track and will provide them desired results. Marr (2012) also explains that the KPI framework, dashboards, or scorecards can be a comprehensive approach to visualizing all the data available. All these important aspects demonstrate how the authors approached reducing the process deviations and measuring by building a dashboard to measure the organization's performance with deeper insights. The process models extensively focused on improving the bottleneck areas present in previous and having a decision-making criterion to provide an extra cushion for changes in specifications, forecasts, and delivery dates to CCs The KPIs included quality aspects, machine forecast accuracy, and on-time delivery as the performance indicators to witness the changes after implementation of the process models.

10.3 Green Lean Six Sigma

Green lean six sigma, according to Gholami et al. (2021), is a circular business strategy that aims to reduce waste, improve process capabilities, and decrease environmental pollution, emissions, wastes, and defects to increase profitability and provide customers with environmentally sustainable products. Empirical evidence has shown that green lean six sigma would lower emissions and have a good influence on the environment. Additionally, the technique aids in process standardization, raising knowledge of its advantages among all members of the organization. According to the evidence, implementing green kaizen would be a wonderful place to start to have a beneficial impact on the environment. Additionally, including R&D and green thinking from the beginning would have a huge impact and help the entire production. This is corroborated by (Gholami et al., 2021) and (Garza-Reyes et al., 2018), who mentions that adopting a green mindset improves organizational efficiency and enables improvement in profitability, customer satisfaction, responsiveness, and quality as well as compliance with environmental standards.

Yadav et al. (2021) claim that the GLSS technique aids practitioners in locating possible trouble areas that require quick response to increase organizational sustainability. This is directly related to one of the empirical findings that the GLSS technique aids in the development and monitoring of specific KPIs, hence contributing to positive impacts and general improvement. All of this demonstrates how the GLSS approach is considered an important source and how it affects organizational systems in a big way. Furthermore, it is critical to raise awareness of the approach and ensure that everyone knows what it accomplishes and how valuable it is. This is in complete agreement with Kaswan and Rathi (2020), who say that management has the power to affect green projects and that allocating adequate human, educational, and financial resources is crucial to putting the ideas into process.

Garza-Reyes (2015) asserts that environmental concerns have played a crucial role in the development of greener manufacturing processes, services, and recyclable product design. According to the empirical evidence, it is essential to include circularity and circular methods of thinking from the R&D stage onward and to establish a plan for using them to increase sustainability and lower emissions. This aids in lowering costs, using fewer parts, and enhancing operating procedures. Reuse, recycle, and reduce (the 3Rs) are examples of green activities, according to Garza-Reyes (2015), who also makes this point. The literature Chugani et al. (2017) states that improving the supply chain would help the business reduce costs. Additionally, one of the interviewees mentions that it is crucial to reduce the number of part numbers to reduce the complexity of the machines. As a result, modularizing the machines would be of great significance to reuse the parts, reduce the lead time, standardize the processes, and improve the delivery times. Additionally, Kaswan and Rathi (2020) note that better planning, coordination, and control contribute to the successful use of GLSS techniques. Empirical evidence demonstrates how important it is to have effective communication throughout the supply chain to comprehend what each department needs and how each department should behave to prevent bottlenecks in the operations. For instance, it would be quite difficult to create anything that would affect all the departments involved without the assistance of a supplier.

11

Conclusion

The researchers analyzed the processes at Epiroc using the DMAIC methodology with the focus on finding the most relevant process deviations and improvising the processes to reduce carbon emissions. The DMAIC methodology influenced the researchers to collect information available in all the departments for a better understanding of processes. Through extensive quantitative and qualitative analysis, improvements ideas, and recommendations were proposed. The improvement models and recommendations were based on reducing a few activities in the processes.

The researchers aimed to highlight that GLSS techniques can be utilized in the various departments of Epiroc to reduce carbon emissions and achieve the 2030 agenda. To improve the processes for achieving the agenda, authors have proposed a process model for implementation. The departments include marketing and sourcing extensively but involve other organizational sectors for better communication and information flow. The model is based on the stage-gate product development process. The researchers have also proposed the PDCA cycle to sustain the process models to help reduce carbon emissions and achieve the agenda. Lastly, along with the model and PDCA cycle, the researchers have prepared a KPI dashboard that covers the overall performance of the organization for quality and forecasting accuracy to denote the changes made in the processes. In the next section, the readers will have an overview of the future work that can be carried out to the recommendations and outcomes of this research work.

11.1 Future Research

A KPI dashboard and two improvement models are recommended by the authors. It is advised to assess the model's efficacy after adoption to make future improvements. Additionally, to effectively estimate delays and eliminate them, strategies for predictive modeling for forecasting models should be investigated. In the future, a separate project may be added to examine the suggestions for modularization, transportation strategies, sourcing strategies, and material tracking systems to identify various themes and determine how they affect the emissions associated with process deviations and how to lessen or eliminate them. The underground division of the Epiroc plant is the focus of the thesis, hence the conclusions may not apply to the other division, which would be an interesting topic for further research. However, given that certain data imply that standardization makes it easier to cut carbon emissions, it could be worthwhile to look deeper into how standardization affects each machine's process variations.

11.2 Theoretical Implications

The goal of green lean six sigma (GLSS), according to its philosophy, is to produce ecologically sustainable goods while emitting fewer emissions while minimizing waste. This thesis further broadens the perspective on the context of modularity and circular views by throwing light on the current theory.

11.3 Managerial Implications

To improve processes, break away from resistance to change, and ultimately accomplish the goals, managers must create an atmosphere that supports and fosters creativity in the culture. Managers must also make sure that the team and department have full management support to make changes that are advantageous to the company. Additionally, managers guarantee to foster a climate of environmentally friendly thinking by presenting fresh perspectives that lower emissions and give clients eco-friendly options. Finally, it is important to remember that making bad decisions will influence the process, creating a bad atmosphere.

References

Ahi, P., & Searcy, C. (2013). A comparative literature analysis of definitions for green and sustainable supply chain management. *Journal of Cleaner Production*, *52*, 329-341. Retrieved from `https://www.sciencedirect.com/science/article/pii/S095965261300067X` doi: https://doi.org/10.1016/j.jclepro.2013.02.018

Ahlstrom, P. (2004). Lean service operations: translating lean production principles to service operations. *International Journal of Services Technology and Management*, *5*(5-6), 545–564.

Alonso, G., Dadam, P., & Rosemann, M. (2007). *Business process management: 5th international conference, bpm 2007, brisbane, australia, september 24-28, 2007, proceedings* (Vol. 4714). Springer.

Alsmadi, M., Almani, A., & Jerisat, R. (2012). A comparative analysis of lean practices and performance in the uk manufacturing and service sector firms. *Total Quality Management & Business Excellence*, *23*(3-4), 381–396.

Andersson, R., Eriksson, H., & Torstensson, H. (2006). Similarities and differences between tqm, six sigma and lean. *The TQM magazine*.

Angelis, J. J., & Fernandes, B. (2007). Lean practices for product and process improvement: involvement and knowledge capture. In *Advances in production management systems* (pp. 347–354). Springer.

Antony, J. (2004). Some pros and cons of six sigma: an academic perspective. *The TQM magazine*.

Antony, J. (2006). Six sigma for service processes. *Business process management journal*.

Antony, J., Antony, F. J., Kumar, M., & Cho, B. R. (2007). Six sigma in service organisations: Benefits, challenges and difficulties, common myths, empirical observations and success factors. *International journal of quality & reliability management*.

Apuke, O. D. (2017). Quantitative research methods: A synopsis approach. *Kuwait Chapter of Arabian Journal of Business and Management Review*, *33*(5471), 1–8.

Arifin, S. R. M. (2018). Ethical considerations in qualitative study. *International Journal of Care Scholars*, *1*(2), 30–33.

Bahari, S. F. (2010). Qualitative versus quantitative research strategies: contrasting epistemological and ontological assumptions. *Sains Humanika*, *52*(1).

Barnham, C. (2015). Quantitative and qualitative research: Perceptual foundations. *International Journal of Market Research*, *57*(6), 837–854.

Baskarada, S. (2014). Qualitative case study guidelines. *Baškarada, S.(2014). Qualitative case studies guidelines. The Qualitative Report*, *19*(40), 1–25.

Braun, V., & Clarke, V. (2012). *Thematic analysis.* American Psychological Association.

Bringer, J. D., Johnston, L. H., & Brackenridge, C. H. (2006). Using computer-assisted qualitative data analysis software to develop a grounded theory project. *Field methods*, *18*(3), 245–266.

Bryman, A., & Bell, E. (2019). *Social research methods (fifth canadian edition.).* Oxford University Press.

Carleton, S. A. (2016). *The lean six sigma tools memory jogger: The concise reference guide for lls success.* GOAL/QPC.

Chang, C.-J., Yu, L., & Jin, P. (2016). A mega-trend-diffusion grey forecasting model for short-term manufacturing demand. *Journal of the Operational Research Society*, *67*(12), 1439–1445.

Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A., & Benhida, K. (2016). The integration of lean manufacturing, six sigma and sustainability: A literature review and future research directions for developing a specific model. *Journal of Cleaner Production*, *139*, 828-846. Retrieved from `https://www.sciencedirect.com/science/article/pii/S0959652616312495` doi: https://doi.org/10.1016/j.jclepro.2016.08.101

Chugani, N., Kumar, V., Garza-Reyes, J. A., Rocha-Lona, L., & Upadhyay, A. (2017). Investigating the green impact of lean, six sigma and lean six sigma: A systematic literature review. *International Journal of Lean Six Sigma.*

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC medical research methodology*, *11*(1), 1–9.

Dalrymple, D. J. (1987). Sales forecasting practices: Results from a united states survey. *International journal of Forecasting*, *3*(3-4), 379–391.

De Koning, H., Verver, J. P., van den Heuvel, J., Bisgaard, S., & Does, R. J. (2006). Lean six sigma in healthcare. *Journal for Healthcare Quality*, *28*(2), 4–11.

De Mast, J., & Lokkerbol, J. (2012). An analysis of the six sigma dmaic method from the perspective of problem solving. *International Journal of Production Economics*, *139*(2), 604–614.

Denscombe, M. (2017). *Ebook: The good research guide: For small-scale social research projects.* McGraw-Hill Education (UK).

Direction, S. (2005). The new improvement frontier: Developing lean administration. *Strategic Direction*, *21*(11), 33–35.

Emiliani, M., & Stec, D. (2005). Leaders lost in transformation. *Leadership & Organization Development Journal.*

Etikan, I., & Bala, K. (2017). Sampling and sampling methods. *Biometrics & Biostatistics International Journal*, *5*(6), 00149.

Etikan, I., Musa, S. A., Alkassim, R. S., et al. (2016). Comparison of convenience sampling and purposive sampling. *American journal of theoretical and applied statistics*, *5*(1), 1–4.

Fang, J., Zhao, L., Fransoo, J. C., & Van Woensel, T. (2013). Sourcing strategies in supply risk management: An approximate dynamic programming approach. *Computers Operations Research*, *40*(5), 1371-1382. Retrieved from `https://www.sciencedirect.com/science/article/pii/S030505481200189X` doi: https://doi.org/10.1016/j.cor.2012.08.016

Gajjar, D. (2013). Ethical consideration in research. *Education*, *2*(7), 8–15.

Garza-Reyes, J. A. (2015). Green lean and the need for six sigma. *International Journal of Lean Six Sigma*.

Garza-Reyes, J. A., Kumar, V., Chaikittisilp, S., & Tan, K. H. (2018). The effect of lean methods and tools on the environmental performance of manufacturing organisations. *International Journal of Production Economics*, *200*, 170–180.

Gholami, H., Jamil, N., Mat Saman, M. Z., Streimikiene, D., Sharif, S., & Zakuan, N. (2021). The application of green lean six sigma. *Business Strategy and the Environment*, *30*(4), 1913–1931.

Grönlund, J., Sjödin, D. R., & Frishammar, J. (2010). Open innovation and the stage-gate process: A revised model for new product development. *California management review*, *52*(3), 106–131.

Grosfeld-Nir, A., Ronen, B., & Kozlovsky, N. (2007). The pareto managerial principle: when does it apply? *International Journal of Production Research*, *45*(10), 2317–2325.

Gupta, S., & Jain, S. K. (2013). A literature review of lean manufacturing. *International Journal of Management Science and Engineering Management*, *8*(4), 241–249.

Heaton, J. (2008). Secondary analysis of qualitative data: An overview. *Historical Social Research/Historische Sozialforschung*, 33–45.

Hess, J. D., & Benjamin, B. A. (2015). Applying lean six sigma within the university: opportunities for process improvement and cultural change. *International Journal of Lean Six Sigma*.

Hines, P., Holweg, M., & Rich, N. (2004). Learning to evolve: a review of contemporary lean thinking. *International journal of operations & production management*.

Höglund, R., & Allanson, L. (2021). *Co2-utsläpp från transporter som uppstår på grund av processlöserier.*

Hussain, K., He, Z., Ahmad, N., Iqbal, M., et al. (2019). Green, lean, six sigma barriers at a glance: a case from the construction sector of pakistan. *Building and Environment*, *161*, 106225.

Hyett, N., Kenny, A., & Dickson-Swift, V. (2014). Methodology or method? a critical review of qualitative case study reports. *International journal of qualitative studies on health and well-being*, *9*(1), 23606.

Iranmanesh, M., Zailani, S., Hyun, S. S., Ali, M. H., & Kim, K. (2019). Impact of lean manufacturing practices on firms' sustainable performance: Lean culture as a moderator. *Sustainability*, *11*(4), 1112.

John, W. S., & Johnson, P. (2000). The pros and cons of data analysis software for qualitative research. *Journal of nursing scholarship*, *32*(4), 393–397.

Kallio, H., Pietilä, A.-M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of advanced nursing*, *72*(12), 2954–2965.

Kaswan, M. S., & Rathi, R. (2020). Investigating the enablers associated with implementation of green lean six sigma in manufacturing sector using best worst method. *Clean Technologies and Environmental Policy*, *22*(4), 865–876.

Kelle, P., Song, J., Jin, M., Schneider, H., & Claypool, C. (2019). Evaluation of operational and environmental sustainability tradeoffs in multimodal freight transportation planning. *International Journal of Production Economics*, *209*, 411–420.

Kitto, S. C., Chesters, J., & Grbich, C. (2008). Quality in qualitative research. *Medical journal of Australia*, *188*(4), 243–246.

Kovács, G., & Spens, K. M. (2005). Abductive reasoning in logistics research. *International journal of physical distribution & logistics management*.

Krishnan, B. R., & Prasath, K. A. (2013). Six sigma concept and dmaic implementation. *International Journal of Business, Management & Research (IJBMR)*, *3*(2), 111–114.

Lawrence, J., & Tar, U. (2013). The use of grounded theory technique as a practical tool for qualitative data collection and analysis. *Electronic Journal of Business Research Methods*, *11*(1), pp29–40.

Liker, J. K., & Convis, G. L. (2012). *Toyota way to lean leadership: Achieving and sustaining excellence through leadership development*. McGraw-Hill Education.

Liker, J. K., & Hoseus, M. (n.d.). Culture—the heart and soul of the toyota way, tata mcgraw-hill edition, new delhi, 2008, xxx+ 562 pp. rs. 450, soft.

Liliana, L. (2016). A new model of ishikawa diagram for quality assessment. In *Iop conference series: Materials science and engineering* (Vol. 161, p. 012099).

Mann, D. (2005). *Creating a lean culture: tools to sustain lean conversions*. Productivity Press.

Marr, B. (2012). *Key performance indicators (kpi): The 75 measures every manager needs to know*. Pearson UK.

Marton, F. (1986). Phenomenography—a research approach to investigating different understandings of reality. *Journal of thought*, 28–49.

McDermott, R. E., Mikulak, R. J., & Beauregard, M. R. (2009). *Fmea*. New York: Taylor & Francis Group.

Mihyeon Jeon, C., & Amekudzi, A. (2005). Addressing sustainability in transportation systems: definitions, indicators, and metrics. *Journal of infrastructure systems*, *11*(1), 31–50.

Montgomery, D. C., & Woodall, W. H. (2008). An overview of six sigma. *International Statistical Review/Revue Internationale de Statistique*, 329–346.

Moon, K., & Blackman, D. (2014). A guide to understanding social science research for natural scientists. *Conservation biology*, *28*(5), 1167–1177.

Nakhai, B., & Neves, J. S. (2009). The challenges of six sigma in improving service quality. *International Journal of Quality & Reliability Management*.

Neha, S., Singh, M. G., Simran, K., & Pramod, G. (2013). Lean manufacturing tool and techniques in process industry. *International Journal of Scientific Research and Reviews*, *2*(1), 54–63.

Oppong, S. H. (2013). The problem of sampling in qualitative research. *Asian journal of management sciences and education*, *2*(2), 202–210.

Pepper, M. P., & Spedding, T. A. (2010). The evolution of lean six sigma. *International Journal of Quality & Reliability Management*.

Pojasek, R. B. (2003). Lean, six sigma, and the systems approach: Management initiatives for process improvement. *Environmental Quality Management*, *13*(2), 85–92.

Power, M. (2004). The risk management of everything. *The Journal of Risk Finance*.

Prashar, A. (2020). Adopting six sigma dmaic for environmental considerations in process industry environment. *The TQM Journal*, *32*(6), 1241–1261.

Rock Drills AB, E. (n.d.-a). *About epiroc.* Retrieved from `https://www.epirocgroup.com/en/about-epiroc`

Rock Drills AB, E. (n.d.-b). *Epiroc sustainability goals.* Retrieved from `https://home.intranet.epiroc.com/sites/IMSGlobal/MRIMS/_layouts/15/WopiFrame2.aspx?sourcedoc=%7B4727C5CB-74E8-443D-B9D9-31F4AA1C8CCE%7D&file=Epiroc+2030+Sustainability+goals.pptx&action=default&DefaultItemOpen=1`

Sagnak, M., & Kazancoglu, Y. (2016). Integration of green lean approach with six sigma: an application for flue gas emissions. *Journal of Cleaner Production*, *127*, 112–118.

Shamsuzzoha, A., & Helo, P. T. (2011). Real-time tracking and tracing system: Potentials for the logistics network. In *Proceedings of the 2011 international conference on industrial engineering and operations management* (pp. 22–24).

Singh, B., Garg, S. K., & Sharma, S. K. (2011). Value stream mapping: literature review and implications for indian industry. *The International Journal of Advanced Manufacturing Technology*, *53*(5), 799–809.

Sližytė, A., & Bakanauskienė, I. (2007). Designing performance measurement system in organization. *Organizacijų vadyba: sisteminiai tyrimai*(43), 135–148.

Steurer, R., Langer, M. E., Konrad, A., & Martinuzzi, A. (2005). Corporations, stakeholders and sustainable development i: a theoretical exploration of business–society relations. *Journal of business ethics*, *61*(3), 263–281.

Tellis, W. (1997). Introduction to case study. *The qualitative report*, *3*(2), 1–14.

Tracy, S. J. (2010). Qualitative quality: Eight “big-tent” criteria for excellent qualitative research. *Qualitative inquiry*, *16*(10), 837–851.

Tuli, F. (2010). The basis of distinction between qualitative and quantitative research in social science: Reflection on ontological, epistemological and methodological perspectives. *Ethiopian Journal of Education and Sciences*, *6*(1).

Vaismoradi, M., Turunen, H., & Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing & health sciences*, *15*(3), 398–405.

Vignesh, V., Suresh, M., & Aramvalarthan, S. (2016). Lean in service industries: A literature review. In *Iop conference series: materials science and engineering* (Vol. 149, p. 012008).

Wu, X., Zhang, L., & Luo, M. (2020). Current strategic planning for sustainability in international shipping. *Environment, Development and Sustainability*, *22*(3), 1729–1747.

Yadav, V., Gahlot, P., Rathi, R., Yadav, G., Kumar, A., & Kaswan, M. S. (2021). Integral measures and framework for green lean six sigma implementation in manufacturing environment. *International Journal of Sustainable Engineering*, *14*(6), 1319–1331.

Zarbo, R. J. (2012). *Creating and sustaining a lean culture of continuous process improvement* (Vol. 138) (No. 3). Oxford University Press Oxford, UK.

Ángeles Cadarso, M., López, L.-A., Gómez, N., & Ángeles Tobarra, M. (2010). Co2 emissions of international freight transport and offshoring: Measurement and allocation. *Ecological Economics*, *69*(8), 1682-1694. Retrieved from `https://www.sciencedirect.com/science/article/pii/S0921800910001151` doi: https://doi.org/10.1016/j.ecolecon.2010.03.019

A

Appendix 1

A.1 Project one pager

General Information: About Epiroc Drills AB

Drill rigs, rock excavation and construction equipment and tools for surface and subsurface applications are among the products Epiroc create and supply. In addition, Epiroc at Örebro consists of underground division and distribution centres. Epiroc provides world-class service and other aftermarket support, as well as automation, digitalization, and electrification solutions. Epiroc has more than 15 500 dedicated workers that serve and collaborate with clients in more than 150 countries. In 2021, the company had revenues of SEK 40 billion.

Problem Theme: Process Improvements to reduce CO2 emissions

The three main process deviations contributing to the large quantity of CO2 emissions (8184 tonnes) are delayed materials, 90-kits, and lack of quality. The major goals are to:

- Identify the causes and minimize or eliminate those using green lean six sigma tools and methods.
- Eliminate or lower the deviation related to delayed materials, 90-kits, and lack of quality to reduce CO2 emissions from transportation.
- Providing suggestions and exhibiting a strategy for controlling and maintaining

the situation.

- Increase sales, output, sustainability, and decrease climate change by maximizing consumer value.

Thesis expectation

The authors of the thesis will define the scope of work, identify key areas for improvement, and develop ways by create a model/ framework to decrease or eliminate the causes of process deviations including late materials, 90-kits, and poor quality, which result in unnecessary transportation and CO2 emissions, as well as alternative solutions.

Team Member	Current position	Organization	Background	University	Black Belt Role
Raghul Subramanian	Master thesis student	Epiroc Drills AB	Bachelor's Degree in mechanical engineering	Easwari Engineering College	Problem Owner
Navaneet Subbaram	Master thesis student	Epiroc Drills AB	Bachelor's Degree in mechanical engineering	Visvesvaraya Technological University	Problem Owner
Ulrika Ford	Quality & SHEQ Manager	Epiroc Drills AB	Bachelor's degree in Business & Finance	IHM Business school	Industrial supervisor
Matthew McCarthy	Global Sustainability booster	Epiroc Drills AB	Master's in International Administration & Global Governance	University of Gothenburg	Industrial supervisor
Bo Bergman	Professor	Chalmers University of Technology	PhD in Mathematical Statistics	Lund University	Academic supervisor

Figure A.1: Project One-Pager

A.2 Effective Scoping

Process owner (org): Epiroc Drills AB		Project sponsor: Ulrika Ford		Six Sigma champion, MBB: -		
Effective Scoping of continuous improvement projects						
The __sequence in itself__, of questions Q1-Q4, Q5-Q7 and Q8-Q9 below, is key to facilitate consensus in the shift of an organisation's mindsets from push to pull, in accordance with the principles of Lean Six Sigma						
Supplier	**Input**		**Process**	**Output**		**Customer**
8b. Who supplies the inputs?	Q8a. What are the inputs to the system?	Q9. What does the system require of the inputs?	Q7a. Team/project jurisdiction of changes	Q1. What comes out (of the physical flow) - OUTPUT?	Q3. What is required of the output from this particular user (List of big Y's and improvement proposals)	Q2. Who uses the output?
			Changes in the work flow, Reducing emissions in the transports, Sustainability		Reducing the excess transportation needs and halve the CO2 emissions in the transportation (Can write it other way around)	Climate, Environment, Customers like mining industries, Contractors, Consutruction firms, even Epiroc and its suppliers
			Q7b. What competences are needed in the team (WHO)?		**Q4. __What ONE MEASURE (y)__ should be understood and improved? The y that scope the project and drive further exploration. Each small y has its own underlying system of influencing parameters, sometime overlapping. Use one template per y to reduce complexity Scope on y (not x - upstream) and don't proceed until Q1-Q4 is thoroughly understood!**	
Örebro plant, suppliers	Forecast, machine specifications, order preparation, production planning, Purchasing, material planning, assembly of the machines, and testing the machines.	Material standards & drawings for production, assembly instructions, quality inspection of the components for the production and skilled personnel for the operations	planning, Sourcing & purchasing, Quality department, Transport planning, and Market	1. Machines from the underground division of the örebro plant 2. Excess transportation needs (CO2)	Reducing or eliminating the process deviations of delayed material, 90-kits, and lack of quality thus reducing the CO_2 (8184) tonnes emissions	
			Name of the underlying system that build up the y to be improved:		Q5. What is the baseline of the y and can that precis y be measured today (and can old data be trusted)? In other words: What is the **facts** behind the problem that form the base for our improvement promise? Show the data/proof of a problem!	
					The baseline for the emissions in 2019 is 8184 tonnes, In 2021 5199, and In 2022 expected is 7,700	
			From where is the physical output shipped?		Q6. What other Y can not be lost in the process (constraints)?	
			Örebro to suppliers and customers, and from Suppliers to örebro		Social and economic sustainability, reliability of inspections, and the cycle time of the operations, Quality, and lead time between the operations.	

Figure A.2: Effective Scoping

A.3 Process-Failure Mode Effect Analysis

Process Step	Input	Potential Failure Mode	Potential Effect(s) of Failure	S e t e r y v i	Potential Cause(s)/Mechanisms of Failure	O u e c r n e c r c	Current Process Controls Detection	D e i e c o t t n	R P N
Forecasting	Forecasts from CC's	Over and underforecast	High storage inventory cost, wastage of material,	10	Dynamic market & lack of standardisation	7	Lack of process control	8	560
	SRP planning	Itereation of machine forecast	Delays in material, delivery time, and assembly process	6	No accurate forecasting model & forecast is purely on a historical basis	6	Lack of process control	4	144
	MO confirmation	Late changes in MO	Missing customers deadline causing air freight	4	New customer request, production issues, and market demand	5	Lack of process control	4	80
Sourcing & Purchasing	Forecast BOM	New customer request, market demand causing changes in the BOM	Changes in production planning and other departments in the value chain	8	Lack of standardised process and rule configuration approach	7	Lack of process control	4	224
	Supplier forecast	Short notice on forecast change and short lead time to respond	Receiving materials on time, capacity and supply shortage	8	Lack of sourcing strategies with the suppliers	6	Lack of process control	3	144
	Material tracking	Lack of transparency and system support causing delays in materials	Losing the material ordered and buying new material. Increases the lead time causing delays and air freight	5	Lack of IT support and lack of alert systems and other functionalities to keep track of the materials	4	Lack of process control	7	140
Machine structure specification	Forecast BOM	Sudden changes causing delays in firm order being prepared	New material being purchases. Wastage of materials. Adds additional cost and resources	8	Lack of standardised process and rule configuration approach	6	Lack of process control	3	144
	Complexity of Components	Wrong forecast being predicted	Material wastage, increases cost of production. Lead time increases for the assembly process	8	Lack of modularised parts and high number of variants for each machines causing complexity to forecast accurately	8	Lack of process control	4	256

Figure A.3: P-FMEA

A.4 KPI Dashboard's Description

KPI Code	KPI Group	KPI Criteria	Metrics	Description
101	Quality	Yield	%	Indicates the percentage of machines that are manufactured correctly and to the specifications, i.e. FTT without scrap or rework
102	Quality	Incoming supplier quality	%	Percentage measure of conforming components received for in-house production process from a specific supplier
103	Quality	Production Defects	%	Percentage measure of non-conforming products in the production line
201	Rework	Time to Make changes	Days	Time taken to implement changes in the process for producing various machines
202	Rework	Forecast BOM Changes	Days	Time taken to make changes in the forecast depending upon the change request from customers, markets, and other factors.
301	On-time delivery	Machines shipped on time	%	Percentage measure of number of machines produced & delivered to the customer as per the scheduled date.
302	On-time delivery	Material handling	%	Percentage measure of components/modules available to manufacture the machines without any delays in time
401	Forecasting Acuracy	Predicted Forecast v/s Actual Volume	%	ercentage measure of the difference of error between the predicted and actual forecas

Figure A.4: Description of KPI's

A.5 Updated Process-Failure Mode Effect Analysis

Process Step	Input	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanisms of Failure	Occurrence	Current Process Controls Detection	Detection	RPN	Recommended Actions(s)	New RPN
Machine Forecast	Forecasts from CC's	Over and underforecast	High storage inventory cost, wastage of material, additional resources	10	Dynamic market & lack of standardisation	7	Lack of process control	8	560	Forecasting model with rule based configuration process has been developed. Further, new KPI's has been developed to keep trackand monitor the process of the forecasting process	60 (5,4,3)
	SRP planning	Itereation of machine forecast	Delays in material, delivery time, and assembly process	6	No accurate forecasting model & forecast is purely on a historical basis	6	Lack of process control	4	144		36 (3,4,3)
	MO confirmation	Late changes in MO	Missing customers deadline causing air freight	4	New customer request, production issues, and market demand	5	Lack of process control	4	80		36 (3,4,3)
Sourcing & Purchasing	Forecast BOM	New customer request, market demand causing changes in the BOM	Changes in production planning and other departments in the value chain	8	Lack of standardised process and rule configuration approach	7	Lack of process control	4	224	Forecasting model with an integraton of sourcing model with a rule based approach has been developed to eliminate or reduce the causes. Further KPI dashboard are provide tp monitor the progress.	24 (4,3,2)
	Supplier forecast	Short notice on forecast change and short lead time to respond	Receiving materials on time, capacity and supply shortage	8	Lack of sourcing strategies with the suppliers	6	Lack of process control	3	144		12 (4,3,1)
	Material tracking	Lack of transparency and system support causing delays in materials	Losing the material ordered and buying new material. Increases the lead time causing delays and air freight	5	Lack of IT support and lack of alert systems and other functionalities to keep track of the materials	4	Lack of process control	7	140	New tracking system model has been developed and new functionalities are suggested to not lose track of the materials	24 (3,2,4)
Machine structure specification	Forecast BOM	Sudden changes causing delays in firm order being prepared	New material being purchases. Wastage of materials. Adds additional cost and resources	8	Lack of standardised process and rule configuration approach	6	Lack of process control	3	144	Forecasting model with an integraton of sourcing model with a rule based approach has been developed to eliminate or reduce the causes. Further KPI dashboard are provide tp monitor the progress.	24 (4,3,2)
	Complexity of Components	Wrong forecast being predicted	Material wastage, increases cost of production. Lead time increases for the assembly process	8	Lack of modularised parts and high number of variants for each machines causing complexity to forecast accurately	8	Lack of process control	4	256	Modularisation projects has been intiated to reduce the number of parts and also to increase the accuracy of forecast	32 (4,4,2)

Figure A.5: Updated P-FMEA

A.6 Interview Guide

In this section, the interview guide are provided for gathering the information and understanding the problem with different respondents from the sample chosen.

Changed forecast:

What is the main challenge caused by the changed forecast?

- How do you handle (Eg: new customer request) this in an efficient way in order to avoid delayed material, 90-kits?

- Which departments in the value chain have an impact on the changes?

- What methods/strategies do you take to help avoid causing delayed material and 90-kits?

On what basis has the forecast changed and what is the accuracy (Tolerance) of the order forecast?

Machine structure specification:

What is the main challenge regarding machine structure specification which causes delayed material, 90-kits and lack of quality?

- Why is this perceived as a challenge?

- By whom is this perceived as a challenge?

- Can these specifications be confirmed before the manufacturing order confirmation?

- What methods/strategies would you say to help avoid causing delayed material and 90-kits?

When does the updating of machine structure specification occur?

- Is there any sensitive process that gets affected due to this?

- On what level machine structure specification is changed, is it on small components level or on module level?

Suppliers & lead time:

What are the main challenges you face with suppliers regarding material delays and 90-kits?

- Why is this perceived as a challenge?
- How does supplier handle volume change in production due to changed forecast and machine structure specification update?
- How do you involve the suppliers in the forecasting process for them to interact more and avoid delays?
- What methods/strategies would you say to help avoid causing delayed material and 90-kits?

Do you have any alert system to signal you about the increase in forecast to suppliers?

How does geographical location affect the process deviations?

90-Kits:

What are the main challenges you face while creating a 90-kit?

- Do you have any standardized procedure to create a 90-kit?
- How do you handle the process of 90-kits now? (From start to end)?
- Who must support it to avoid or reduce the process deviations?

When it seems unavoidable to deliver the parts included in the 90-kits – would it be possible to delay the delivery of the main equipment to avoid 90-kits?

- Are there sometimes more than one 90-kit to the same customer? Possibilities to co-plan?

Green lean six sigma:

Green Lean Six Sigma (GLS) is an eco-friendly approach that mitigates carbon footprints and produces high specifications products.

How does the methodology of green lean six sigma be beneficial to reduce or eliminate the process deviation?

- Is that feasible to start working on green design from the R& D

Material handling:

What are the main challenges that lie behind material handling causing delayed material, and 90-kits? (Quality issues while handling the material)

- Why is this perceived as a challenge?

- What support is needed to improve and avoid it in the future?

- How does this affect the production floor and what are the causes regarding it and why?

For the inbound movement of the material from the suppliers and warehouse along with milk run concept?

- On what basis is the mode of transport chosen?

Order preparation & Information flow:

How does the process of order preparation work include the information flow?

- What are the challenges you face in order preparation leading to material delays and 90-kits?

- When is the 90-kit order being confirmed and how is the information provided to the planning department regarding the 90-kit?

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