JÖNKÖPING UNIVERSITY
School of Engineering

Identifying Challenges Regarding Sustainability and Circularity in Foundries

A multiple-case study of OEMs and SMEs in the Swedish foundry industry

Main area: Industrial Engineering and Management
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This thesis is conducted at the School of Engineering at Jönköping University within Industrial Engineering and Management. The authors are responsible for the opinions, conclusions and results herein presented.

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ABSTRACT

Purpose: The purpose of the thesis is to identify Swedish foundries' challenges regarding circularity and sustainability demands and explore how SME foundries can be more sustainable and circular.

Method: The research approach used in this study is an exploratory multiple-case study. The research questions are answered by using qualitative data through interviews and observations as data collection methods.

Findings: The study's findings present many challenges for Swedish foundries. The main challenges identified are fluctuations in demand, Just-in-Time, extra transports, and the availability of suitable supply chain partners.

The challenge of demand fluctuations for SME foundries resulted in a recommendation on how SMEs can face the challenge. The recommendation aims to reallocate capacity by warehousing, followed by increasing communication in the supply chain. The study concludes that Swedish foundries are far from achieving circular supply chains but strive for sustainable foundries.

Practical Implications: Organizations could use this thesis as a point of reference to compare and reflect on their foundry operations. Since SMEs are targeted for facing challenges in the industry, practical implications could provide a recommendation for organizations and managers in the foundry industry to collaborate more efficiently with OEMs.

Theoretical Implications: This study contributes to the existing knowledge with a new perspective as the challenges connected to sustainability and circularity have been a gap for academia in the foundry industry.

Delimitations: This thesis delimitates within the supply chain of one SME and two OEMs in the Swedish foundry industry. The SME's role in the supply chain is a supplier of casted components, while the OEMs are both a producer of castings and a customer of components. The areas within the supply chain studied are castings, materials, logistics, production, and sustainability & circularity.

Keywords

castings, challenges, circular economy, foundry industry, OEM, planning, SME, supply chain, sustainability.

TABLE OF CONTENTS

List of Figures

List of Tables

LIST OF ABBREVIATIONS AND ACRONYMS

CE	Circular Economy
JIT	Just-in-Time
OEM	Original Equipment Manufacturer
SME	Small & Medium-sized Enterprise
TBL	Triple Bottom-Line

1 INTRODUCTION

The first chapter of the report represents an introduction and background to the problem studied. Furthermore, the purpose and research questions are defined. The chapter concludes with the scope & delimitations, and outline of the thesis.

1.1 Background

Today's industries within Europe cause environmental degradation in terms of pollution, fossil fuel use, and waste. In the past, the European Union has focused on sustainable waste management in a traditional linear economy. At the end of 2015, the European Commission presented four new pieces of legislation under an action plan to implement a circular economy (CE) before 2050 (Amanatidis, 2022). Unlike a linear economy that focuses on eliminating waste, the circular economy focuses on sharing, borrowing, recycling, and repairing existing materials and products. This aims to continue creating value for as long as possible and extend the life cycle of products (Europaparlamentet, 2023).

One strategic target with the transition to a circular economy, according to the European Commission (2019), is the transition within Small and Medium- Sized Enterprises (SMEs). As stated in the strategic long-term vision, this transition and a climate-neutral economy should be pursued together, based on strong industrial collaboration. New circular business models, recycling, resource, and material efficiency, and changing consumption patterns all contribute significantly to improvements in global greenhouse gas emissions. This cooperative approach can reduce production costs and promote unique commercial alliances, such as industrial collaboration, among organizations, including SMEs. Also, the utilization and handling of raw materials will be greatly influenced by circularity and sustainability, especially for SMEs in the EU (European Commission, 2019).

The transition from a liner to a circular economy followed by the EU regulations is affecting the foundry industry. Foundries are greatly affected by the transition due to being an industry that generates a high carbon footprint. Until 2018, there has been a large increase in castings by 42 million tonnes worldwide. Within Europe, Sweden produces 2% of the castings; in the Nordics, Sweden is considered the largest producer. As an industrial country, Sweden has a large consumption of castings in terms of population. This consumption leads to compliance with quality, customer requirements, security of supply, and sustainability demands. The consumption of castings is highest in the automotive industry, which is responsible for 50% of consumption in Sweden (Swedish Foundry Association, n.d.).

The production of castings is a highly energy-consuming process, which generates a high carbon footprint. The part of the manufacturing process that requires the most energy is the melting of materials, including the re-melting of waste materials. In Sweden's foundries, electricity is the most used energy source in the melting processes. Furthermore, a climate impact is created by the production of purchased electricity and emissions from the associated transportation from foundries to customers (Swedish Foundry Association, n.d.).

Sweden's foundries generate the least climate impact among the countries studied (Nayström, Klimatpåverkan av gjutgods, 2020). However, the validity and reliability of that study are uncertain. Foundry processes are very uncertain processes that are different depending on the metal, which creates uncertainty in the data collection (Nayström, Klimatpåverkan av gjutgods, 2020). Sweden's good result is mainly due to electricity production consisting of hydro and nuclear power. The study indicates that Sweden's foundries must continue to develop and improve on the issue of climate impact. If foundries in Sweden do not develop due to their current low climate impact, there is a risk that they will lose production efficiency and market shares (Nayström, Klimatpåverkan av gjutgods, 2020).

The EU's requirements for a circular economy place great demands on the foundry industry throughout Europe, including Sweden. In Sweden, internal and external environmental regulations were introduced to the foundry industry. These regulations include objectives to make the foundry industry attractive, a producer of advanced products, and the transition to competitive and sustainable production (CIC, 2019). This led to many foundries classified as SMEs going out of business within Sweden. The new requirements for a sustainable foundry industry and circular economy are a costly transition for SMEs, which led to reduced competitiveness followed by bankruptcy (Swedish Foundry Association, n.d.).

1.2 Problem Statement

To continue the development of a circular economy, the agenda for a sustainable Swedish foundry industry by 2035 presented three main objectives (CIC, 2019). One of the goals involves competitive and sustainable production. This means that Swedish production of castings should be climate neutral while maintaining global competitiveness. Specifically, this goal implies that unplanned production stops are reduced to less than 20%, customers and foundries are well integrated, and the implementation of a well-developed circular economy. Sweden's foundries will be market leaders in life cycle efficiency and carbon dioxide emissions during the total life cycle will be reduced by 60%. These aspects will enable the foundry industry to become fossil-free and climate-neutral (CIC, 2019).

Proposals are developed to achieve the goals that specifically aim to create flexible production. This means becoming more adaptable to change batch sizes from large to small, to reduce lead times. Smaller batch sizes should also enable the final products with castings to reach the market faster. Furthermore, sustainable development should include input recycling, energy efficiency, circular economy, and reuse to create climate-smart castings. Finally, it will enable casting to be the shortest route from raw material to finished product/component (CIC, 2019).

One of the goasl of competitive and sustainable production presents some challenges for the Swedish foundry industry. A critical factor is to minimize lead times throughout the value chain for castings. This includes both the value chain for new products and existing products. Another challenge is to continue to be the market leader with the lowest carbon dioxide emissions per kilo of castings. Further work is required in a long-term perspective to reduce the climate footprint of the foundries. Preventive work is required in the form of resource efficiency in the entire life cycle and value chain (CIC, 2019).

The agenda's objectives are expected to be achieved through a better understanding of the foundry industry and authorities (CIC, 2019). Furthermore, the relationship and consensus between foundries, their customers, and suppliers will be strengthened. At present, the foundry industry is a major player in the reuse and recycling of scrap as it is a raw material for castings. To develop material use, opportunities with other residual products should be studied. Thus, the Swedish foundry industry faces several challenges in achieving its goals and requirements. The foundry industry in Sweden is currently unknown and unexplored from a general perspective, even by authorities (CIC, 2019).

The agendas' objective is divided into sub-targets to be achieved by 2025, 2030, and finally 2035. The interim objectives in the near future, i.e., by 2025, include creating an understanding of the needs and challenges of the foundry industry with this transition. The needs must be mapped and planned to create a roadmap for the climate challenges mentioned (CIC, 2019). Previous research on Swedish foundries has only studied the climate impact of energy composition and CO_2 emissions from transportation. This thesis will contribute to the research gap in the challenges that are not mentioned in the previous studies for the foundry industry in Sweden.

1.3 Purpose and Research Questions

The Swedish foundry industry faces several challenges in becoming circular and more sustainable, as highlighted in the problem description. The first milestone towards becoming more sustainable and circular is to understand and map the challenges for foundries (CIC, 2019). As explained in the background, a strategic target for the transition to a circular economy is SMEs. Therefore, the purpose of the study is:

To identify the challenges that Swedish foundries are facing regarding circularity and sustainability demands and explore how SME foundries can be more sustainable and circular.

The purpose will be achieved by investigating two research questions. The first research question aims to identify the challenges regarding circularity and sustainability for the foundry industry, including both OEMs and SMEs:

RQ1: *What are the challenges that Swedish foundries are facing regarding the demands of becoming circular and sustainable?*

The challenges will be presented for the Swedish foundries regarding circularity and sustainability by answering RQ1. For exploring how the foundries can be more sustainable and circular, the target is SMEs. A recommendation for SMEs is formulated to be more circular and sustainable by facing one of the challenges.

Hence, the second research question is formulated:

RQ2: *How can SMEs in the foundry industry be more circular and sustainable?*

To achieve the study's purpose and answer the research questions, a multiple-case study will be conducted. The study will investigate one SME and two OEMs in the Swedish foundry industry to create a holistic perspective on the overall supply chain of castings.

1.4 Scope and Delimitations

The study focuses on investigating the supply chain between an SME supplier of casted components and two OEM customers in the Swedish foundry industry. The OEM companies are considered both a customer and a producer of castings. The supply chain aspects of the foundry industry that will be highlighted in this study are the overall supply chain, material, logistics, production, and sustainability & circularity.

This study only includes engineers' and managers' perspectives on the chosen topics. The technical details of processes in the foundries are not included. Therefore, operators' and other coworkers' perspectives are not relevant and are excluded from the study. The study focuses greatly on the environmental aspect of sustainability. However, the economic and social aspects are rather briefly mentioned for a richer analysis.

For the second phase research question, since the focus is on SMEs, the supply chain between SME supplier and OEM customers are investigated. The remaining processes of the overall supply chain are excluded. In this case, production and materials planning, sourcing, and purchasing are included for the OEM customer.

1.5 Disposition

This chapter presents the outline and disposition of the thesis report. Figure 1.1 illustrates the report's disposition, structured in seven chapters. The framework aims to organize and guide the reader easily through the report.

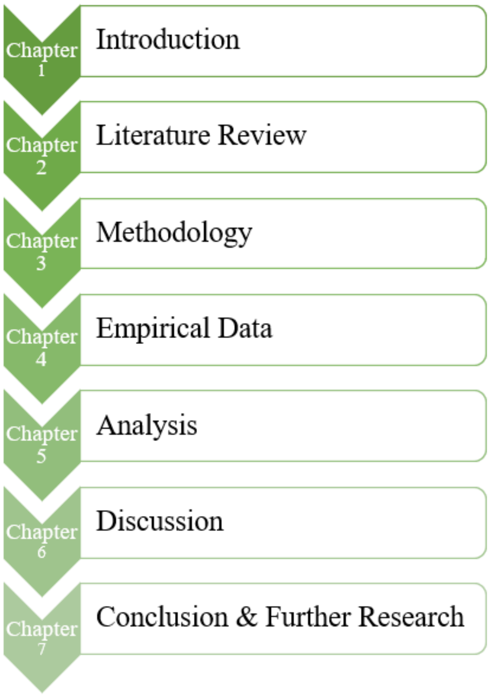

Figure 1.1, Disposition of the Report

Table 1.1 presents briefly how the report will be organized within the different chapters. Also, the content of each chapter is described.

Table 1.1, Outline of the Report

Chapter 1 - Introduction	The introduction chapter begins with the background of the study and the problem definition. Followed by the problem statement, two research questions are established along with the purpose. Lastly, the study's scope and delimitations, followed by the outline are presented.
Chapter 2 – Literature Review	This chapter presents the literature review in a systematic review. Relevant studies are presented to provide an overview of the literature that exists in the topic of this thesis.
Chapter 3 – Methodology	The methodology describes the overall method of the thesis. This chapter begins with the research design, which also includes information about the case companies. Further, the approach of the study is presented, followed by the choice of literature review. The data collection methods are explain in detail and its relation to the research questions is presented. Lastly, the data analysis process is defined, and the assessment of the data quality is elucidated.
Chapter 4 – Empirical Data	This chapter presents the raw data collected from the case companies. Based on the data collection method, the data will be presented based on conducted interviews, and observations.
Chapter 5 - Analysis	Analysis chapter synthesizes the empirical data and the literature review to answer the research questions.
Chapter 6 – Discussion	The discussion includes a discussion of the result. Also, the chapter discusses practical and theoretical implications from the study. The chapter concludes with a methodological discussion.
Chapter 7 - Conclusion & Further Research	The report ends with a conclusion and a recommendation for future research.

2 LITERATURE REVIEW

This chapter presents previous research on the subject and explains key theoretical ideas. The study's themes are given, and the results of earlier investigations are discussed in more detail. The aim of the chosen literature is to present previous research on challenges and possible solutions that have been implemented by other companies in terms of circularity and sustainability.

Figure 2.1 illustrates the structure of the chapter by showing the connection between the presented subjects. The chapter is divided into two phases, which are Sustainability and Coordination & Sustainable Planning. Within sustainability, operations impact on sustainability is presented, followed by environmental impact from different areas. Further, drivers for sustainable manufacturing are presented and phase one ends with challenges identified within the circular economy.

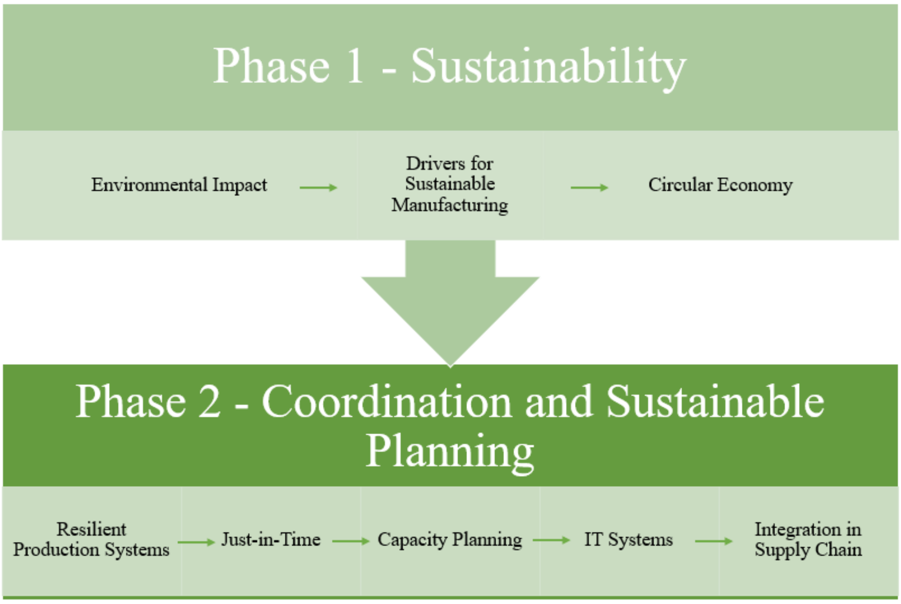

Figure 2.1, Literature Review Overview

Furthermore, possible tools for facing the challenge of demand fluctuations for SMEs in the foundry industry are presented. Firstly, resilient production systems are mentioned, followed by the Just-in-Time theory. Different alternatives for capacity planning are then presented, along with theories about IT systems and integration in supply chains.

2.1 Sustainability

Sustainability is described as an approach to business that considers economic, environmental, and social challenges in a balanced, comprehensive, and long-term manner that benefits both the present and the future generations of concerned stakeholders (De Lange et al., 2012). Sustainability tends to include the model triple bottom line (TBL) approach. The triple bottom-line approach consists of environmental, economic, and social sustainability as seen in Figure 2.2. According to the TBL approach, businesses have created measurement systems that take financial, ecological, and social outcomes into account. TBL is a broader baseline for performance measurement that incorporates social and environmental considerations in addition to economic factors (Grant et al., 2017 & Wikström, 2010).

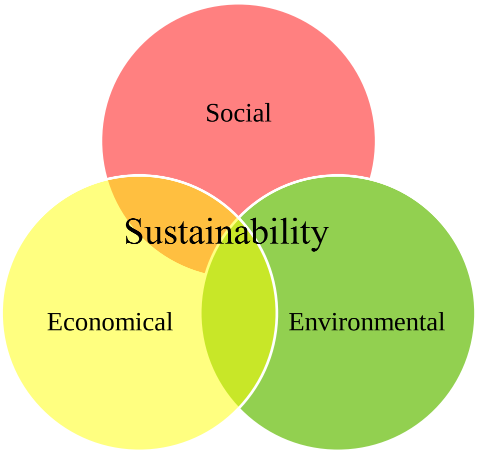

Figure 2.2, Triple Bottom Line influenced by Grant et al. (2017)

TBL is introduced to include people, profit, and the planet for resilient supply chains. Resilience and sustainability are linked to successful businesses. When emphasizing the planet for cleaner supply chains, the book highlights the importance of resilience through efficient planning, purchasing, production, and distribution for less pollution and environmental damage (Bals & Tate, 2016).

The manufacturing phase has a severe impact on nature and the ecosystem quality due to electricity, natural gas, heavy machinery, and other resources used in manufacturing. Moreover, the raw material phase has also shown significant impacts on the environment. Harmful and toxic gasses are also found to negatively impact the environment in the manufacturing and disposal of packaging material. Distribution and logistics were the third most significant environmental impact shown in the study (Sangwan et al., 2018).

2.1.1 Environmental Impact from Transporation

Within logistics, transportation is responsible for major fossil fuel use and greenhouse gas emissions, such as carbon dioxide. Therefore, the transport sector has a major financial and societal responsibility to focus on sustainable transport. Implementing sustainable transport is assumed to involve an increased cost, leading many companies not to invest in sustainable transport. However, there are high demands on companies to become more sustainable and implement sustainable supply chains. These requirements mean that both shippers and carriers need to take joint initiatives to implement fossil-free transport and reduce emissions (Novack et al., 2019).

Logistics has several different objectives, one of which is environmental impact. There can often be conflicts between financial and environmental objectives. An example of this is fast and frequent transport, which can mean low costs, but due to low fill rates and frequent transport, the environmental impact increases. Customer requirements can thus influence the company's priorities, where, for example, fast deliveries are prioritized over sustainable transport (Jonsson & Mattsson, 2016).

The environment is negatively affected when the speed and frequency of transport is increased. Transport distances also have a negative impact on the environment and lead to increased emissions. It is common for suppliers and subcontractors to be geographically located at long distances, requiring long and complex transport (Jonsson & Mattsson, 2016).

Furthermore, external transport affects the environment through evaporation from fuels to air, soil, or water and exhaust gases. The exhaust gases involve emissions of mainly carbon monoxide, carbon dioxide, nitrogen oxides, etc. which generate environmental threats. These environmental threats include the greenhouse effect, eutrophication, acidification, depletion of the ozone layer, broken cycles, and exploitation of nature (Jonsson & Mattsson, 2016).

The cycle specifically means that resources from nature are returned to nature at the rate at which they are extracted from nature. This means that the natural cycle is broken when more resources are extracted than can be reproduced, such as when transport is powered by fossil fuels such as coal, oil, and gas (Jonsson & Mattsson, 2016).

Beyond nature, social sustainability is affected by transport, especially in urban areas. Transport emissions can lead to health problems and noise can lead to sleep disturbance and stress (Jonsson & Mattsson, 2016).
For minimizing the environmental impact of logistics, some of the solutions mentioned by Bellow (2016) are minimizing the extra stock, and suppliers shipping directly to the customers rather than having a distribution warehouse to decrease the CO_2 consumption from the extra transports. Moreover, reducing the number of reshipping is found to be an important aspect of environmental sustainability. Demand is further connected to the social aspect of TBL. Understanding the culture of the customers and building better relationships allow having a more optimized supply management which results in higher resilience and hence lower carbon footprint (Bellow, 2016).

2.1.2 Environmental Impact from Products and Packaging.

In logistics, products and their packaging affect the environment through their impact on transport and waste. The products or components being transported can affect transport according to the design of the component/product. This can challenge material handling and make efficient transport difficult. Circular products that are considered recyclable or reusable after they have reached the final customer, must be transported back from the customer to the supplier. This can cause an increase in transport (Jonsson & Mattsson, 2016).

Goods with specific requirements, such as bulky, dangerous, or damage-sensitive can challenge the possibility of sustainable transport. In addition to transport, products and their packaging can generate waste that requires transport and waste management (Jonsson & Mattsson, 2016).

2.1.3 Environmental Impact from 3PL Usage

Third-party logistics (3PL) means a service that offers external management of all logistics processes of a company. 3PLs often offer several different services that are integrated into the offer (Novack et al., 2019). Companies using 3PL services must choose a 3PL service based on their willingness to contribute to a sustainable supply chain. A lot of 3PLs have embraced technologies to help them optimize routes and cut down on idle miles, which will help them utilize resources more sparingly. However, a considerably lesser number of 3PLs have invested in alternative fuel equipment (Novack et al., 2019).

2.1.4 Environmental Impacts of Lean Wastes and Production in Foundries

Torielli et al. (2011) believe that the foundry industry is encountering challenges mostly regarding economic and environmental sustainability. In the article, a theoretical framework is created for environmentally and economically sustainable foundries by implementing lean management philosophy and its tools. Torielli et al. (2011) associates eight lean wastes to possible environmental impacts on foundries in Table 2.1.

Table 2.1, Eight types of lean wastes associated with the foundries and the environmental impacts, inspired by Torielli et al. (2011).

Waste type	Brief Description	Environmental impacts
Defects	Products and components that result in defects during production	o Energy consumptions and raw materials waste o Defect components require extra work for disposal or recycling. o Increased energy use for rework including heating, cooling, and lighting
Waiting	Delays due to long processing, scarcity of material, stock-outs, equipment downtime	o Material spoilage causing waste. o Energy waste from heating and cooling of the machines.
Unnecessary Processing	Redundant processes that are not needed for the production.	o Consumption of unneeded raw materials o Energy consumption & emissions o Unnecessary raw materials and energy consumption
Overproduction	Producing more items than required causing extra inventory	o Risk of obsolete batches o Extra emissions, employee exposure to chemicals, and waste disposal.
Unnecessary Movement	Motion that is redundant. This could include human's, forklift's or lorries' movement. Work in process (WIP) is another movement that could be reduced.	o Energy use & emissions for transport o Extra packaging required to protect products during internal and external transportations o Increased damage and spilling risk during transport
Excessive inventory	Excessive stocking of raw material, finished goods, and WIP.	o Extra packaging required o More materials required to replace damaged or obsolete goods in the inventory o More energy used to preserve finished goods and raw materials. o More energy used to heat, cool, and lighting for the inventory.
Unused employee creativity	Not utilizing employees for their insights and improvement solutions in the operations.	-
Complexity	Increased lead times due to excessive parts and steps	-

Lean philosophy aims to achieve the best quality at the lowest cost and the shortest lead- times by eliminating 8 wastes that are defined in the lean production system. Casting scrap is a form of direct waste in the foundries. Since lean promotes eliminating waste, eliminating scrap could impact environmental and economic sustainability. Scrap casting repair, for instance, is a process that does not add value to the customer and is a waste (Torielli et al., 2011).

Foundry operations are highly energy-consuming. Greenhouse gases produced from natural gases are a major concern for foundries (Torielli et al., 2011). Moreover, according to Šehić-Mušić et al. (2013), the existing technology (gas-fired furnaces) has a significant negative effect on the environment due to the high amounts of release of air pollutants such as carbon dioxide and sulfur dioxide, burnt fuel, etc. higher output of castings production is related to higher environmental pollution.

2.1.5 Drivers for Sustainable Manufacturing

The external pressure of the increasing environmental and social legislation is having a large impact on manufacturing companies. Some companies see the implementation of sustainability tools and legislations as a concern to their company. It is foreseen as wasting resources and hence reducing efficiency in the manufacturing processes and overall operations. However, it is also found that sustainable practices reduce operation costs in longer terms and boost employee satisfaction (Nordin et al., 2014).

The drivers of sustainability may differ from organization to organization. Adopting sustainable manufacturing practices requires support from the management as well as internal and external factors as seen in Table 2.2 (Nordin et al., 2014).

Table 2.2, Drivers for sustainable manufacturing inspired by Nordin et al. (2014).

Management	Strategy
	Mindset
Internal Factors	System
	Measures
	Needs for improvement
	Performance improvements
External Factors	Law regulations
	Social pressure
	Market Trends
	Competition

2.1.6 Challenges for the Circular Economy

A linear economy is based on the take-make-dispose mindset. The concept of a circular economy (CE) differs from a linear economy and instead focuses on a reuse, repair, and recycling mindset. The concept advocates the use of natural components and materials that do not harm the environment (Gallaud & Laperche, 2016). To increase sustainability and competition among businesses, the circular economy has been introduced. The transition from a linear economy to a circular economy poses various challenges for companies. The circular economy affects entire supply chains and requires a redesign of the chain (Gianmarco et al., 2019). 15 different challenges within the circular economy (CE) have been selected from three previous studies. The selection of challenges is based on the relevance of this study and is presented in Table 2.3.

Table 2.3, Challenges for a Circular Economy

Category	Challenge	Reference
Supply Chain Management	Return flows uncertainty	Gianmarco et al. (2019)
	Transportation and infrastructure	Gianmarco et al. (2019)
	Availability of suitable supply chain partners	Gianmarco et al. (2019), Sousa-Zomer et al. (2018), and Kumar et al. (2019)
	Coordination and information sharing	Gianmarco et al. (2019)
	Product tracability	Gianmarco et al. (2019)
	Cultural issues	Gianmarco et al. (2019), Sousa-Zomer et al. (2018), and Kumar et al. (2019)
Standards and regulation	Taxation and incentives	Gianmarco et al. (2019)
	Measures, mertics, indicators	Gianmarco et al. (2019) and Kumar et al. (2019)
	Lack of standards	Gianmarco et al. (2019) and Kumar et al. (2019)
Product charateristics	Fashion change	Gianmarco et al. (2019) and Kumar et al. (2019)
	Product complexity	Gianmarco et al. (2019)
	Product (mass) customisation	Gianmarco et al. (2019)
Risk	Financial risk	Gianmarco et al. (2019) and Kumar et al. (2019)
	Operational risk	Gianmarco et al. (2019) and Sousa-Zomer et al. (2018)
	Investments	Kumar et al. (2019)

The challenges in Table 2.3 are categorized according to challenges within supply chain management, standards and regulations, product characteristics, and risk. These categories were chosen based on the frequency in the three previous studies and also based on the topic for this study.

Supply Chain Management Challenges

Planning for capacity is difficult when there is uncertainty regarding the quantity, variety, quality, timing, and location of returns of end-of-use products. Therefore, the challenge of "return flows uncertainty" was introduced. This uncertainty also lowers the possibility that an economic scale can be attained. Illegal disposal practices result in a reduction in the number of products collected and processed at the end of use, which heightens this uncertainty and negatively affects circularity (Gianmarco et al., 2019).

Transport and infrastructures are challenged due to the geographical dispersion of the base which would drastically increase transport operations and transport costs as all products should be shipped back to the manufacturer or third-party companies that refurbish, dismantle, or remanufacture products (Gianmarco et al., 2019).

Furthermore, companies wishing to move to a circular economy often experience difficulties in finding suitable supply chain partners. This is because companies need appropriate circular economy tools and skills that match their own company's principles and approach (Gianmarco et al., 2019). There is a lack of suitable partners in a circular supply chain which becomes a challenge for the circular economy. This complicates supply chain cooperation in terms of material flow and customer satisfaction (Kumar et al., 2019). This challenge also involves the lack of incentives for the key partners, which makes it difficult to find suitable cooperation partners. These partners should have similar business models that match; if this is not fulfilled, it can lead to conflicts of interest. (Sousa-Zomer et al., 2018).

Furthermore, a challenge in the supply chain is the coordination of information and the flow of information. A circular economy requires more sharing of information within the supply chain and increased collaboration between all parties. This can be difficult to achieve, especially if it is a global supply chain. The challenges are based on competition, levels in the supply chain, non-integrated IT systems, sensitive information, etc. (Gianmarco et al., 2019).

Product traceability is a challenge when firms do not have control over the produced materials and components. The advantages are that it improves the collection of components and the renovation of processes but makes the accessibility of the information flow more difficult. Accessibility should be easy to facilitate efficiency, return flows, end-of-use activities, and the capacity to make accurate demand forecasts (Gianmarco et al., 2019).

Lastly, a linear mindset can cause resistance within the corporate culture. Employees risk being stuck in a linear mindset and may be resistant to change of mindset. This can lead to limited commitment and awareness throughout the organization, from top management to the lowest level of employees (Gianmarco et al., 2019). Leadership behavior can also be a challenge to corporate culture in the shift from a linear to a circular economy. Leaders are required to implement a new business plan, which can be difficult to define, and to change their mindset. Both managers and employees may have attitudes and behaviors that are contrary to a circular economy, requiring cultural adaptation (Sousa-Zomer et al., 2018).

Businesses are challenged by low awareness of a circular economy in general. Even though the concept of CE has been introduced by authorities and other companies, there is a lack of awareness of CE. Specifically, the implementation phase of CE is difficult to manage as there is no standard for companies to follow. This leads to companies continuing to work with their old standards and ways of working (Kumar et al., 2019).

Standards and Regulations Challenges

Standards and regulations pose additional challenges for businesses in a circular economy. Currently, in a linear economy, there are no good taxation systems or policies that are aligned with a circular economy. There is a lack of standards in general in processes, activities, and materials regarding CE. In the linear economy, there are Key Performance Indicators (KPIs) but these need to be redesigned and adapted to a circular economy where the focus should include a holistic approach to environmental, social, and economic sustainability (Gianmarco et al., 2019).

As the benefits of a circular economy are currently quite unknown, it is difficult to create laws and policies to guide businesses. This also complicates the implementation of a new vision, mission, targets, and indicators. Furthermore, the implementation of systems to measure performance through data collection, statistics, assessment, calculations, and documentation is made difficult. Finally, CE is a challenge for companies because the current tax legislation does not favor CE (Kumar et al., 2019).

Product Characteristics Challenges

Product characteristics are also a factor that faces challenges in a circular economy. In CE, the aim is to produce products with a long lifespan, which makes it difficult to adapt the design to trends. The complexity of the products is also challenged by new materials that make it difficult to manage reuse and recycling. The complexity is further challenged by customer-specific and personalized orders, which creates challenges regarding the disassembly and reuse of the components (Gianmarco et al., 2019).

Previous studies find that people largely buy products for their appearance, rather than for their sustainability or environmental impact. People prefer products that look better with new materials rather than those made from scrap. For this reason, it becomes a challenge for companies to implement CE strategies as there is a low demand for remanufactured products. In addition, specific agreements are required with customers who buy circular products in a circular supply chain, as the final products must guarantee the return of the products. These situations impair CE efforts by disrupting the steady flow of materials and increasing waste production (Kumar et al., 2019).

Risk Challenges

When implementing service business models (BMs), the service owner carry financial and operational risks with the services provided. Suppliers are responsible for the costs associated with the operation of the solution they offer, such as the cost of maintenance activities, and are financially exposed to the risks of early cancellation of agreements by consumers (Gianmarco et al., 2019).

Furthermore, there are many financial risks associated with CE. It is an expensive transition to a circular supply chain that requires costly investments. These investments have a long payback period, and although they pay off in the long term, companies hesitate because of the long payback period. In addition, the lack of financial support and tax incentives affects CE investments. Especially for SMEs, these are large investments that are not possible without government support or similar (Kumar et al., 2019).

2.2 Coordination and Sustainable Planning

For a sustainable and efficient supply chain, integration, and coordination are vital factors. Integration consists of a choice of partners, network organization and inter-organizational collaborations, and leadership. The use of information and communication technology, process orientation, and advanced planning are crucial factors for coordination in supply chains (Stadtler et al., 2015).

For sustainable development and to meet demand, production planning is highlighted. One of the most crucial aspects of industrial operations is production planning.

Production planning and management are crucial to the success of major manufacturing enterprises due to the expanding product range, shorter product life cycles, frequent changes in demand, and shorter delivery periods (Piyush et al., 2021).

Businesses with thorough planning may thrive in an intense market rivalry between industrial enterprises and rising customer demand. Large industrial firms with vast supply networks require thorough and efficient planning to remain competitive. However, this puts pressure on resource sustainability and circularity by requiring businesses to employ production processes that are quick and inexpensive without considering the long-term consequences of their decisions (Aydin & Tirkolaee, 2022).

2.2.1 Resilient Production Systems

In a resilient production systems study, a framework for appropriate measures of resilient production planning is described. The study suggests the importance of resilience in production plants and its connection with supplies (Heinicke, 2014).

<u>Flexible Production Systems</u>

Resilience is the adjustability of a system to changes. In the context of production systems, it is the ability to cope with changes in demand or other external factors. Robustness is a system's ability to withstand change or outside factors without changing its original, stable configuration and continuously produce the targeted output. Robust systems are known to be proactively designed and therefore would not require changes due to disturbances and deviations. Since robust production systems are proactively designed, they aim to prevent supplier-related concerns. Therefore, robust systems are resistant to predictable changes. It is argued that there are limited possibilities to improve or redesign robust production systems for ongoing changes (Heinicke, 2014).

Agility is a term often associated with flexibility in production systems. Agility is the response pace to unexpected and unpredictable changes. Therefore, agility is a reactive approach and a factor that complements the robustness of a production system. Since the time of response to changes and fluctuations are dependent on agility and robustness, the correct levels of agility and robustness are crucial for the sustainability of the production (Heinicke, 2014).

While agility is the response to environmental changes through rapidly reconfiguring production systems, robustness is the response to forecasting and prevention proactively. Therefore, Figure 2.3 provides a hierarchical framework for resilience. While agility requires visibility and speed, robustness requires anticipation and preparedness.

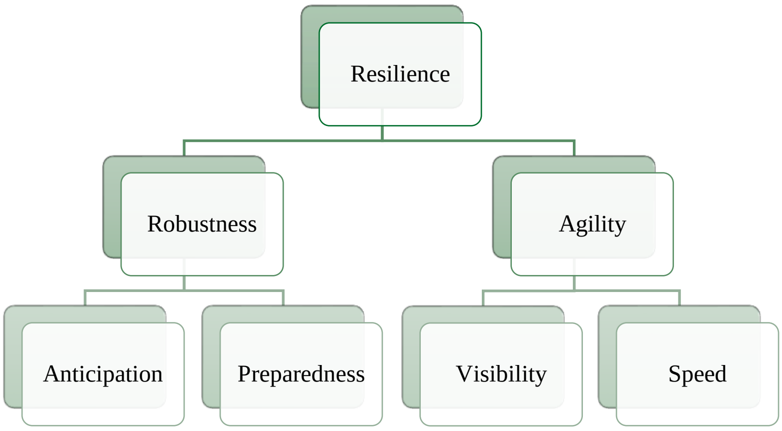

Figure 2.3, Resilience hierarchy inspired by Heinicke (2014).

Production Control

Production control is another major factor that has an impact on production planning. Usually in production operations, the aimed target will not be achieved perfectly due to uncertainties. Therefore, production control is highly significant for managing lead time, capacity utilization, inventory, and accurate delivery times (Heinicke, 2014).

Heinicke (2014) believes that the quantitative aspects of orders are mainly based on customer demands. The production type of customers is dependent on their customer orders. Based on the customer demands, production principles can be set which will determine the strategy. Order release, the sequence of production orders, resource allocation, and batch sizes are highlighted for choosing strategies such as push or pull strategies.

It is also highlighted that specific production orders cause other jobs on the shop floor to be delayed due to deadline prioritization. The article also mentions the importance of neglected socio-technical aspects in the workplace. The workers, production planners, and other stakeholders require a hierarchy and support. The workers that have an impact on production planning affect the resilience of the production (Heinicke, 2014).

Table 2.4, Influences on production planning inspired by Heinicke (2014).

	Control Variable	**Distrubance Variable**
Internal	Capacity	Malfunction of production facilities
	Utilization	Defecs in workmanship
	Inventory	Uncertanities of planning (e.g. estimation of process time)
External	Market pressure	Changes in customer demand
	Delivery times of supplier	Insufficient material availibility due to supply shortage

It is also implied that in production systems where robustness is not sufficient, agility and flexibility are required considering reconfigurability, adaptability, convertibility, etc. Heinicke (2014) finally presents a case in the steel processing industry where the rework rate is decreased by 40% and thus overall lead times and fluctuations in the production are decreased. The production process was stabilized by having clear delivery times and decreased external disturbances as also shown in Table 2.4.

2.2.2 Just-In-Time

Different production methodologies are mentioned within the Lean manufacturing philosophy. The most applicable production methods for PPS are Just-in-time (JIT) and Kanban scheduling systems. Moreover, constraint-oriented production is mentioned. JIT is defined as the right quantity, right time, and right material at the right place. This is applied for optimizing production flow in the factories. JIT also requires a change from push to pull system which highlights the customer demand causing to start the production. This also suggests the use of smaller batch sizes (Heck & Vettiger, 2014).

In a study of JIT from the perspective of environmental sustainability, a swot analysis of the implications and applications of JIT is done (Melo et al., 2022). According to the results, the strengths of JIT are flexibility in meeting customer demands, lower inventory volumes, fewer lost products/increased batch quality due to defects and obsolesces. The weaknesses of JIT are presented as using transport vehicles below their full load capacity, increased road traffic due to frequent transports that cause higher CO_2 release and increase Green House gas emissions, delays in the production of the customers due to delays in the deliveries, increase in transport costs (Melo et al., 2022).

In terms of opportunities, the following are shown:

- Utilizing intermediate storage or cross-docking to optimize vehicle usage and cargo organization, adapting Just-in-Time (JIT) to suit specific requirements and circumstances of suppliers
- Coordinating collections among multiple suppliers to improve efficiency
- Employing smaller transport vehicles to align with shipment sizes and reduce fuel consumption
- Establishing a local production arrangement where primary suppliers are located near the central factory
- Enhancing delivery planning and minimize loading bay wait times to reduce vehicle speeds which results in lower greenhouse gas emissions.

Moreover, integrating JIT with other methodologies like Six Sigma and green manufacturing to enhance overall performance and sustainability is also considered an opportunity for the environment with JIT (Melo et al., 2022).

Melo et al (2022) also mentions the environmental threats that JIT may possess are as follows:

- Higher demands require higher levels of control for coordination of the deliveries
- Requiring higher communication which would harm the delivery quality in case poor communication between partners
- Greenhouse effect gas emissions may not satisfy the customers’ target goals due to frequent transports

2.2.3 Capacity Planning

Planning is necessary for production and material control in manufacturing. Its purpose is to identify and plan future needs and activities. This may involve different time horizons, such as a week, six months, or for a single order. Manufacturing requires information on capacity, which is a measure of the extent to which production resources can add value. This concept usually balances the need for capacity against the demand for capacity (Jonsson & Mattsson, 2016).

There are four different ways to achieve a match between capacity demand and capacity supply. These are reallocating capacity, increasing/decreasing capacity, reallocating capacity needs, or increasing/decreasing capacity requirements. These courses of action are presented in Table 2.5 with associated solutions for both the short and long term (Jonsson & Mattsson, 2016).

Table 2.5, Compilation of policy options to match capacity availability with capacity needs, inspired by Jonsson and Mattsson (2016).

Type of action	Long term	Short term
Increase/decrease capacity	New recruitment/temporary lay-offs	Overtime
	New machinery	Deferred maintenance
	Number of shifts/short week	Outgoings
	Outgoings	
Reallocating capacity	Transfer of capacity between departments	
Increase/decrease capacity needs	Changing production plans	
	Marketing activities	
Reallocating capacity needs	Change delivery times	Pre-/postponement of orders
	Increase/decrease stock	Change order quantities
		Alternative production groups

Reallocation of capacity needs works well when companies manufacture against the stock. This means that, in the long run, the company can reduce capacity needs in certain seasons and supply from stock. The opposite is also an option, as capacity needs to increase in other seasons when producing against the stock. This indicates using seasonal stocks when the demand forecast is unstable. Companies that produce according to customer orders, on the contrary, can reallocate capacity needs by changing delivery times. This means extending delivery times when demand increases and reducing delivery times when demand decrease (Jonsson & Mattsson, 2016).

The short-term solutions for reallocating capacity needs offer different possibilities. One solution is to bring forward or postpone part of the capacity to another time period. However, this requires that material is available earlier than the original plan. This generates more capital tied up as the items are finalized too early and postponement can lead to material shortages during production. Alternative production groups are the last possible short-term solution. This means unloading the resources in production that are overloaded and instead loading the production that has room for it. For example, the company can reduce order quantities to produce smaller batches over a time horizon, but this means that later larger batches will have to be produced to cover the total demand (Jonsson & Mattsson, 2016).

2.2.4 *IT Systems for Planning and Scheduling*

IT advancements have enabled supply chains to be more efficient for planning.
For advanced planning, advanced planning systems (APS) and the use of ERP systems are reinforced. Communication through EDI systems is highly beneficial for companies and plays a big role in receiving the correct order information (Stadtler et al., 2015). Another study identifies ERP systems as essential for production planning and scheduling. ERP systems represent the information system within manufacturing companies and are necessary for all the core business activities in a manufacturing company (Heck & Vettiger, 2014).

A study comparing SMEs and larger enterprises' SCM (supply chain management) performances indicate that planning and production control is highly vital for SMEs to face supply challenges. The study provides technology-based solutions for better planning. A possible solution for that is given as SMEs cooperating horizontally in the SC (supply chain) to reduce the information gap, developing more partnerships with their customers to have more visible and shared planning and control systems, and using IT solutions. These IT solutions include EDIs, computer-aided ordering systems, ECR-efficient consumer response systems, etc. In conclusion, network collaboration, sharing of resources in the supply chain, and the contribution of IT tools are highlighted for SMEs to adopt better planning and production control (Vaaland & Heide, 2007).

According to the study by Heck and Vettiger (2014), the most common problem with ERP systems is the wrong implementation of ERP solutions. This is an even bigger problem for production planning due to the insufficient use of software programs and solutions at SMEs. More specifically, the study indicates that 33% of SMEs are not using ERP systems for planning and scheduling their production. The remaining 67% of the SMEs do not integrate all the aspects of ERP systems and their operations with their production plan. According to the setup of IT landscapes in SMEs, 67% of the companies have their master data stored in several IT systems, preventing having one single system for production planning. The SMEs that use several IT solutions for production planning have had complaints regarding non-optimized production plans, manual selection of input data, additional effort consumed during manual steps, and the functionality of systems not fitting the production setup (Heck & Vettiger, 2014).

Heck and Vettiger (2014) also argue that ERP systems could be costly and therefore SMEs should consider the investments for the perceived benefits of an expensive and extensive ERP system. The authors also mention that an ERP implementation project has a higher probability of succeeding if lean and continuous improvement processes are supporting the implementation (Heck & Vettiger, 2014).

2.2.5 *Integration in Supply Chains*

Integration in the supply chain refers to improving the competitiveness of a supply chain which improves supplier relationships and hence supply chain efficiency. Therefore, the choice of partners, inter-organizational collaborations, and leadership in the supply chains are highly significant for integrating suppliers for a well-functioning supplier-customer relationship. (Stadtler et al., 2015).

A focal company relies on specialized suppliers to supply the materials, components, and other inputs required by its assembly line. Supplier adaptability and flexibility are essential for the focal organization to be able to meet the changing demands of its customers. Supplier flexibility is defined as the behavioral outcomes capturing how well a supplier can satisfy the expectations of their customer and fulfill its special orders and requirements. A flexible supplier has a higher possibility of providing better service/supplies to its customers and increasing both its' and the customer's competitiveness. The study explains the relationship between power, shared goals, and supplier flexibility to increase competitiveness in the supply chains (Liu et al., 2022).

Power over supplier is described in two terms. These are coercive and legal-legitimate power. The supplier takes action to manage its dependency on the focal firm when it believes that the firm's coercive power has gone beyond a certain threshold. The supplier will be less inclined to accommodate the focal firm's unique needs as a result. In contrast, the suppliers will be more inclined to accommodate the focal firm's needs and supplies when the focal firm applies a high legal-legitimate power to the supplier instead. Therefore, it is important to imply low levels of coercive and high levels of legal-legitimate power to pressure suppliers to be more flexible to the demands of the focal firms (Liu et al., 2022).

The study also presents results on the relationship between shared goals and supplier flexibility. A high level of shared goals shall follow a high level of legal-legitimate power on the suppliers to increase the flexibility of the suppliers to the changing demands of the focal firms. Therefore, focal firms shall pressure suppliers to comply with the regulations, legal bonds, and integrity policies before sharing goals and information (Liu et al., 2022; Stadtler et al., 2015). Moreover, Stadtler et al. (2015) also imply the importance of information sharing in the supply chain for improved planning. To secure information sharing and competitiveness between suppliers, legal bonds, social bonds, technical, and knowledge-sharing bonds are encouraged between the suppliers and the focal companies (Stadtler et al., 2015).

3 METHOD

The methodology chapter describes the study's choice of method to fulfill the purpose and answer the research questions. The design of the study is presented followed by the approach. Further, the strategy for collecting data and data analysis is presented. The chapter concludes with an account of the quality of the collected data.

3.1 Design of the Study

The purpose of the study is to identify the challenges that Swedish foundries are facing regarding circularity and sustainability demands and explore how SME foundries can be more sustainable and circular. To conduct the study and achieve the purpose, an explorative multiple-case study is conducted to investigate several actors of different sizes in the Swedish foundry industry. There is a knowledge gap in the foundries connected to sustainability and circularity, which indicates that this is an exploratory study. This type of study aims to gather information and knowledge about the phenomenon. Being creative and resourceful are important qualities when conducting exploratory research (Patel & Davidsson, 2019).

A case study is an empirical method that investigates a contemporary issue or matter in real life situation. A case study helps understand a real-life condition and enriches the understanding of the study through the circumstances of the situation (Yin, 2018). To achieve multiple case studies, it is common to apply multiple data collection methods (Patel & Davidsson, 2019). The justification for the choice of method is that three case companies are studied. One Small and Medium-sized Enterprise (SME) and two Original Equipment Manufacturers (OEMs) are investigated in this thesis. This generates information and knowledge about two different roles' perspectives in the supply chain. The reason for that is to be able to create a holistic perspective with as much information as possible in the foundry industry within the limitations of the study.

In the selection process of case companies, some aspects are considered mandatory. The companies must be a part of the foundry industry as producing companies. In addition to this, four requirements are imposed on the companies. The first is that the company is part of the GRETA research project since the project is already initiated. Secondly, the companies should cast products/components in aluminum or steel and be considered SMEs or OEMs. The SME needs to be a supplier to a larger product-owning company. Similar requirements apply to OEMs but with the requirement to be a product-owning company with suppliers and subcontractors. The case companies remain anonymous in this study due to confidentiality. Therefore, the companies are referred to as Company A, Company B, and Company C. Company A is defined as an SME, and B and C are defined as OEMs.

3.1.1 Description of Case Companies

The case companies in this study are three different companies within the foundry industry. Table 3.1 presents an overview of the companies. The overview includes the type of the companies, their role in the supply chain, the materials used in the casting processes, annual turnover, employees, and the number of interviews and observations carried out for data collection.

Table 3.1, Case Companies Overview

Case companies overview	Company A	Company B	Company C
Company type	SME	OEM	OEM
Role in the Supply Chain	Supplier of casted components	Manufacturer	Manufacturer
Material	Aluminium	Aluminium and Magnesium	Aluminium and iron
Turnover (MSEK)	~1300	~54000	~170000
Employees	~40	~2000	~14000

Besides Table 3.1 the companies' operations are further described. Company A is a supplier of casted components to both company B and company C. Company B and C is both a manufacturer of casted components/products and a customer of casted components.

Company A

Company A is defined as an SME in the foundry industry. The company carries out die-casting and finishing of alloys with the main material being aluminum. Shortly, their supply chain starts from raw materials to finished casted components. The company supplies casted components to both SMEs and OEMs within Sweden and globally. The annual turnover presented in 2023, is approximately 1300 MSEK. The company has 40 employees in the unit involved in this study.

Company B

Company B is an OEM in the foundry industry. The company both purchase casted components for their assembly lines and produce castings in their foundry for all production units within the organization. The main material of their alloys is aluminum and magnesium. The company's annual turnover in 2022 resulted in approximately 54.000 MSEK. The company has 2000 employees in the unit involved in this study.

Company C

An OEM in the foundry industry is company C. This company cast its own components and purchases components for its assembly lines from different suppliers. The company only produces castings for their organization. The material company C works with is aluminum and steel. Company C has 14.000 employees at the unit involved in this study. The annual turnover in 2022 resulted in 170.000 MSEK.

3.2 Approach

The study begins with a literature review of previous theories and studies related to the study's problem description and background. Based on the literature, semi 'structured interviews and unstructured observations are designed and conducted for the primary data collection. This is done in the first phase of the study, as illustrated in Figure 3.1, where primary data and literature are collected as a basis for answering the first research question. After the primary data is analyzed, the selection of the problem area is made, which is addressed in research question two. Since the selected problem is identified during the data collection for the first research question, the study needs to be supplemented with more previous theories and studies in an extended literature review.

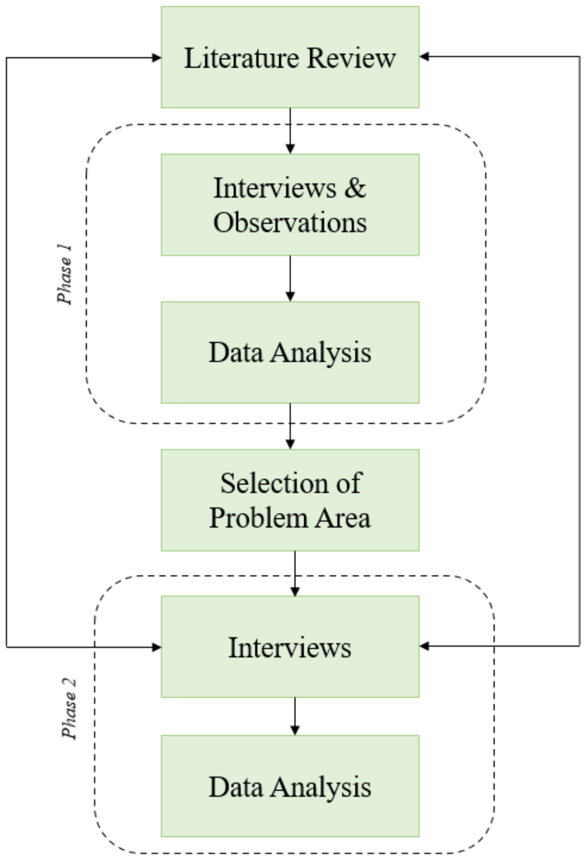

Figure 3.1, Method Approach Overview

Also, additional primary data collection through more interviews is needed to be able to answer the second research question. Therefore, the study is divided into two phases. Literature review in this study is a circular process, where literature is added as primary data is collected after the selection of the problem area, as shown in Figure 3.1.

Triangulation is a research method that enables the use of multiple data collection sources and methods rather than one single source. This is widely used to gain richer and more fulfilling data to verify the correctness of the research findings (Yin, 2018). This study uses multiple methods to research the challenges that Swedish foundries are facing regarding circularity and sustainability demands. Therefore, a triangulation of multiple methods is suitable for this multiple case study. In this triangulation method, interviews and observations are used simultaneously to collect data.

Qualitative research is the collection, organization, and documentation of textual material collected from forms of conversation. Qualitative data provides the researcher with a more intricate view of human organizations (Grossoehme, 2014). To identify the challenges directly from the source, e.g., the companies and managers, the use of interviews and observations are suitable for this thesis Therefore, the method approach indicates the use of qualitative data.

3.3 Literature Review

A literature review has a significant role in all types of research. It provides an overview of the research discipline and the previous work carried out in the field (Synder, 2019).

In this report, books and peer-reviewed scientific articles are used for literature review. A literature review is highly applicable to synthesizing research findings for a comprehensive and reliable analysis (Synder, 2019). Therefore, the findings of the literature review are used to analyze and synthesize the findings of this study. The literature review is conducted based on phase one and phase two as explained in 3.1 design of the study. After the data collection for phase one, a data analysis is done where the results determined the content of phase two. When phase two is determined, the relevant literature review is conducted and added.

The search engines used to access literature databases are Primo Search by Jönköping University's online library and Google Scholar. The databases used for searching peer-reviewed articles are Emerald Insight, Proquest, Researchgate, and ScienceDirect. The keywords used for searching the literature for phase one are sustainability, circularity, foundries' challenges, pollution, supply chain, emissions, logistics, and production. The search keywords used for the second phase of the literature review are production planning, materials planning, resilience, supply chain management, communication, and planning. Moreover, similar vocabulary is used to search for increasing the richness of the literature review.

The literature used is not older than 16 years which provides new and up-to-date information for more valid research. Doing a literature review on a contemporary topic with current databases is important for acquiring reliable findings (Efron & Ravid, 2019). The concept of "sustainability and circularity" is a fast-changing and growing field that requires adjusted research aligned with the new information. However, since there is a research gap in the foundry industry regarding sustainability and circularity, the literature used provides a substantial overview of the topics issued in the literature review.

To choose the suitable literature, the title is observed as the first step. Later, if the title is relevant to the field of the thesis, the abstract is read. If the abstract is of interest, the article's findings and results are skimmed through to have an overview of the literature. The article is saved to categorize for further reading. The number of citations is also considered for the reliability of the articles.

3.4 Data Collection

To answer the research questions and fulfill the purpose of the study, there are links between the method and the research questions. In Figure 3.2 the relationship between the research questions and the methodology is illustrated.

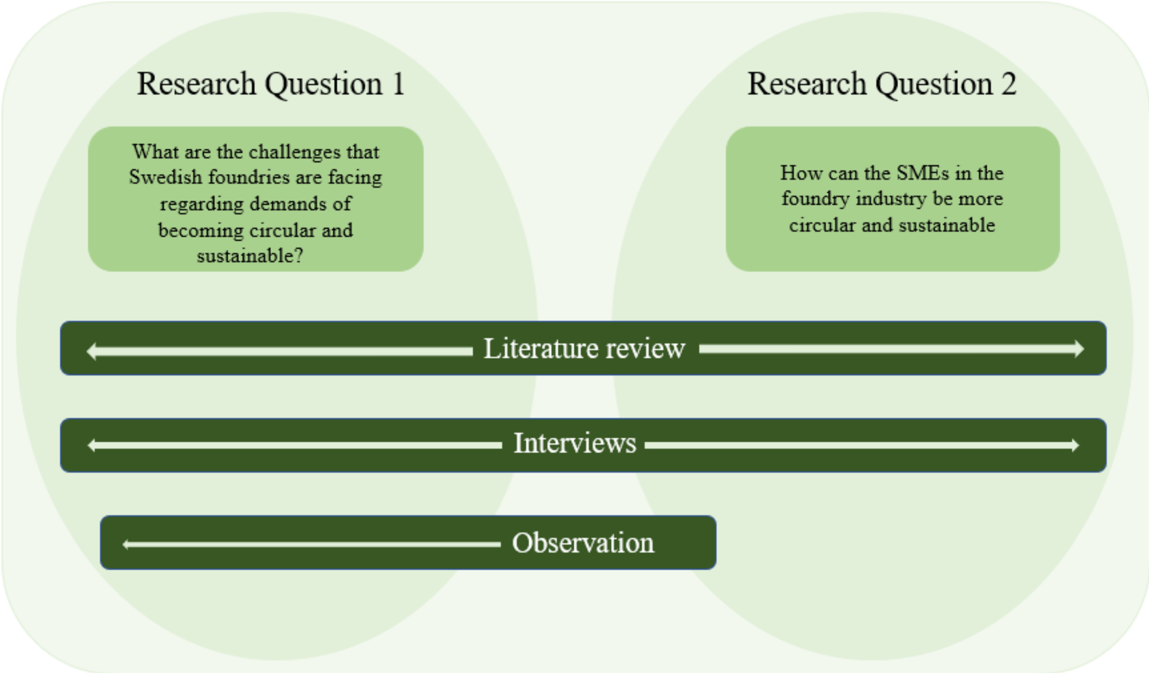

Figure 3.2, Relationship Between Research Questions and Methodology

The first research question is answered using interviews and observations. The second research question is answered using only interviews. Also, the literature review is implemented to analyze and answer both research questions. The interviews and observations enable a current situation analysis of the case companies. The literature contributes to the research questions by identifying previous research (Gustavsson, 2019).

3.4.1 Interviews

The main method of the study is qualitative interviews. This is a relevant method if the researcher wants to collect data on an individual's feelings, thoughts, and experiences about one or more phenomena. The role of the interviewer is to understand the current state of a phenomenon described by the respondent. The most common form of interview is the semi-structured interview, which is implemented in this study (Gustavsson, 2019). Unlike a structured interview, the interviewers ask the respondent about broader issues, with spontaneous follow-up questions. Prepared questions are avoided to create more freedom and follow-up questions on the respondent's answers (Thomas, 2022). Instead of pre-determined questions, a guideline is often followed by the interviewers. Unlike pre-determined questions, a guide contains different topics to be discussed with single questions. These topics should be linked to the research questions and the purpose of the study. The questions can be for example demographic, introductory, follow-up, and exploratory questions (Gustavsson, 2019). Since the possible challenges are unknown to the authors of this study, semi-structured interviews are used to gather a wide range of challenges within the interview guide and themes of the interviews. This allowed follow-up questions which increase the richness of the interviews.

The interviews conducted in phase one of the study focus on material, supply chain, production, logistics, and sustainability & circularity themes. Further, the selection of the problem area initiates phase two of the study, which focus on the themes of material planning, purchasing, and sourcing. These themes are carefully selected based on the interviews and the purpose of the study. Based on the topics, the respondent openly described the organization's processes concerning the topics (Gustavsson, 2019). Furthermore, follow-up questions are asked by the interviewers to achieve a deeper discussion, see Appendix A, B, and C. The respondents are allowed to answer all questions freely and openly.

Table 3.2 illustrates when the interviews are conducted at which company along with the respondent, method, form of communication, and time. Also, the phase of the data collection is presented for each interview. The interviewees are carefully selected to generate the optimal data for the purpose of the study.

The respondents vary depending on the company, as seen in Table 3.2. The authors focused on the knowledge and the experience when selecting interviwees. Therefore, different titels of the respondents are used, since the authors were forwarded to the person with the best knowledge within the topic.

Table 3.2, Conducted Interviews Overview

Date	Phase	Company	Respondent	Abbreviation	Method	Form of Communication	Time
2023-02-23	1	A	Sales Manager	SM	Semi-structured interview	Video call	75 min
2023-02-15		C	Logistic Manager	LM	Semi-structured interview	Video call	85 min
2023-03-06		A	Sales Manager	SM	Semi-structured interview	Physical meeting	60 min
2023-03-08		B	Production Manager	PM	Semi-structured interview	Video call	60 min
2023-03-08		B	Production Engineer (1)	PE1	Semi-structured interview	Physical meeting	80 min
2023-03-21	2	B	Production Engineer (2)	PE2	Semi-structured interview	Physical meeting	60 min
2023-03-22		B	Sourcing Manager	SM	Semi-structured interview	Physical meeting	60 min
2023-03-30		B	Materials Planning Manager	MPM	Semi-structured interview	Video call	60 min

Most interviews are conducted via video call due to the distance between the company and the interviewers. When time or distance is not an issue, physical meetings are organized. The video calls are recorded with sound, and no notes are taken during the interview to increase the focus and create better discussions and flow. The language used is mainly English, but sometimes Swedish is used when there are language difficulties. After the interviews are completed, the interviews are transcribed manually to English.

3.4.2 Observations

Observations are used for qualitative data collection in this multiple case study. There are two types of observations, these are structured and unstructured observations (Thomas, 2022). Unstructured observations are the kind of observations where the observers are observing informally and do not have a specific goal of knowing what to get as results. These types of observations may include recording, taking notes, and/or watching from a distance (Thomas, 2022).

In this report, two unstructured observations are used to understand the challenges regarding sustainability and circularity that are connected to the foundries, which corresponds to phase one of the data collection. Therefore, to answer the first research question, "What are the challenges that Swedish foundries are facing regarding demands of becoming circular and sustainable", observations are used simultaneously with interviews.

Table 3.3 summarize the performed observations at the companies. The participant at the company is presented along with the observation method and duration.

Table 3.3, Conducted Observations Overview

Date	*Phase*	*Company*	*Participant*	*Method*	*Time*
2023-03-06	*1*	A	Sales manager	Unstructured observation	60 min
2023-04-17		B	Production Engineer (1)	Unstructured observation	60 min

The authors do not know what exact issues they were aiming to find. Therefore, two unstructured observations are conducted at two foundries to observe the possible issues in the facilities at an SME and an OEM. The observations are performed together with one representative from the companies to be able to ask questions during the observation. Therefore, qualitative data is observed, and no numeric data are collected during the observations. The approach to the observations is to walk around the foundry and its associated processes such as logistics, production, etc. The data is documented through on-site and post-observation notes.

3.5 Data Analysis

Data is collected through interviews and observations. According to Yin (2018), using theory is beneficial for acknowledging previously resulted studies. Previous fieldwork enriches the perspective of data analysis and helps guide the research to be less biased. The data analysis process is done simultaneously with literature review and data collection to have dynamic guidance on the selection of literature and data type to collect. (Patel & Davidsson, 2019) suggests that flexible research is beneficial for a better selection of theories. Therefore, this study maintains a flexible exchange between the data analysis and the literature review.

For categorizing the empirical findings in the first phase, material, supply chain, production, logistics, and sustainability and circularity are used as themes. Material, supply chain, production, and logistics are analyzed with relation to the sustainability and circularity impacts. The reason for having a separate sustainability and circularity themes is for analyzing the sustainability and circularity from its own perspective. It is also done to analyze the actions and results of sustainability and circularity regardless from the other categories used in the data analysis. Having the categories structured as themes for a more holistic view of the terms and concepts provides a good categorization and separation of the results (Grossoehme, 2014).

Both the physical and online interviews were transcribed manually from the voice recordings to have better results quality. For the interviews, each of the case company's results are presented separately. Since the interview questions were similar, all the interview results are presented with the same themes for the companies. When the results are collected and written in the empirical data, a summary table for each of the case companies is provided for the readers to have a comprehensive overview of the results. Thereafter, observations are presented to the readers followed by a summary of the observations in a table form.

Since the observations are conducted unstructed, the notes are taken during the visit at the companies. These notes are then compiled and supported with the observers' memories from the observation the same day. Based on the findings, the themes of the observations are categorized accordingly to the key findings. Later, these themes are presented in text and a table form.

For the second phase of the data analysis, additional interviews are conducted to understand the challenge and to investigate more thoroughly. Therefore, the interviews are structured based on the themes from the selection of the problem area from phase one findings. Moreover, the literature review is also adapted to the second phase of data analysis. For the data analysis, the selection of the problem area also enabled the categorization of the themes.

3.6 Data Quality

Validity refers to what is being measured in relation to what the study is investigating. This concept is divided into internal and external validity. Internal validity relates to the performance of the study in relation to answering the research questions and the purpose. External validity concerns the generalizability of the study. It includes whether the results of the study can be implemented and transformed by people other than the researchers involved with case companies (Gustavsson, 2019).

Since this study is a multiple case study benefiting from three case companies, the results are aimed to be replicable by other actors of the foundry industry. Therefore, the generalizability of the study is high considering both OEMs and SMEs in the foundry industry are used for data collection. The selected companies enrich the study by providing a holistic perspective from different parts of the supply chain of castings. The research questions are answered with the triangulation method to increase the internal validity. Moreover, the data collection methods support the purpose and the research questions through accurate interview questions, discussions, and observations.

A concept that is related to validity is reliability. Reliability means whether the study can be carried out by other people or repeated and obtain the same results (Gustavsson, 2019). Since the interview questions are semi-structured and are sent to the interviewees beforehand, any reader can read and understand the results with high similarity to the authors. Thus, the observations conducted are unstructured, and there is no guide to follow which makes it more difficult to repeat the same observations and expect the same results from another person.

To increase reliability and validity, both online and physical interviews are voice recorded. This enables authors to avoid interpreting and having bias on the interview results. Moreover, using themes for structuring the findings reduces bias in analysis and how the results should be presented (Yin, 2018). Therefore, themes are used in this study to structure the empirical findings in the same design for each company for phase one to have a more reliable data analysis.

4 EMPIRICAL DATA

Empirical data in this study is obtained through interviews and observations. Since this is a multiple case study, responses from the interviews for each of the companies are presented separately for each theme. The interviews are then summarized through tables where the main challenges are highlighted for each company. The observations are presented for two of the companies in different themes, and then the key findings are summarized in a table for each company. The chapter concludes with a selection of problem areas.

4.1 Interviews Phase One

The interviews conducted in phase one provide information on the current situation of the case companies. The results of the current situation are conducted based on the themes of materials, supply chain, production, logistics, and sustainability & circularity. Within these factors, different challenges are identified for the companies regarding the demands of becoming circular and sustainable.

4.1.1 Company A

Materials

Company A is a supplier of aluminum (Al) casted components. Company A buys secondary standard alloys from Stena Metall and does not use new virgin material.

Supply Chain

A simple supply chain for Al material is illustrated in Figure 4.1. It is not feasible to have most of the operations in-house and therefore, company A is looking for outsourcing as many operations as possible, which is challenging for the company.

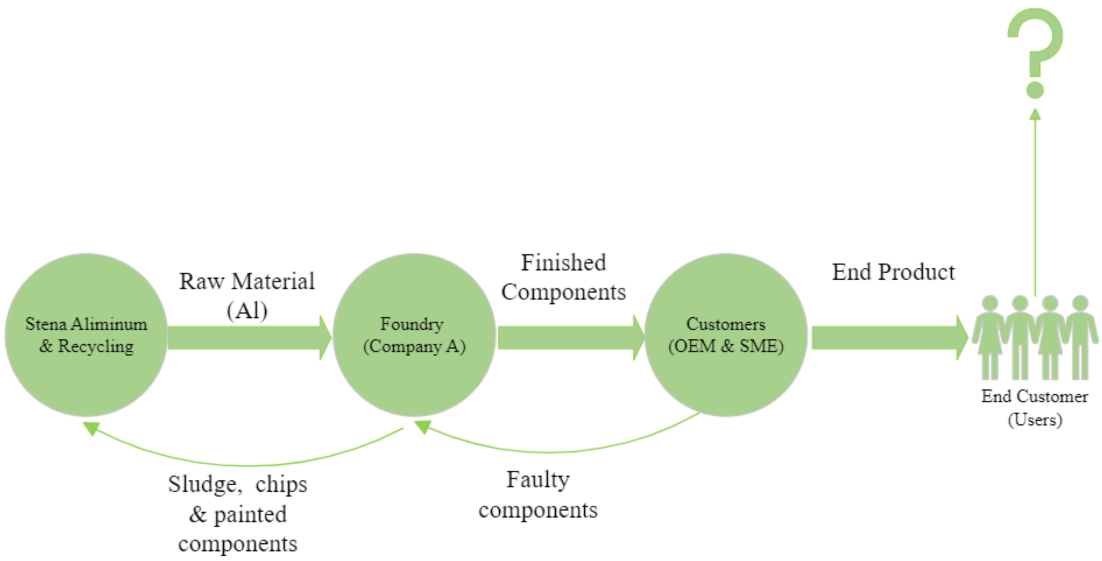

Figure 4.1, Simple Supply Chain Illustrative of Castings at Company A

Within the supply chain, another issue that is highlighted by the Sales Manager (SM) is the contracts. Contracts are not easy to manage for company A when they work with OEMs according to the SM. The negotiation period should be improved every three years according to the SM. The SM also explains that it is very difficult to negotiate the price with OEMs.

<u>Production</u>

SM mentions challenges regarding complying with OEMs' production schedules. He mentions that OEMs use Just-in-Time (JIT) for production schedules and Electronic Data Interchange (EDI) for communication and data exchange regarding volumes and batch sizes. SM quotes "If the quantity is very stable, it is fine. However, if the fluctuation in demand becomes massive, it is difficult to plan for that". SM wishes to have a longer time between scheduling and delivery times to deliver on time. Currently, their order system is frozen two days before the delivery so the customers cannot alter the demand. To make the flow more even, locking the order system for one week would be highly optimal according to the SM. Moreover, the solution for that shall be discussed in the customer contract adds SM.

Company A uses a demand forecast for 12 months ahead of its production and plans its production according to that. The order stock is high at the moment and the company is working overtime to be able to deliver on time. He also mentions that it is difficult to be flexible closer than three weeks to the delivery of the orders. Sales manager quotes:

> If we work with OEMs and we get the order on Thursday and deliver on Monday, they cannot change the order size on Wednesday and expect us to produce new components. This is because we have long production times for lots of products. Our shortest production time for an order is a week and the longest is six weeks to eight weeks. As we have lots of different products, even for the shortest product, it is difficult to have that flexibility within one week because the production planning is full.

Company A wishes to see a minimum of 14 weeks in advance in case of a change in the order. The forecasting is easier with OEMs. It is easier to plan production and make decisions about investments when the company receives a longer-term demand from bigger OEMs. With smaller customers, it is more difficult to identify the needs in the upcoming three years period. If company A need to do an investment, they need five years of demand forecast to take decisions in production.

SM further mentions an issue regarding OEMs. He states that when OEMs change their short-term demand due to poor planning, company A is forced to prioritize OEM customers and therefore the current batch becomes waste. Moreover, if the OEM demands a different product to be casted, set-up times become an issue. Set-up times take about four hours. The first time to start-up the production of a manufacturing order takes even longer than four hours at company A. According to SM, this is an unacceptable situation and financially not viable. Therefore, Company A wishes to produce bigger batches with better planning to reduce set-up times and costs related to waiting.

During the change-over time of a new manufacturing order, some of the parts always go to waste while adjusting the process parameters. The first ten components are wasted during the calibration process due to deviations. This is another shortcoming of changes in short-term demands by OEMs since company A cannot produce its batches according to company B's production planning, the SM claims.

The company works two shifts with possibly three shifts if needed. Ten machines are operating during the day. Five to six machines are operating overnight. Due to operating overtime, the company operates on the weekends. SM believes that this is due to having high order stock in the last two years based on the demand. SM believes that it is better to have high-order stock than to have more frequent shipments. It is easier to plan the production and easier to cast the highest-demanded components.

He also states the importance of long-term planning and demand from the OEMs. When short-term deliveries are demanded frequently by OEMs, Company A must stock finished components to be shipped to OEMs to reduce lead times and eventual shipping delays. When the finished components are stored in the warehouse to be shipped, sales uncertainty becomes an issue for Company A, which results in obsolete products and therefore higher inventory holding costs. Company A complains regarding late orders from OEMs. SM claims that the most optimal situation for them is to have long-term planning and better forecasts.

Logistics

The customer is the owner of the transport. 2PL and 3PL companies are used for transport. The reason for working with external transportation companies is efficiency and price according to the SM. Different deliveries can be shipped to different customers in the same truck through 2PL and 3PL companies. Moreover, the lack of expertise and knowledge in external logistics directs Company A to use external transport companies.

SM indicated that some of the customers do not wish to own the transport and want company A to be responsible for the deliveries. In that case, SM does not believe that it is a good idea. When the company does not own the transportation, the company does not have sufficient impact on the route of the lorries. SM quotes “The deliveries depend on the customers. Whilst some customers come to collect their deliveries once a week, some come twice a week”.

Packaging is a major problem that is discussed by SM. He mentions that some OEMs force company A to use the packaging materials that are provided by OEMs. Buying specific packaging material is not economical for Company A according to the SM. The packaging material that OEMs require has high fees and it could be avoided by using their packaging material. SM adds that the packaging material that they use is made from recycled material. Moreover, the packaging material that is supplied by the OEMs is sometimes not delivered on time. As an example, when the packaging material is delivered on Monday or Tuesday, the shipments are required to be packed on Thursdays or Fridays at company A. In that case, they do not have the time to produce, pack, and store in the warehouse directly with the provided packaging material. For that reason, Company A wishes to be provided with the required packaging material three weeks ahead of the production instead of two days.

Another issue that was discussed by SM is the extra transports that are arranged by company A. When they cannot ship the whole order that is scheduled to be shipped, the company must arrange extra transport with their small truck to avoid production stops at their customers. If the production at the OEM stops due to component scarcity sourced by the supplier, company A must pay a fine to the OEM to cover the stop-time expenses. He also quoted that “this fine could be very expensive and to avoid that, we need to be able to produce parts in time”. The customers are not charged for the extra transportation.

Sustainability & Circularity

Company A uses a combination of electricity and LPG for the melting process in the foundry. SM describes that using LPG for melting Al is highly efficient, however, not a sustainable process. The demand from customers is to be fossil free. However, the goal set to be completely fossil-free by customers varies substantially. Whilst some set the year to be 2035, other companies set 2045. According to SM, the biggest issue in this electrification process is the current prices of electricity and the availability of electricity.

Another problem is the infrastructure of the foundry and the new electricity cables required to be bought to replace LPG. He describes it as a massive investment to be completely fossil-free and these investments would result in increasing the price per product. Despite OEMs’ demands on being more sustainable and fossil-free, they are not willing to pay increased prices for the same products. SM, therefore, adds that they do not have internal goals set to be completely fossil-free.

Almost 100% of the materials are recycled. The waste is remelted in the foundry. The only waste that is not recycled in-house is the chips, slag, painted, and surface-treated components. Chips are pressed and shipped to Stena Metall for recycling. Slag is recycled in Germany since Sweden does not have the facilities to melt it. The painted components cannot be melted in the foundry due to the smoke that is produced during melting. Therefore, they are sent to Stena Metall for recycling. Almost all damaged components are melted back into the foundry excluding the surface-treated components. The company uses half of the material from remelting the waste, and the other half is new material bought from Stena Metall. The purchased material is 100% recycled. SM quotes that “If we would only use scrap all the time, we would lose some of the alloy elements in the aluminum casting alloys, that’s why it is 50/50”.

Another goal Company A wishes to achieve is to reduce wastewater. Water from the tooling and casting process is not recycled or reused. In that sense, SM believes that more improvement could be done in reusing water in the foundry.

SM further mentions that almost all the products are marked with chemical alloy as well as the manufacturing date. Therefore, the products are all traceable. However, in terms of circularity, the products that are shipped to Stena Metall for recycling cannot be traced since they are melted. Company A is paid for selling their waste to Stena Metall. However, when they purchase recycled materials, they do not know if it is the same material that they that is sold to Stena Metall for recycling.

The packaging material that is provided by OEMs is already recycled. Company A’s own packaging material is recycled as well. However, not all cardboard sheets are recycled. The recycled cardboard sheets are covered in plastic foam that is recycled in the supply chain and is circular. Moreover, the company only buys one-color cardboard boxes due to other colors not being recycled completely.

4.1.2 Company B

Materials

The production manager (PM) of the foundry explains that Aluminum (Al) and Magnesium (Mg) are the raw materials used in the casting processes. The standard alloy AZ91 is the most used, otherwise, specific recipes are used for the alloys. Some single alloys are produced only for Company B's use and are patented. The material is sourced from multiple suppliers if they have enough suppliers. This is due to a supply shortage of Mg.

Supply Chain

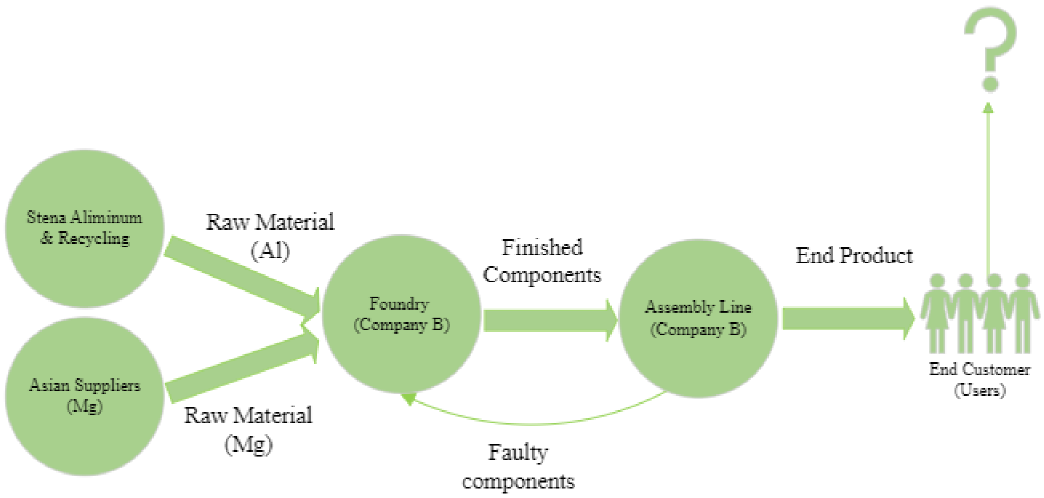

Figure 4.2, Simple Supply Chain Illustrative of Castings at Company B

Company B is a large company with many different functions on site. The foundry is located at the headquarters. Moreover, they also source magnets and package material for the foundry. The company has five sub-contractors for the foundry including three of them supplying ingots. Mg is sourced from China and Al is bought from Stena Metall; Sweden as illustrated in Figure 4.2. The deliveries are received couple of times a week according to the PM. The foundry only supplies casted components in-house and to Company B’s other assembly plants.

Production

PM believes that working with lean philosophy is not highly essential anymore. To follow up with production, Key Performance Indicators (KPIs) are observed daily. For company B, these are people, quality, delivery, and cost. PM mentions that they are implementing JIT with an altered version in their production to secure the ingots in the foundry. Having sufficient ingots enables continuous foundry operations. According to the PM, it is better to have a higher inventory holding cost than to have production stop due to material shortage. She also believes that JIT is to be used downstream rather than upstream of a supply chain. Flexibility is better to achieve in the downstream supply chain actors.

PE1 names JIT as one of the biggest issues for the foundry. When the demand from the assembly lines fluctuates, the foundry is forced to change the product type that they are casting which results in waste and long change-over times. The solution, according to PE1 is to have the correct information at the correct time.

The change-over time is four hours. During the change-over, the employees are not doing their designated jobs. Moreover, production stops, and the change-over work is intensive according to the PM. As an example, the PM quotes:

> Up at the surface treatment, you do not want to have less than batches of 1000 components and it depends on the changeover. That is the minimum amount for the batch sizes. Because then you will not bother to change the model in the surface treatment if we have a 1000 cylinder standing and waiting. That is about ten pallets. You do not want to do less than that unless you absolutely must.

To avoid long change-over times, the foundry has a stock target with the assembly line. 70% of the casted components are delivered directly to the assembly lines. The target is to have two weeks of stock. This reduces the risk of stopping the casting process and starting a new batch. The batch sizes depend on the change-over frequency and the forecast to reduce frequent set-up times. According to PM, they aim to use the same tooling for two weeks of casting job in the foundry.

PE discussed an issue regarding employing trained employees. There are not many trained employees for die-casting processes. Die-casting is a complicated process and therefore, training and education of employees take time.

<u>Logistics</u>

PM mentions that, often, company B’s transport agreement is used when they work with suppliers. She says that it is often the bigger manufacturing companies that have better-planned routes and transportation solutions.

The batch sizes are adapted based on the order forecast and volume. In terms of orders, company B plans 12 months ahead based on the forecasts. When the delivery dates are closer, the demand becomes more uncertain.

For the suppliers that are close by, a special packaging system is used that enables high recycling. The pallets and packages are circulated between the supplier and the foundry, and within the organization of company B. She highlights the importance of the packaging system where their suppliers become a member of such a system. PM mentions that this is a sourcing strategy, and the suppliers must use this packaging system if they are supplying to company B. The reason for using such a packaging system is connected to the automation system used in the foundry of company B. The robots are handling the packages and boxes in the foundry and the assembly lines. This is also a cost-effective solution according to PM since it reduces the extra purchasing cost of packing materials.

One challenge mentioned with the packaging material is the shortage of cardboard boxes. PM further quoted that “When the suppliers do not get enough boxes back, they complain, but the agreement says that they are allowed to buy a specific type of packaging. They also buy directly from our packaging suppliers because their operation needs to keep going". When the suppliers are provided with the packaging material, they are charged for it since they do not have to buy their packaging material.

Sustainability & Circularity

Regarding circularity and sustainability, the PM believes that company B can be more sustainable than it is currently. There is no possibility to know if the end products are recycled. Even though they are marked for traceability, this traceability only supports quality errors and defects. It is not possible to know if the products are reused or recycled once the end-user purchases the goods.

There are not many foundries that work with Mg in Sweden and therefore it is an issue to recycle Mg. PE1 further mentions that when they purchase Mg, they do not know how much of the Mg is recycled in the ingots since it is bought from China. Mg slag and chips are very difficult to recycle in-house. The PM also mentions that it is not certain that Stena Metall recycles the Mg completely. The company intends to ship the Mg waste to the US where Mg can be recycled. However, due to its highly flammable properties and the complicated paperwork of shipping, it is highly difficult to transport the Mg waste to the US.

When faulty products occur after it is shipped to the customers, they are recollected. Since the end product is painted, and has bolts and screws, it is not possible to be recycled in-house. Therefore, it is shipped to Stena Metall. In terms of Al, everything is recycled and reused except for slag and chips. Stena Metall recycles slag and chips two times more than company B can.

A goal of company B is to recycle painted components in-house since painted components cannot be recycled currently in the foundry. A highly significant concern for the foundry is the melting system. The company is looking for electric solutions such as induction ovens. PE1 quotes "If the company is not using coal as the primary energy source, it is going in the right direction".

Foundry is 90% electric. Only the melting furnaces use LPG which corresponds to 10% of the foundry operations at company B. PE1 has tried to calculate the investment opportunities for inductive furnaces, however, regardless of the electricity prices, it was still a very costly investment that the board of company B did not approve. He claims that LPG is not beneficial for the environment and the locals have been complaining about the dust and the noise created by the foundry. Authorities have been demanding to keep the level of dust lower. PE1 finds it difficult and works towards collecting the dust directly from the machines more effectively.

It is a big modification to move from LPG furnaces to induction furnaces for the melting process. The company had attempted to buy greener LPG, however, the LPG supplier only offered company B to purchase 100% green LPG which company B could not afford. PE1 believes that it is not a good decision since the price difference is not high.

The energy consumption is mostly capitalized from the heating of the furnaces. The melting and heating of the die consume energy as well as the cooling processes. PE1 believes that to save energy, they are considering operating five days a week and pausing operations from Friday to Monday. In that case, the machines would be turned off. This is an ongoing project to save energy. However, it is not certain that it will save more energy. Furthermore, PE1 mentions that it is not possible to use induction furnaces for cost-saving due to high electricity prices, however, it is a good initiative for environmental sustainability. Therefore, he believes that the whole organization should move towards the same goals. The top management shall dedicate themselves into this transition. The internal goals and strategies should be aligned within the bigger organization.

PE1 interprets the foundry industry as highly conservative and comfortable. The foundries have been working with the same processes for over 50 years and nobody wants change. He believes that the most optimal solution for being sustainable is to produce the parts correct the first time. Every scrap part that is produced due to quality issues become waste. It results in more time, money, and energy. Therefore, stable processes are key to being more sustainable.

4.1.3 Company C

Material

The Logistics Manager (LM) explains that Iron is their most common raw material in the casting process as well as Al. The foundry mixes its own alloys. This means that they do not purchase finished alloys and do not use standard alloys. Their foundry uses ten different alloys where Zinc and Magnesium are commonly used materials.

The LM further describes that it is a challenge to work with a proprietary system with alloys. Quality testing is one of the major challenges regarding the material. It is challenging to produce products exactly according to plan and to achieve expected results when the company works with its own alloys.

Supply Chain

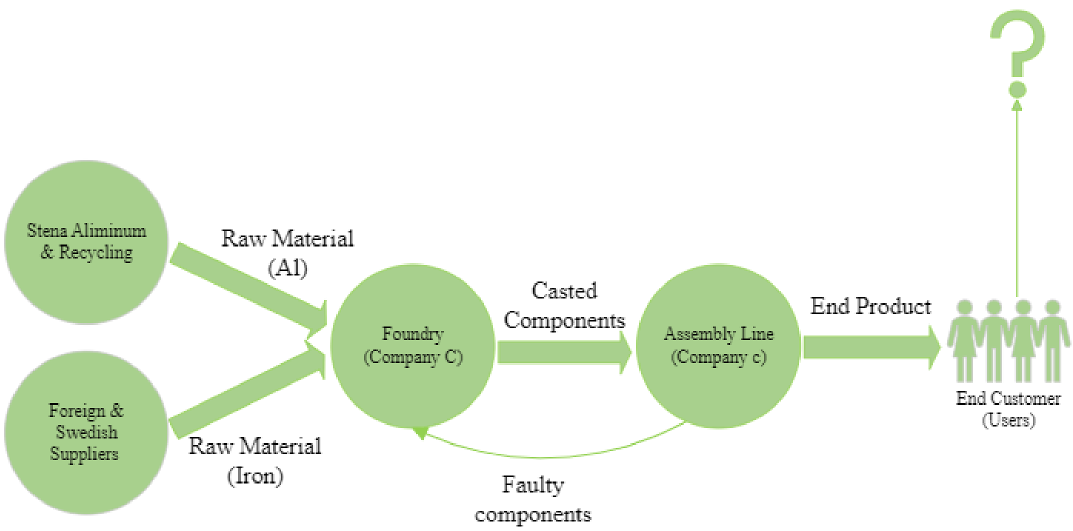

Figure 4.3, Simple Supply Chain Illustrative of Castings at Company C

Company C belongs to the automotive industry, where the foundry produces components for engines. The company only molds components for their own units and production as seen in Figure 4.3. A lot of raw material is purchased from several subcontractors as well as components from suppliers.

Furthermore, the LM says that they buy very specific materials and components because they produce unique engines. Usually, they have a specific subcontractor for a specific material, but there are also several subcontractors that supply the same material to the foundry. The durability and the preciseness make it hard to find suppliers for blanks for machining.

In terms of subcontractors and suppliers to foundries, the company has about 20-40 different ones. The suppliers are located both locally in Sweden and globally. The highest volume of purchased components and materials is purchased from Sweden. The LM informs that it is not common to localize the desired material. Therefore, there is a maximum of 1-2 suppliers of the desired materials. This allows for a tougher selection process as the company must use the suppliers available on the market.

The company has specific packaging requirements for its subcontractors. The requirements are very strict because of the cleanliness requirements, the LM explains. They have engineers who work specifically to provide the subcontractors with packaging and help with the packaging process. The subcontractors are paid to follow the packaging requirements of the company.

The selection process of subcontractors consists of various projects, research, and negotiations by the purchasing department. One requirement that the company places on the subcontractors is to reduce lead times. The LM explains that it depends a lot on the inventory management and whether the company wants to be responsible for the inventory management itself or keep the inventory at the subcontractor. Sustainability is also a factor that is taken into account as it is part of the company's vision, mission, goals, and principles.

The main challenges with subcontractors vary depending on the subcontractor, but quality and delivery times are common. This means that subcontractors do not deliver according to the agreed quality or delivery time. The LM believes that the main challenge their subcontractors and suppliers usually complain about changes in production planning. The subcontractors and suppliers experience difficulty in being flexible and adaptable to changes in the predetermined planning. If problems in assembly occur at company C, the suppliers, and subcontractors must adapt to their schedule change. As a result, the subcontractors find it difficult to supply to company C.

<u>Production</u>

Production works in five shifts because the foundry needs to be operating continuously. If the machines in the foundry are turned off, it can take one to two weeks before the machines are operating again.

The system implemented in the production is a two-way Kanban system. The choice of the Kanban system is because it is simple and easy to work with buffers when there is limited space. JIT is a planning philosophy that is implemented variously in the company's processes, the LM explains. The foundry cannot perform JIT correctly because the molding process is unstable and slow, which requires buffers. The assembly works with JIT which requires the foundry to deliver casted components to the assembly according to JIT. Hence finished components are kept in stock for a maximum of one to two days, or less.

The LM believes that the lead times that occur in production are due to waiting and quality controls. The quality checks for a whole batch take 24 hours to complete. The checks are carried out at different checkpoints in the molding process. Downtime also occurs when the machines change programs from one product to another. Finally, the longest lead time is to get a molded component approved to be sent to the assembly according to the LM.

The biggest challenge facing the foundry is currently the transition to a new fully electric foundry. The foundry is a living process that is very difficult to manage according to the LM. Expertise is also a challenge as it requires time and skills to learn new machines and processes as the melting is done in electric melting furnaces. Also, a lot of changes towards digitalization is a difficult process to adapt to for both the workshop employees and the management.

Logistics

The logistics process consists of an extensive flow in and out of the foundry. Several different means of transport are used, such as ships, trains, airplanes, and trucks. The transport is owned by both Company C and external firms. The LM explains that the external firms are transport companies working under the same organization as Company C. Company C has extensive security which requires reliable transport and transport companies.

The main problem with the logistics process is that the deliveries are delayed to the foundry. Deliveries of raw materials to the foundry are delivered daily in varying batch sizes and packaging. The subcontractors have individual delivery schedules, with some delivering to order. Some subcontractors also have regular deliveries under the contract.

Storage space is also a challenge, according to the LM. Company C has different standardized processes for inventory management where the safety stock is calculated according to the number of days the stock covers. There are also standards for when the stock level falls below the safety stock level. The stock for castings is calculated according to how many days they can supply the assembly with components. The length of stockholding varies depending on the product. Some products that are produced by a single machine need a large buffer because the company is very dependent on the machine working well, the LM explains. Furthermore, some molding components require a three-to-five-day buffer, while others require much longer.

The company's inventory strategy is to take a risk and keep inventory as low as possible. The inventory is mainly dependent on the reliability of the molding process, so they need inventory to be flexible in production. Finished components in foundries are sent almost directly to the assembly or are kept for a maximum of one to two days.

Sustainability & Circularity

The LM considers sustainability to be one of the company's core values. They strive to be a leader in sustainability in the market and it is considered in all processes. Regarding circularity, the LM believes that the company is doing everything it can to contribute to a circular economy.

The recycling process in the foundry is very circular internally. If casting components become obsolete in the manufacturing process, they are re-melted and reused in the same process. The recycling process varies depending on where in the process the component becomes obsolete. For example, surface-treated castings cannot be recycled within the company, the LM explains. Surface-treated products are shipped to an external waste management and recycling company. Surface-treated products are shipped to an external waste management and recycling company.

Furthermore, the management of sand in the molding process is intended to be circular. The LM explains that it is a difficult material to work with because it gets stuck in different filters in the machines. The recycling of the chip residue is also a challenge. The company has calculated and implemented a standard to recover as many chips as possible from the machines. Residual products that neither Company C nor external firms can recycle are sold as scrap.

Regarding traceability, this is something that works well in the foundry. The company has good traceability on all casted components, but they have poor or no traceability in the machinery. The biggest challenge regarding traceability is digitalization. For example, scrap that they transport to external recycling companies has no traceability or circularity. The reason for this is that the company does not know if the same scrap returns to the foundry as a recycled secondary raw material. The process works in that they sell scrap to an external company and then place a new order for recycled raw material from the same company, the LM explains.

The LM says that the main sustainability challenge is the amount of electricity the foundry requires. The company tries to reuse all the heat from the foundry and has its solar panels to produce sustainable electricity. Finally, the LM explains that they will never be fully sustainable because of the characteristics of the automotive industry.

4.1.4 Summary Interviews

To achieve the purpose of the study and answer the research questions, the most important outcomes of the interviews have been summarized in tables for each case company. The tables are organized according to the themes of the interviews with associated challenges in each theme, as well as a short description of the challenge. The themes presented are the ones with associated challenges. If a theme is excluded from the table, it means that the company does not experience any significant challenge regarding that theme. The tables are presented respectively for each of the case companies.

Table 4.1, Summary of Identified Challenges for Sustainability and Circularity at Company A

THEME	CHALLENGE	DESCRIPTION
Supply Chain	Outsourcing operations	It is not feasible to have most of the operations inhouse
	Agreemenst with OEM customers	Difficulties in negotiation prize and the negotiation period should be improved
Production	Adjusting to customers with JIT	The casting process is not stable enough to be able to adjuts to JIT
	Fluctations in demand	Hard to change production scedules when there is fluctations
	Short freeze time in the planning system	The order systems freezes two days before the delivery which creates an uneven flow
	Flexibility closer than three weeks of delivery	Cannot change the production plan closer than three weeks. Long production time for castings
	Difficult to identify the demand long-term with SME customers	SME customers have a hard time forcasting demand
	Forced to prioritze OEM customers	When short-term demand changes, the company needs to waste the current batch and change the production.
	Set-up times	Long set-up times in the foundry. When changes needs to be made in the planning, there are long set-up times.
	Working overtime	High order stock and changes in the demand cause working overtime
	Casting process not being stable	The machine's calibrations fluctuate and problems with electrical equipment occurs when measuring the speed and the pressure of the machines
Logistics	Lack of expertise and knowledge in external logistics	Using 2PL anf 3PL transportation comapnies and which reduces the control over the logistics
	Packaging material	Forced to use OEM customers packaging material.
	Deliveries of packaging material	Late deliveries
	Extra transportations	When they cannot ship the whole order that are scheduled to be shipped, the company must arrange an extra transport
Sustainability & Circularity	Using LPG in the melting processes	Not a sustainable fuel
	No external circularity	Only internal circular processes
	Customers demanding the company to be fossil free	The company lacks internal sustainability goals. The demands fom customer vary
	Becoming fossil free	Electricity prices and the demand for big investments for electricty cables and new infrastructure
	The price for being sustainable	OEM customers are not willing to pay for sustainable components
	Reduce waste water	Water from the tooling and casting process is not recycled or re-used

Table 4.2, Summary of Identified Challenges for Sustainability and Circularity at Company B

THEME	CHALLENGE	DESCRIPTION
Material	Supply shortage of Magnesium	Magnesium is a rare material
	Long transportation time for the material	Magnesium is shipped from China
Production	Just-in-Time	When the demand from the assembly lines fluctuates or are planned badly, the foundry is forced to change the product type that they are casting which results in waste and long change-over times
	Change-over-time	Long change-over time in the foundry
	Separate ingots and the scrap from the alloys	Time consuming during change-overs. Especially for Mg alloys that they send away for recycling.
	Workforce	There are not many trained employees for die-casting processes
Logistics	Packaging material shortage	
Sustainability & Circularity	No tracability for recycling the end-products	The current tracability is only used for quality issues
	Issue to recycle Mg	Mg slag and chips are very difficult to recycle in-house and externally
	Material loss in re-metling process	Have to add new material in the processes
	Cannot reuse slag and chips	Needs to be sent to Stena Aluminium to be recycled multiple times.
	Melting system in the foundry	The company is looking for electric solutions such as induction ovens. Melting furnaces use LPG at the moment.
	Water, air pollution and noise	Since the foundry is in the city, the company works with reducing the noise for the locals living nearby.
	A big modification to move from LPG furnaces to induction furnaces for the melting process	The price is to high to use electricity or "green" LPG.
	Energy consumption	High energy cunsuming processes in the foundry
	Sustainability goals not aligned in the organisation	The whole organization should move towards the same goals. The top management shall dedicate themselves into this transition. The internal goals and strategies should be aligned within the bigger organization.
	Conservatie and linear mindset in the foundry	The foundry industry as highly conservative and comfortable. The foundries have been working with the same processes for over 50 years and that nobody wants change

Table 4.3, Summary of Identified Challenges for Sustainability and Circularity at Company C

PROCESS	CHALLENGE	DESCRIPTION
Material	Working with proprietary system	Challenging to work with their own alloys and recipies
	Quality testing	It is challenging to produce products exactly according to plan and to achieve expected results when the company works with its own alloys.
Supply Chain	Delivery conidiitions of suppliers	Subcontractors do not deliver according to the agreed quality or delivery time.
Production	Changes in production planning	When problems in assembly occur, the suppliers and subcontractors must adapt to company C's schedule change. As a result, the suppliers find it difficult to supply Company C
	Machines downtimes	If the machines in the foundry are shut down, it can take one to two weeks before the machines are fully operating again.
	JIT cannot be implemented in the foundry	The moulding process is unstable and slow, therefore, it requires safety stock.
	Learning and managing new technologies	It requires time and skills to learn new machines and processes.
	Digitalization in production	Difficulties in adapting to digital production
	Long lead times in production	Lond lead times due to waiting and long quality checks
Logistics	Delay in deliveries	
	Storage space	
Sustainability & Circularity	Material not being collected from the machines completely	The material gets stuck in different filters in the machines
	Recycling of chip residue	Chip recidue cannot be recycled by any company in Sweden
	Lack of circularity tracebility	The company ships their waste to be recycled externally. However, the company do not know if the same scrap returns to the foundry as a recycled secondary raw material.
	Electricy use	High processes and low availability of electricity
	Possibility of never being 100% sustainable	Due to being in the automobile industry

4.2 Observations Phase One

The observation carried out contributes to the study with an understanding of the foundries' behavior and processes.

4.2.1 Company A

Facilities & Production

There are two ovens for melting in the foundry. The material used in the foundry is only aluminum (Al). There are many sludges around the machines. There are many robots utilized in production. The maintenance is done in the same facilities as the casting. There is a line for the forklifts to go through, but it is not well defined. After that, machining, and tooling beings. Many changes are happening in the machining process regarding lean. The flow of production is intended to be improved. Therefore, they are moving the machines and robots to have the most efficient flow. 5S technique from lean is implemented in the workstations.

Warehouse & Logistics

The warehouse is another facility that is connected to the die-casting, and machining. The products are stocked in batch form. The outbound process is located right by the warehouse and there are lots of space for the incoming trucks. During the observation, there were no trucks entered in or out. The packages of the finished components were on pallets and pallet racks for the outbound process. Storage for the incoming material is also stored in the warehouse on pallet racks. Storage for the raw material is not observed in the production site, except for the ones seen in the foundry waiting to be melted on the pallets. The ingots are located close to the ovens for melting.

Waste Handling

A clear waste management system is observed in the foundry. There are different bins in the colors blue, red, and green where the different alloys are sorted. The SM explained that the sorting is when the alloys are melted again, they cannot be mixed and must be melted separately. The trays are palletized at each process/machine to allow easy sorting of obsolete components.

Quality controls are located at several different stages of the foundry process and production. A few controls are automated where a robot performed quality controls and sorted the components into approved and unapproved. The robot performed checks on very small components. The components that are not approved are sorted into a box, to be transported away for remelting. Most of the quality checks are carried out manually by operators, but the process resulted in a similar approach. There are chips everywhere on the floor of the foundry. These are the chips that the SM describes as difficult or impossible to recycle.

4.2.2 Company B

Facilities & Production

There are two Aluminum (Al) furnishes and three Magnesium (Mg) furnishes. The Al furnishes are in a separate room whereas the Mg furnishes are by the machines to transfer the fluid melted Mg directly into the machines without making ingots from them. Al waste is added directly to the melting process.

Warehouse & Logistics

The incoming ingots are held in the area before the foundry. The company receives Mg once a week, 25 pallets. Each pallet holds approximately one ton of Mg ingots. Al is received twice a week from Stena Metall. Each delivery consists of ten pallets of Al ingots constituting 20 tons of Al ingots per week. The amount of Mg and Al delivered per week is enough for one week's production. The finished goods are stored in the warehouse and later to be shipped to facilities nearby or other facilities around the world owned by company B.

Waste Handling

In terms of sustainability, waste handling is observed thoroughly. The sludges are stored in buckets around the furnaces to be sent to Stena Metall for recycling. There are not many sludges on the floor, they are well-collected. When the buckets are full, they are transferred to small containers.

In terms of chips, each machine has its box where the waste material is transferred to the boxes underneath. The chip from machining is collected in red boxes. Later, they are composed of oil to decrease the size of the chips. When the boxes are filled, they are sent to Stena Metall.

4.2.3 Summary Observations

The summary of the observations is presented in Table 4.4 for each company that is observed.

Table 4.4, Key Findings Identified from the Observations at Company A and Company B

Key findings	Company A	Company B
Facilities & Production	Multiple Quality Controls. Both manually and automated	Automated Quality Controls
	Ingots located near the furnishes	Ingots located near the furnishes
	Two furnishes for Al melting	Two furnishes for Al & Three furnishes for Mg melting
Warehouse & Logistics	Flow of the production is improving	One delivery for incoming Al & Two deliveries for the incoming Mg per week
Waste handling	The different wastes are separated in coloured boxes.	Waste is separated to be remelted in-house or sent to Stena Metall.
	Chips around the machines	Well collected chips in the buckets

4.3 Selection of Problem Area

The selection of the problem area is to further investigate an important challenge in the foundry industry. This factor is based on the significance of impacting the sustainability and circularity of an SME within the delimitations of this thesis. The selected challenge is to be addressed in research question two.

Based on the collected data, adapting to demand fluctuations is a frequent and major problem for an SME, company A, as displayed in Table 4.1, company A is encountering problems in supplying to larger OEM customers due to demand forecasting uncertainty as repeatedly mentioned by the SM. Also, the challenge is the root cause for other challenges, for example extra transports and waste in the production. By facing the challenge of demand fluctuations, other challenges might be solved. Therefore, the report investigates the challenge for SMEs to adapt to OEM customers demand fluctuations.

4.4 Interviews Phase Two

To understand the causes for the challenge with demand fluctuation at the SME foundry, further data collection through interviews is conducted at one of company A's OEM customers. The selected themes are purchasing, sourcing, and material planning regarding purchased casted components for Company B's assembly lines. The aim of phase two is to create a holistic view of the cause and effect of the challenge, from the perspective of the supplier and the customer.

4.4.1 Company B

Purchasing

The Commodity Manager (CM) at Company B works with the purchase of cast components from external companies for assembly. The products purchased include cycle cylinders, pistons, powder metal parts, and clutches. These components are made from the raw material aluminum, the CM explains.

The main challenge with suppliers for molded components is that there are too few suppliers on the market. This means that customers cannot be too demanding and need to be humbler, so long-term relationships are very important. For purchased molded components, the strategy is always to focus on long-term relationships. Since the market is very niche and involves complex products, it is important to protect these relationships. However, if there is a new supplier that can generate a good deal where the company can make a lot of money, it is something that is challenged to increase sales, the CM explains. The contracts with suppliers consist of a framework agreement that is valid for 3-5 years usually. However, the agreement works in such a way that suppliers need to terminate it, otherwise, it is an open-ended agreement with no time limit. Over the years, prices are negotiated to adapt to changes in the market and the business environment.

The CM believes that the suppliers' main challenges with company B as an OEM are the tough demands on price and quality. Delivery times are often something suppliers are very understanding of and adapt to. However, the material planning system can be a challenge because the system is not functioning as it is supposed to. The CM says that orders are sent for the next 12 weeks. After that, depending on the geographical location of the supplier, the order enters a freezing zone where no changes can be made. It is important that the supplier is prepared and aware of the forecast.

If problems or complaints arise from suppliers, a root cause analysis is always carried out. Sourcing then communicates with different departments and processes to see what happened; the CM explains. After the analysis is done, the sourcing department can explain to the supplier what happened and then make sure to improve for the future. However, material planning is often a problem where some suppliers are always disappointed. The CM claims that some suppliers are disappointed because they feel that company B makes too tough and unreasonable demands.

For example, if there is a quality problem with the supplier, different standards are applied. The CM explains that the size of the problem is first assessed, and then a team is set up to investigate the problem. This group is called a technical counsel, which, together with the relevant quality department, investigates the problem.

Depending on the geographical location of the supplier, obsolete components are treated differently. The CM says that they always ask the supplier if they want to have the goods returned or if the components should be scrapped. Sometimes a third party is appointed to sort the defective batch and then decide what should be scrapped, reused, or shipped back to suppliers. The biggest factor considered is the price when these issues arise.

Sourcing

The company applies mostly single sourcing but in a few cases multiple sourcing with two suppliers. The choice of sourcing is mostly assessed based on the level of risk and satisfaction with the current suppliers. The risk usually involves lead times, tooling development, volume, and demand.

Sustainability is not a factor that is considered when selecting suppliers. The main factors are a global approach, volume, capacity, interest, and long-term relationships. Sustainability in supplier selection is becoming more important, says the CM. Currently, sustainability managers in sourcing are working to improve the sustainability aspect. However, the CM believes that they should have started working with sustainability at an earlier stage. However, there are no main areas in sustainability that are particularly interesting, and they have no KPIs that they measure in sourcing. In the past, the problem has been that employees have not had the time to spend on sustainability, the CM believes. Employees have enough to do with their regular duties, so we need people working full-time on sustainability. Circularity is also something that is excluded from the sourcing process.

Materials Planning

The supply planning at company B is explained by the Material Planning Manager (MPM). The supply department generates a demand forecast from the customers. To produce the finished product, the supply department directs the customer demands in their systems for further planning. Then, the production and materials planning department creates a production plan. Based on the production plan, demand for incoming materials and components is generated. MPM mentions that company B purchases the majority of the casted components from Asia, however, the company has a few suppliers in Sweden for casted components.

The delivery schedules are sent weekly to the suppliers. Depending on the delivery lead times of the suppliers, orders are frozen. This is two weeks for the Swedish suppliers and 15 weeks for the Asian suppliers. After the freeze time, orders are not to be changed. MPM also added that it is highly common to not have demand fluctuations until the freeze weeks. Fluctuations in demand occur instantly during freeze time where company B contacts the suppliers for rescheduling of orders.

Company B implements JIT in its assembly line. The MPM believes that flexibility is highly crucial to enable JIT. PE2 also mentions that JIT is implemented at the assembly lines at company B, but not as much for purchased components, mostly for their products. Otherwise, lean production is implemented throughout having low stock and minimizing waste. For JIT to function, the MPM highlights the importance of communication, transparency, and good relations with suppliers. Company B has had higher success working with Swedish suppliers than Asian suppliers due to Asian suppliers' attempts to ship bigger batches. However, this results in higher inventory holding costs according to the MPM. He wishes to receive smaller batches; however, he names logistical issues such as the risk of lost components that could occur with frequent deliveries. Furthermore, MPM mentions that their production line is too flexible. He quotes:

> We are too flexible. We are more flexible than we should be. We can take a production order planned for three weeks and throw it in tomorrow. We would try to get the lines roll in but that would have consequences in production order.

PE2 explains that a key challenge with suppliers is the information flow. Issues occur for company B when they do not receive information about challenges encountered by the supplier. The issues can be, for example, when the supplier cannot deliver the order. When that information is not communicated, it causes problems at the assembly lines at company B. Further, quality defects that reach the assembly line cause a lot of issues and most of the order becomes scrap. PE2 mentions that the components should be quality tested earlier in the process before the assembly line, therefore they assume that 100% of the components are quality checked. When a hidden fault is found, they need to do a quality check of the whole batch.

MPM further mentions the capacity of the suppliers has been an issue. Suppliers cannot increase their production output to satisfy company B. Moreover, the competence of the suppliers in the foundry industry is not sufficient. Suppliers have also reportedly had complaints regarding demand uncertainty. This is due to the implementation of a new ERP system according to the MPM. The delivery schedule is not accurate. Regardless of the new ERP system, he also mentions that since the end customers are private persons and other businesses, it is not easy to forecast the demand and create demand for the suppliers. Matching the production plan and the delivery schedule sent to the customers is a vital issue that Company B is encountering.

To improve the situation, MPM believes that the freeze period in the order system in the last weeks of the deliveries should be for a longer period. However, since demand changes occur frequently closer to the delivery dates, it results in higher material stock for certainty in production. MPM quotes “Another thing to do is to build up safety stock for items and we would be more flexible but then we would have higher stock-keeping costs”.

5 ANALYSIS

This chapter answers the research questions by analyzing the collected data against the literature review. The answer to first research question is answered through a structure where different challenges are presented according to the themes implemented during data collection. The second research question is answered by analyzing possible solutions to the chosen problem according to the literature. The chapter ends with a proposal for improvement where the problem, causes, recommendation, expected effect, and priority are presented.

5.1 What are the challenges that Swedish foundries are facing regarding the demands of becoming circular and sustainable?

The first research question is answered by identifying the challenges of SME and OEM companies in the foundry industry. Further, the cause of the challenge is explained as to why it is a challenge for becoming more sustainable and circular, where theory and empirical data are compared. Lastly, the challenges are prioritized according to the effect of the challenge and the possibility to create an improvement suggestion.

5.1.1 Material

Based on the data, an SME in the foundry sector does not experience any challenges related to the sustainability or circularity of materials. This is because they use standard alloys and readily available materials. However, materials are a bigger challenge for OEMs in the foundry industry. Table 4.2 and Table 4.3 present four different challenges. OEMs usually work with proprietary systems and their own patented alloy recipes. This leads to challenges with quality control, as proprietary products do not follow a standard, and it is a challenge to achieve expected results.

This complexity of products and materials leads to challenging reuse and recycling processes, which will lead to even more challenges in a circular economy. The complexity of the products increases the use of third-party companies for recycling since OEMs or SMEs can’t recycle everything in-house. However, this is challenging the transport system and infrastructure when being more circular since it requires more transportation (Gianmarco et al., 2019). External transport affects the environment through emissions, among other things. This leads to negative impacts on the greenhouse effect, eutrophication, acidification, depletion of the ozone layer, broken cycles, and exploitation of nature. The environmental impact is further affected by frequent transport (Jonsson & Mattsson, 2016).

External transport should be carefully selected when implementing third-party logistics (3PL). 3PL is used by both SMEs and OEMs in the foundry industry. The choice of an external partner should be carefully selected based on the third party's commitment to a green supply chain. Third-party partners should therefore use sustainable fuel for transport, although this is rare (Novack et al., 2019).

As OEMs work with strategic choices of more unusual materials, material- and subcontractor availability are very limited. As a result of these limitations, OEM foundries must cooperate with existing subcontractors as the choice of subcontractors is limited. This means that many subcontractors are geographically located far away from the foundry, usually in Asia. This affects sustainability since transport has a negative impact on the environment. It is even more negatively affected by long-distance transport. OEMs that have long distances to their suppliers and subcontractors contribute to increased emissions from long-distance transport. Also, the transition to a circular economy with circular molded components/products is affected. This is because the circular economy requires final products to be transported back to the supplier from the end customer, in order to be recycled or reused (Gianmarco et al., 2019). This leads to an increased negative impact on transport and hence, emissions (Jonsson & Mattsson, 2016).

The main difference between SMEs and OEMs in the foundry industry regarding materials is that SMEs produce standard components while OEMs work with proprietary products that are unique to their company. This difference is because companies are located at different stages and processes in the supply chain. SMEs produce standard molded components for many customers, both large and small, while OEMs produce and purchase molded components/products for their own production. OEMs' foundries only supply castings within their own organization and do not sell to external customers.

The challenges in materials mainly affect OEMs but are not considered a high priority because the consumption of materials and subcontractors is difficult to impossible to influence at present. The affected materials, such as magnesium, are not found in Sweden, hence there are no sustainable subcontractors given the distance.

5.1.2 Supply Chain

SMEs experience two identified challenges in the supply chain. Table 4.1 first presents the challenge of outsourcing operations. For SMEs, it is not possible to have all operations in-house. Therefore, SMEs try to outsource as many operations as possible with appropriate supply chain partners. The availability of suitable supply chain partners is judged to be a challenge for the circular economy by three previous studies. This becomes a challenge for SMEs in the foundry sector as they need to find partners that match the company's approach and principles. However, there is a lack of such partners. This complicates the flow of materials, as well as customer satisfaction. A matching partner in the supply chain needs to have a circular business model otherwise it can lead to a conflict of interest (Gianmarco et al., 2019; Kumar et al., 2019; Sousa-Zomer et al., 2018).

Furthermore, contracts and agreements with larger customers in the supply chain are a major challenge for small foundries. This challenge is due to small foundries not having much bargaining power and need to follow the price demands of the large parties. OEMs, on the other hand, experience challenges with their subcontractors when they do not deliver the material according to the agreed contract, as presented in Table 4.3. This can concern, for example, quality and delivery times.

A few challenges were identified in the supply chain. Mainly SMEs are affected by the challenges where it is assessed that the contracts and the relationship with their OEM customers are the main challenges.

5.1.3 Production

The identified challenges in Table 4.1 are highly related to production planning and order flexibility in the foundry of the smaller company. SMEs are encountering the use of JIT as an issue when working with suppliers. Since it is difficult for SMEs to adjust the production and delivery schedules based on their customers' production schedules, order fluctuations from the customers result in deviations and waste of material for the foundries.

Forecasting is identified to be a challenge for the SMEs. When the forecasting from the larger customers is not accurate due to last-minute orders, the smaller foundries are forced to prioritize larger customers over smaller customers due to the bargaining power these companies possess.

As the last-minute orders from larger customers are prioritized for SMEs, based on the process, the casting process could be stopped. Therefore, the material used as well as the heat, electricity, manpower, etc. can become waste. This waste consists of all three dimensions of the triple bottom-line approach. It increases environmental waste such as waste material, waste of energy for heating, electricity, etc., economic waste of requiring more material and personnel, and social waste (Bals & Tate, 2016).

As Torielli et al. (2011) mention the lean wastes in foundries, the waste that occurs from stopping production and casting a new batch is unnecessary processing and overproduction. This causes energy waste, emissions of internal transports, increased damage and spilling risks during transports, unnecessary raw materials consumption, extra emissions, and employee exposure to chemicals. Therefore, the challenge receiving of last-minute orders results in many complications and sustainability problems for the SMEs. As change-over times are very long in the foundries, changing equipment for casting another batch could result in unnecessary waiting which is another lean waste mentioned by Torielli et al. (2011) resulting in energy waste from heating and cooling of the machines.

Working overtime is another challenge that SME foundries encounter due to uneven planning and last-minute orders from their OEM customers. The smaller companies believe that stocking is a good solution for encountering this problem. However, this issue is categorized as excessive inventory according to Torielli et al. (2011) which implies environmental harm due to higher energy use and extra stocking material.

JIT supports producing small batches and frequently delivering to the customers (Heck & Vettiger, 2014). By definition of JIT, since relatively smaller batches are not possible for foundries, the stocking and higher inventory costs are more present in foundries despite the negative environmental outcomes. These negative environmental outcomes for holding excessive inventory are displayed as more energy used to preserve finished goods and the raw material that are procured, energy used to preserve the inventory, and extra packaging (Torielli et al., 2011).

While lean principles suggest the reduction of stock keeping through JIT as mentioned by Prasad et al. (2016), it is highly difficult to implement JIT due to the long change-over times, which makes small batches not sustainable for the foundries. Smaller batches may result in large electricity and propane gas used for re-heating the ovens. During the change-over times, the employees do not operate actively which is not economically sustainable for companies to pay salary for an employee who does not work efficiently.

The reason for the challenge of production planning not having similar effects for OEMs is due to larger companies' foundries only supplying to their facilities. In this case, SMEs are supplying many different customers. For instance, OEMs are found to encounter challenges in adapting to new technologies in the foundry as well as training employees for the use of new machines.

As for the larger companies, the foundries are having the more significant issue for quality and the time loss during quality checks due to casting is an unstable process. This is also mentioned by the SME which creates a common problem for the foundries. Therefore, in terms of production, some of the issues are common for all types of foundries in Sweden whereas other ones differ from the type of operations the foundries follow, the customers, and the company size.

5.1.4 Logistics

In Table 4.1, four challenges in logistics are identified for the SME. The first challenge is based on the use of external logistics, which leads to reduced control and influence over the supply chain. Even though logistics has a large environmental impact, companies that use outsourced logistics cannot control the environmental impact, except for the choice of which external partner to work with. If companies in the foundry industry want to become sustainable and move to a circular economy, the choice of a third-party logistics provider must be considered. Companies using 3PL must choose a partner that contributes to sustainable transport, such as fossil-free transport (Novack et al., 2019).

The logistics that SMEs have control over are when they need to carry out extra transport to their customers. This challenge arises when the foundry cannot send the entire order on time to the customer. In this case, the foundry sends a port of the order that they have in stock each day until the order is complete. This is to avoid production stops at the customer's site, as this would result in a fine for the foundry. According to the data collected, the extra transports are planned to go one way to a customer and then back to the foundry. Even if extra transport is needed for several customers, the goods are not consolidated and no 'milk runs' are carried out.

The extra transports are an example of when there are conflicts between economic and environmental sustainability. As the SME supplier is penalized with a fine if they do not deliver the goods on time to the customer, they need to prioritize cost over sustainability. In this case, this means that frequent transport is applied where fill rates are not taken into account and there is no sustainable route planning. This has a negative impact on the environment through increased emissions, which in turn affects the greenhouse effect, among other things (Jonsson & Mattsson, 2016).

Furthermore, the packaging is a challenge for SME foundries when working with their OEM customers. The OEM customers require them to use the packaging material that they provide to the suppliers, but the SME suppliers feel that the deliveries of the material are often too late. The small foundries wish to have packaging in stock to be able to package finished casted components immediately after final assembly. At present, they must pack the components in their own packaging and then repack the components in the customer's packaging before sending the goods to the customer.

According to Table 2.1, unnecessary processing is described as waste. This means that the processes that are not necessary are not creating value. This impacts the environment through the consumption of unnecessary materials, in this case, packaging that is not needed. Excessive stockpiling is also referred to as waste that impacts the environment. For the SME foundry, they must stock finished molded components in packaging that they later have to repackage. This has an environmental impact due to the need for extra packaging (Torielli et al., 2011).

However, OEMs in the foundry industry are experiencing a challenge with packaging material shortage, especially for cartons. The packaging material is a circular process implemented by OEMs, meaning that OEMs purchase packaging which they then provide to their suppliers. Eventually, the packaging comes back to the OEM who can reuse it.

This process is only implemented with local suppliers and subcontractors. The reason for this system is since OEMs are largely automated. The robots require specific packaging and therefore the suppliers must adapt to this.

In summary, SMEs experience more logistics challenges than OEMs in the foundry sector. The most significant challenge is external transport as this is considered to be the most damaging to the environment. This is a challenge that needs a high priority, but the root cause is based on the planning and flexibility of production. If the production is better planned to avoid the need for extra transport, the extra transport will be significantly reduced.

5.1.5 Sustainability & Circularity

In this section, in addition to the subchapters connected to sustainability and circularity above, the challenges with environmental sustainability and becoming circular in the foundries are analyzed.

<u>Environmental Damages</u>

Environmental damage is a major challenge that all case companies encounter regardless of the size or the type of materials they work with. Pollution, dust, water, noise, and energy are different types of waste that are seen in foundries. All the companies have continuous improvement projects to collect as many chips and sludges as possible from the machines, however, some of them are stuck in the machines.

According to Company B, the foundry industry is an old-fashioned industry where the need to change is not high. Environmental damage could occur due to bad quality of the casting according to company B. Casting is a long and difficult process with long change-over times and calibration techniques. As Šehić-Mušić et al. (2013) and Torielli et al. (2011) explain, induction furnaces and casting general have significant negative effects on the environment. The higher output of production equals higher amounts of pollution. Therefore, defects result in higher energy consumption, extra work, and energy use in the foundries which results in money, time, and resources affecting all the pillars of the triple bottom line (TBL).

Electrical Transformation in Foundries

For being completely electric-driven in the casting process, company C has already built a complete electric foundry. However, according to companies A and B, it is not feasible to be 100% electric with the current electricity prices, availability of electricity, and the investment required for such a transition. Company A is using LPG for the melting process which is not sustainable for the environment as admitted by the company. However, the company does not think that the customers are willing to pay for the increased prices in the event of using electric furnishes for the melting. Despite that the customers are asking for more environmentally friendly foundries, Company A does not foresee it achieving success in sales. Company B, however, is in search of electric solutions such as induction ovens. Although company B’s attempts at being electric are promising, when engineers suggested investments into buying only electric furnaces, the management rejected it due to being too expensive. This indicates that company B is not prioritizing sustainability actions in its foundry.

Kumar et al. (2019) mention the difficulty for SMEs to make large investments due to a lack of financial support and their capital for a circular economy (CE) transition. It can be concluded that larger companies with higher capital and resources have more possibilities of transforming into fully electric-operated foundries compared to SMEs that are smaller in size and capital.

According to Nordin et al. (2014), one of the drivers for sustainable manufacturing is the management policies internally and the mindset of the management. With the high external pressure such as environmental and social legislations, sustainable practices are to be more incorporated by the management. Company B has its internal goals for sustainability; however, these goals do not include being completely electric-driven in the foundry. This could be due to company B being a large OEM and the sustainability aspect is covered by other departments of the business. As mentioned by Gianmarco et al. (2019), corporate culture is related to the mindset of the management and thus the employees. This mindset should be spread throughout the organization and the organization shall operate as a whole in terms of circularity and sustainability initiatives.

Company A’s customers require company A to be operating fully electric in their foundry. However, the goals they set for Company A differ largely and the initiatives are not present enough for Company A to begin with the necessary investment. It is an immense culture change for the company to become fully electric, and therefore, the internal goals should be aligned with external goals as Table 2.2 presents.

To conclude the electrical transformation of the foundries, there is still a big gap in terms of unclarity of the internal goals that the companies set to achieve. Dedication from the top management is required to implement changes in the foundries that could be environmentally friendly. As Gianmarco et al. (2019) discuss, to avoid resistance to a more circular mindset in the organization, leaders’ and managers’ commitment is required to increase awareness to implement such changes. Moreover, the high investment and the electricity costs are inconvenient for foundries to implement drastic changes as it is not financially viable. The companies that have already transitioned or are in the process of transitioning to electrical foundries are the foundries that are relatively large and global companies that have implemented sustainability goals throughout the organization.

Circularity, Traceability, Waste Management, and Material Reuse

Circularity is highly important for the foundry industry as all the case companies focus on melting and reusing as much material as possible from the casting processes. When asked about how circular the foundries are, the answers were similar, however, the implications and actions differ for SMEs and OEMs.

In terms of waste management, according to all the case companies, almost 100% of the material waste is recycled in-house by re-melting. A common challenge with the waste is that painted, and surface-treated components, chips, and sludges cannot be remelted in-house. Therefore, all the companies are shipping the waste that cannot be recycled in-house to Stena Metall. For all the foundries, the faulty or damaged components are melted in-house unless they are surface treated or painted.

Both SME and OEM foundries have traceability on the finished components to trace the faulty components. The parts are marked with chemical alloys and the manufacturing date. However, the faulty components, the chips, and sludges that are shipped to Stena Metall cannot be traced as they are all melted.

Company B has projects regarding in-house melting of the painted components to keep the material in-house and benefit more from the waste generated. These projects are investments that require high dedication and capital to increase traceability and circularity in the foundry industry. As Kumar et al. (2019) indicate, it is an expensive transition to become more circular and the short-term payback might not be encouraging. Since company A is an SME and is smaller in terms of revenue and operations compared to companies B and C, the investment opportunities would have larger financial risks.

Both OEM and SME foundries lack information regarding the end user. Since the end-products are used by private customers or other businesses, the traceability of the casting parts lacks when the product life ends. While this could be understandable for SMEs since their customers are other businesses, companies B and C are larger companies that supply finished products to end-users. This indicates a traceability challenge for the foundry industry despite the companies' claims of being circular.

As a result, sustainability, and circularity are concepts that different actors in the foundry industry are differently interpreting and reacting towards it. The size and the capital of the companies determine the number of resources allocated for sustainability and circularity initiatives. Additionally, the organizational goals and the mindset of the top management has an immense role in these types of initiatives.

5.1.6 Summary Challenges for Demands of Becoming Sustainable and Circular.

The demand for becoming sustainable and circular has affected the companies differently. The SME experiences sustainability requirements from its customers but lacks its internal targets. These requirements mainly concern sustainability and not circularity. Even OEMs mention mostly about sustainability more than circularity.

However, OEMs have their own values and objectives, which include both sustainability goals and contributing to a circular economy. Internal circularity is implemented by foundries to a large extent. Externally, the current requirements are mostly enforcing companies to be more sustainable, as the foundry industry is far from achieving circular supply chains.

Several different challenges were identified in terms of sustainability and circularity for both OEMs and SMEs in the foundry industry. The challenges with the greatest negative impact on sustainability and circularity are presented in Table 5.1. These challenges are also rated as high priority due to the ability to address the problem, followed by the impact on sustainability and circularity.

Table 5.1, Summary of Identified Challenges for Sustainability and Circularity in the Foundry Industry

PROCESS	CHALLENGE	SME	OEM
Supply Chain	Availability of suitable supply chain partners	X	
	Customer agreements	X	
	Deliveiers		X
Production	Fluctations in demand	X	X
	Changes in production planning	X	X
	Short freeze time in the planning system	X	
	Change-over times	X	X
	JIT	X	X
	Workforce and new technology		X
Logistics	External logistics	X	
	Extra transports	X	
	Packaging material	X	X
Sustainability & Circularity	Environmental damage	X	X
	Energy consumption	X	X
	Investments	X	
	Linear mindset	X	X
	Traceability for waste management	X	X

Table 5.1 illustrates whether the challenges are applicable to SMEs, OEMs, or both, in the foundry industry. Based on the analysis, SMEs experience more challenges than OEMs. Some challenges are experienced by both SMEs and OEMs, but the way the challenge unfolds can vary based on the analysis.

5.2 How can SMEs in the foundry industry be more circular and sustainable?

The second research question is answered by explaining how SMEs in the foundry industry can be more sustainable and circular. The chapter begins with a brief explanation of the problem, followed by its causes. Lastly, possible solutions are discussed and to conclude the question, a recommendation is given.

The identified challenge for SMEs in the foundry industry is adapting to the demand fluctuations caused by their OEM customers. This challenge can result in energy and other environmental wastes when SMEs are forced to prioritize their larger customers. Furthermore, this leads to SME foundries finding it difficult to deliver complete orders on time. This generates extra transport which has an impact on the environment in the form of increased emissions.

The challenge is based on difficulties in forecasting demand from OEM customers. OEMs have an easier time reorganizing assembly as they are more flexible. This flexibility of OEM customers challenges small foundries as they are not as flexible.

5.2.1 Resilience in Production Systems

The OEMs implement JIT in their assembly lines. However, flexibility is highly crucial for implementing JIT correctly. According to company B, the flexibility is at high levels, and it can start producing a new batch the same day as they receive the order from its end customers. On the contrary, this does not reflect well on the suppliers since it creates complications at the suppliers' sites. According to company A, the last-minute orders after the freeze time reduce flexibility in production since the shortest production time at the supplier is one week due to the long casting process. This causes waste since the supplier must prioritize the orders from OEMs.

As explained by (Heinicke, 2014), agility is the response to environmental changes through rapidly reconfiguring production systems. Whilst both agility and robustness are necessary according to (Heinicke, 2014), agility is not the optimal solution for foundries due to the long change-over, calibration, and casting times. Proactively designed robust systems are resistant to predictable changes (Heinicke, 2014). Therefore, anticipation and preparedness are highly crucial for foundries to have robust production systems that can deliver according to fluctuating customer demands.

5.2.2 Production Planning

Factors that influence production planning are shown in Table 2.4. Internal variables are seen as capacity, utilization, and inventory. The disturbance factors for these are defects in workmanship and uncertainties of planning internally (Heinicke, 2014). According to company A, the problems that occur with planning are not internally sourced. It rather occurs due to uncertain demand planning from OEMs which leads to operating overtime on the weekends since company A prefers stocking more than having frequent transports to customers. This presents positive and negative outcomes for environmental sustainability as explained by Melo et al. (2022). Some of the advantages of not using JIT could be reduced greenhouse gas emissions from the transports and complications and delays in the deliveries. The disadvantages could be not being able to enhance delivery planning, optimizing production flow in the foundry, etc (Melo et al., 2022).

In Table 2.4, external variables are market pressure and delivery times of suppliers. These variables could be disturbed by changes in customer demands and insufficient material availability due to supply shortage (Heinicke, 2014). In this case, company B admits that demand uncertainty is an issue sourced by them due to their customers being both private persons and other businesses. Therefore, demand cannot be forecasted accurately since sales forecasts are very often. Due to these forecasts, the demands fluctuate and therefore, the changed production plan does not match the delivery schedule that is sent to the suppliers. This results in last-minute orders as well as late orders that create problems at the supplier's site.

5.2.3 The Influence of Just-in-Time

Both the customer and the supplier have a mutual understanding of increasing the freeze-time for order deliveries. However, this is not profitable for company B as this results in keeping higher stocking and inventory levels due to uncertainty from its customers. Therefore, it is difficult to find a balance where both the supplier and the customer are satisfied with the demand certainty. Heck and Vettiger (2014) address JIT to enforce supplying the right quantity at the right time while switching to a pull system rather than the conventional push system where stocking is favored.

With JIT, the customer demands to start production based on the order size. OEMs work with JIT for their assembly lines. However, it is not the most optimal production system for foundries as the casting process is long, and casting a different batch requires long change-over times and resources that harm the environment. This also explains the reason for suppliers working with bigger batches despite the higher inventory costs. In 1.1 Background, it is seen that the requirement from the industry is to have smaller batches to reduce the lead times. This may suggest the application of JIT systems. However, due to these factors, it is not feasible for the foundry industry at the moment.

5.2.4 Capacity Planning

As JIT is not a suitable solution for small foundries, there are other alternative capacity solutions. There are different methods to balance the need and demand for capacity, both in the long and short term, as presented in Table 2.5. In the long term, two options involve either changing delivery times or increasing/decreasing inventory (Jonsson & Mattsson, 2016). The SME claims that it is challenging to adjust the delivery times and schedules based on their customer's production schedules. Therefore, increasing/decreasing inventory is the most suitable long-term action for reallocating capacity needs (Jonsson & Mattsson, 2016). The data collected shows that SMEs think that stockpiling is the most appropriate solution to the problem.

This means that smaller foundries can reduce their capacity needs during specific periods and deliver orders from stock. When the need for capacity increases, the foundry can produce from stock (Jonsson & Mattsson, 2016). This may mean that economic sustainability is challenged in terms of increased inventory costs. However, costs may be reduced as the risk of the foundry being fined is reduced. Moreover, the cost of extra transport and the cost of production stops are reduced.

This recommendation aims to increase both environmental and social sustainability. The environment is also affected by warehousing, but this proposal aims to reduce extra transport with low fill rates and poor route planning. Transport can therefore become more sustainable with high fill rates and better route planning. Also, the environment is protected by reducing production stops and avoiding waste (Torielli et al., 2011). Lastly, social sustainability will be improved in the long term as reduced warehousing will lead to less overtime labor.

5.2.5 Communication and Information Flow in Planning

As company B regards communication as an important factor, it also admits that miscommunication causes problems at SMEs which affects the deliveries negatively. Since Company B has recently implemented a new ERP system, it has had a negative impact on demand certainty. Regardless of the new ERP system, company B admits that the overall IT systems that are used for orders are not effective enough. For better planning and scheduling in the supply chain, the importance of ERP systems is highlighted by Heck and Vettiger (2014) and Vaaland and Heide (2007). Specifically for SMEs, better utilization of ERP systems and EDI system is required. Through the correct use of EDI, network collaboration increased IT tools used for forecasts, and a high level of visibility and communication, production planning could be improved between SMEs and OEMs. Therefore, it is highly important for OEMs to implement ERP systems correctly, hence the SMEs in the foundry industry can receive correct order information from their customers.

5.2.6 Shared Goals and Supply Chain Integrity

The relationship between supplier-customer and the shared goals and vision sharing is important for supplier flexibility to handle fluctuating demands (Liu et al., 2022). According to company B, suppliers are complaining about the tough conditions of order changes and unreasonable demands at times. As discussed by Liu et al. (2022), it is important to pressure suppliers with an adequate level of legal-legitimate power to encourage them for being more flexible to fluctuating demands.

Moreover, by sharing vision and goals with the right policies and regulations, SMEs could have higher flexibility to demand fluctuations through better forecasts and be more prepared for the changes in incoming orders. This is a solution that could be undertaken by the focal company, in this case, the OEM has the bargaining power over the suppliers. Therefore, higher visibility, sharing goals and data, and integrating suppliers will increase the overall supply chain competitiveness and lead to better planning to reduce waste at the supplier's site (Stadtler et al., 2015).

5.2.7 Recommendations

Since JIT is not a sustainable solution for SME foundries, capacity planning for the longer term through stockpiling is more suitable for SMEs to avoid negative environmental outcomes. Table 5.2 summarizes the identified problem, the cause followed by recommendations, the expected effect, and lastly priority.

Table 5.2, Table of Recommendations for SMEs to Become More Sustainable

Identified problem	Causes	Recommendations	Expected effect	Priority
Adapting to the demand fluctuations	Difficulties in forecasting demands from OEM customers	Rellocating capacity through warehousing	Better forecast	High
		Increased IT tool use for forecast	Increased flexibility	
		High level of visibility and communication	Increase sustainability	
		Shared goles and vision between supplier and customer		

To apply capacity planning in the long term, accurate forecasting is highly vital. Therefore, a high level of communication between OEM customers and SME suppliers is recommended. For better communication, advancing through IT tools is recommended, as shown in Table 5.2. This enables a more accurate and reliable ordering system between the OEM and the supplier. Integrity, shared goals, and higher visibility in the supply chains between the supplier and the customer enable higher flexibility for meeting the changing demands of OEM customers. In conclusion, this challenge is a high-priority issue for the industry that requires effort and collaboration from both the customer (OEM) and the supplier (SME) in the foundry industry.

6 DISCUSSION

This chapter discusses the results of the study from the collected data and analysis. Further, the implication of the study is discussed. The chapter concludes with a discussion of the methodology.

6.1 Discussion of Results

The purpose of the study, which is “to identify the challenges that Swedish foundries are facing regarding circularity and sustainability demands and explore how the SME foundries can be more sustainable and circular.”, was fulfilled by answering the research questions. In this section, a summarized answer to both research questions is given, followed by a brief discussion of the findings.

6.1.1 Discussion of Research Question One

The first research question fulfills the purpose of the study by identifying the challenges that Swedish foundries face regarding the demands of becoming circular and sustainable. Table 5.1 summarizes the main challenges for SME and OEM foundries, based on the impact on sustainability and circularity, and the opportunity to address the challenge. It is seen in the results and analysis that the size of the foundries is not the only determining factor in terms of the challenges they face. The challenges rather occur due to the type of customers, positioning in the supply chain, and due to how flexible the foundry is.

It also emerged that the challenges relate more to demands of becoming more sustainable than circular. It is assessed that the foundry industry in Sweden is far from achieving circular supply chains. Due to the lack of traceability of the end products and information about the products at the end of the life cycle, circular supply chains cannot be achieved. However, the circularity internally at the foundries is relatively good because of the remelting processes.

6.1.2 Discussion of Research Question Two

The second research question fulfills the purpose of the study by exploring how SME foundries can become more sustainable and circular. One issue identified in research question one was selected to be further explored in research question two. Table 5.2 presents the improvement suggestion for the main issue, which is adapting to demand fluctuations. The cause of the problem is based on OEMs experiencing problems with demand forecasts that they share with their suppliers. Based on the analysis, SME foundries are recommended to reallocate capacity by stockpiling casted components. The relationship between customers and suppliers could be improved by IT tools for forecasting, as well as increased communication and visibility. Finally, customers and suppliers could share their goals and visions. Based on research question one, it was discussed that the Swedish foundry industry is far from transitioning to a circular economy, therefore the recommendations are only based on sustainability.

The study's recommendations are in line with the agenda for a sustainable Swedish foundry industry by 2035, as presented in the 1.2 Problem Statement. These recommendations are expected to lead to better forecasting, increased flexibility for the supplier, and increased sustainability. The presented recommendation in Table 5.2 contributes to the objective of reducing production stoppages. It also contributes to flexible production. However, the objective suggests that foundries should become more flexible by reducing batch sizes. From the collected data and the analysis, it is shown that small batch sizes are not possible for foundries at the moment, especially for SMEs. The casting process is too unstable and has long change-over times which do not make small batches possible without having negative impacts on the sustainability.

6.2 Implications

In this chapter, the implications of this study are discussed for the practitioners and the theory.

6.2.1 Practical Implications

As this thesis highlights the challenges encountered by different-sized foundries, companies could use this thesis as a point of reference to compare and reflect on their foundry operations. This thesis could also be used as a benchmarking tool to understand the weaknesses and the strengths of foundries in terms of material, supply chain, production, logistics, sustainability, and circularity.

Since SMEs are targeted for facing challenges in the industry, practical implications could provide a recommendation for organizations in the foundry industry. Recommendations include both SMEs and OEMs' collaboration for improving production and demand planning at the supplier's site for reduced negative environmental impacts.

6.2.2 Theoretical Implications

Despite the earlier studies that have been carried out regarding the environmental impact of foundries, challenges connected to sustainability and circularity have been a gap for academia in this industry. Previous studies have mostly addressed energy consumption for sustainability in the industry. Therefore, this study adds value to the research field as it highlights multiple areas of challenges in the supply chains (e.g., production, material, logistics, etc.) of the foundry industry in Sweden.

The production and demand planning to reduce negative sustainability impacts has been a well-investigated research field. Therefore, new value to the research field is not added. However, in this thesis, the planning challenge is investigated in the foundry industry, which adds a new perspective to the research. The results indicate that a more integrated supply chain, improved communication with advanced IT tools, and planning for capacity is a better solution for the foundries in comparison to the JIT principle where the inventory is aimed to be reduced. Therefore, this study is a complement to other studies that focus on improved planning in different industries.

6.3 Discussion of Method

The internal validity is considered high as the study has fulfilled the purpose and answered the research questions. External validity and generalizability are high as this study is a multiple-case study targeting the foundry industry where different sizes of companies and actors in the supply chain were studied.

The study is considered capable of being carried out by other people or repeated to achieve the same results; therefore, the reliability is high. Data collection consists of semi-structured interviews and unstructured observations. The semi-structured interviews have associated topics in Appendix A, B, and C. Therefore, the reliability of this study is high.

The interview questions to get an answer for the first research question were identical for all the interviewees for investigating the challenges in the foundries. By asking similar questions to the interviewees, it helped create a strong and unbiased analysis of the results. For the second research question, interviews were different for different roles since different perspectives are tried to be captured to understand the challenge more extensively.

Observations could have been more structured instead of unstructured. While observations with companies A and B are done successfully, observations with Company C did not take place as the communication with the company was not strong. To have a better analysis of the observations, all three companies' foundries could have been observed.

The second research question is answered qualitatively which provides a substantial understanding of the most significant challenge faced by the SME foundries. To achieve more detailed but comprehensive results, quantitative data could have been collected for this study in terms of production planning schedules and the delivery windows of the orders.

Lastly, one more SME foundry could have been included in this study to investigate two cases of SME and OEM relationships in the castings supply chain. This would provide a better holistic perspective and comparison to understand the challenges of becoming more circular and sustainable. Moreover, one of the reasons to have three case companies instead of four is due to low interest in the study despite that this thesis is a part of the GRETA project which many foundries are a part of. This is also the reason to have a different number of interviews with each foundry based on the interest of the companies.

7 CONCLUSIONS & FURTHER RESEARCH

This chapter presents the conclusions from the study, followed by the recommendations. The chapter ends with proposals for further research.

7.1 Conclusions

Swedish foundries experience many challenges regarding the demands of becoming sustainable and circular. The main challenges identified are the availability of suitable supply chain partners, customer contracts, fluctuations in demand, JIT, extra transports, and packaging. Also, traceability, energy consumption, and a linear mindset are challenging for the industry.

The study concluded by examining how SMEs in the foundry industry can become more sustainable and circular. This resulted in an improvement proposal on how SMEs can adapt production to demand fluctuations from OEM customers. The recommendations involve reallocating capacity through stockpiling and increasing the use of IT tools and communication. This is expected to generate better forecasts and increase sustainability. The finalized result of the study implicated that the foundry industry is not yet circular, thus work towards becoming more sustainable is implemented.

7.2 Further Research

The first research question highlights the challenges in the foundry industry and its connection to sustainability and circularity demands. When the results are categorized into their respective subchapters, an overview of challenges is identified and concluded within the limitations of the study. Therefore, a study of how to overcome these challenges for each of the subchapters of the results (e.g., material, supply chain, production, logistics, sustainability & circularity) can be undertaken and investigated separately.

- Since the study is generalizing materials for the analysis, more material-specific research could be generated for identifying the challenges for each casting material used in the Swedish foundry industry.
- There is a research gap for foundries regarding sustainability, CO_2 emissions, and lack of knowledge of circularity for casted components. More circularity and lifecycle analysis research are needed to understand the implications of circular casted components and how that state could be achieved.
- Electrification is a topic that is highly relevant in Swedish foundries. For the foundries to adopt more environmentally friendly practices and use environmentally friendly energy sources, further research can be undertaken for investment analysis.
- The findings imply that with the current technology adopted in the foundries, the use of JIT and smaller batches are not feasible. Therefore, investment analysis and cost calculations for investments in flexible and resilient foundries shall be further studied. These studies will encourage Swedish foundries to be more dynamic and open to new technologies for lower environmental impact.

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Appendix A

Interview Guide - Phase One

Material

- Which material and alloys does the company work with?
- Do you experience any challenges regarding working with alloys?

Supply Chain

- Can you briefly describe the supply chain of castings?
- Do you have suppliers and/or subcontractors for castings and/or materials?
- How does the process work when selecting suppliers and/or subcontractors?
- What are the main challenges with your suppliers/subcontractors and customers?

Production

- Have you implemented any specific production system?
- Do you work with Just-in-Time?
- How does the planning of the production work?
- Where do lead times occur in your production?
- Where does waste occur in your production?
- How do you deal with the waste?
- What are your main challenges in the casting processes?

Logistics

- Can you briefly describe the logistics process?
- Do you see any possibility of developing the logistic to make it more sustainable?
- How does the planning of inbound and outbound work?
- What are the main challenges in the logistics processes?

Sustainability & Circularity

- What are your main challenges regarding sustainability?
- What are your main challenges regarding becoming circular?
- How much castings do you recycle/reuse in the foundry processes?
- How do you implement traceability for castings?
- What drives your company to be more sustainable and circular?
- Do you see a possibility to be more circular?

Appendix B

Interview Guide for Materials and Production Planning – Phase Two

- Do you have any specific requirements that you demand from your suppliers for casted components?
- Do you find it challenging to get suppliers to comply with your requirements?
- Do you get complaints from your suppliers regarding demand uncertainty caused by your company?
- Why do you think that demand uncertainty happens?
- Which ordering systems do you use to communicate and put in orders with your suppliers?
- Do you work with Just-in-time (JIT)?
- Do you demand your customers to deliver casted components according to your production plan?
- How often do you receive casted components to the assembly line that you are responsible for?
- What are the consequences to your suppliers when they cannot supply you?
- Would you rather receive smaller batches if you could?
- What are the main challenges that occur in the assembly process when you use casted components that you purchase?
- How flexible is your production?
- Could you describe the logistics processes for casted component that you purchase?
- How does the warehousing function for the casted components?
- What means of transport do you use for the transports?
- Could you describe the logistical challenges when you purchase casted components?
- What are the challenges that you encounter in the part of the supply chain between your company and your suppliers for casted components?
- Do you see any opportunities for increasing circularity and sustainability?

Appendix C

Interview Guide for Purchasing & Sourcing – Phase Two

- Can you briefly tell us about the casted components you purchase?
- Where geographically are your suppliers based?
- How does the selection of suppliers work?
- Do you consider sustainability and circularity when selecting suppliers?
- Is there any specific demands you put on your suppliers?
- What are the main challenges you experience when purchasing casted components?
- What are the main challenges regarding sustainability & circularity in terms of suppliers