EVALUATION MODEL AND DECISION-MAKING TOOL FOR MANUFACTURING FOOTPRINT DECISIONS

Lappeenranta–Lahti University of Technology LUT

Master’s Programme in Supply Management, Master’s thesis

2024

Kaarin Peltovuori

Examiners: Professor, Veli Matti Virolainen

Professor, Katrina Lintukangas

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT Business School

Business Administration

Kaarin Peltovuori

Evaluation model and decision-making tool for manufacturing footprint decisions

Master's thesis

2025

83 pages, 16 figures and 2 tables

Examiners: Professor Veli Matti Virolainen and Professor Katrina Lintukangas

Keywords: manufacturing footprint, global supply chain, multi-criteria decision-making, weighted sum model

Manufacturing footprint decision-making has become increasingly complex due to globalization. A growing number of factors now influence these decisions, resulting in a multifaceted process that requires careful assessment to make effective choices.

This thesis explores the factors that influence manufacturing footprint decision-making and examines how a decision-making tool can aid in evaluating these factors, providing a more comprehensive approach to the decision-making process. The key factors identified include price/cost, quality, logistics, market area preference, and factory capacity and capability, with price/cost emerging as the most important factor.

The multi-criteria decision-making tool, based on a weighted sum model, was used to evaluate various factors. This approach allows users to define criteria and assign weights according to their own assessment of the relative importance of each factor for the specific case. One of the tool's key strengths is its versatility, making it suitable for evaluating both small and large manufacturing footprint changes.

Designed to assist in the decision-making process, the tool does not aim to provide an absolute answer. Instead, it supports the user's judgment by ensuring that all relevant factors are considered in the evaluation, facilitating a more informed and balanced decision.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT-kauppakorkeakoulu

Kaarin Peltovuori

Arviointimalli ja päätöksentekoväline valmistuksen jalanjälkeä koskevia päätöksiä varten

Kauppatieteiden pro gradu -tutkielma

2025

83 sivua, 16 kuvaa ja 2 taulukkoa

Tarkastajat: Professori Veli Matti Virolainen and Professori Katrina Lintukangas

Avainsanat: valmistuksen jalanjälki, globaali toimitusketju, monikriteerinen päätöksenteko, painotettu summamalli

Tuotannon jalanjälkeä koskevasta päätöksenteosta on tullut yhä monimutkaisempaa globalisaation myötä. Yhä useammat tekijät vaikuttavat nykyään näihin päätöksiin, mikä johtaa monitahoiseen prosessiin, joka vaatii huolellista arviointia tehokkaiden valintojen tekemiseksi.

Tässä tutkielmassa tarkastellaan tekijöitä, jotka vaikuttavat valmistusjalanjälkeä koskevaan päätöksentekoon, ja tutkitaan, miten päätöksentekoväline voi auttaa näiden tekijöiden arvioinnissa ja tarjota kattavamman lähestymistavan päätöksentekoprosessiin. Keskeisiksi tekijöiksi on tunnistettu hinta/kustannukset, laatu, logistiikka, markkina-alueen mieltymykset sekä tehtaan kapasiteetti ja kyvykkyys, joista hinta/kustannukset nousivat tärkeimmäksi tekijäksi.

Eri tekijöiden arviointiin käytettiin painotettuun summamalliin perustuvaa monikriteeristä päätöksentekovälinettä. Tämän lähestymistavan avulla käyttäjät voivat määritellä kriteerit ja antaa painotukset sen mukaan, miten he itse arvioivat kunkin tekijän suhteellista merkitystä kyseisessä tapauksessa. Yksi työkalun keskeisistä vahvuuksista on sen monipuolisuus, jonka ansiosta se soveltuu sekä pienten että suurten valmistusjäljen muutosten arviointiin.

Työkalu on suunniteltu auttamaan päätöksentekoprosessissa, mutta sen tarkoituksena ei ole antaa absoluuttista vastausta. Sen sijaan se tukee käyttäjän harkintaa varmistamalla, että kaikki merkitykselliset tekijät otetaan huomioon arvioinnissa, mikä helpottaa tietoon perustuvan ja tasapainoisen päätöksen tekemistä.

ABBREVIATIONS

AGG	Aggregates (business line)
AHP	Analytic Hierarchy Process
MCDA	Multi-criteria decision analysis
MCDM	Multi-criteria decision-making
SAW	Simple Additive Weighting
SC	Supply Chain
SCM	Supply Chain Management
SCRM	Supply Chain Risk Management
WSM	Weighted Sum Model

During the writing process, the ChatGPT AI application was used as a supportive tool, particularly for outlining the structure and themes of the thesis, as well as for improving the clarity and language of the text.

Table of contents

1 Introduction

The globalization of manufacturing has increased the complexity of making footprint decisions, including site selection, production allocation, and resource distribution. These strategic decisions are critical as they have long-term implications for a company's competitive advantage, operational efficiency, and ability to respond to market dynamics. Global supply chains introduce diverse challenges such as fluctuating demand, geopolitical uncertainties, and environmental regulations, all of which influence the selection and operation of manufacturing sites.

Effective decision-making in this domain requires a robust evaluation model that can accommodate various factors such as cost, logistics, and market access. Traditional approaches to these decisions often emphasize cost-centric analyses, which may overlook qualitative aspects such as political stability, local labour skills, and sustainability considerations. The multifaceted nature of modern manufacturing environments demands a comprehensive approach that integrates both quantitative and qualitative factors into a unified framework.

Despite the strategic importance of these decisions, there is a lack of comprehensive tools that can systematically guide organizations through the complex landscape of manufacturing footprint planning. Existing tools often lack the ability to evaluate diverse and sometimes competing factors cohesively, limiting their usefulness in high-stakes decision-making. This research aims to develop an evaluation model and a decision-making tool that will support strategic decisions in manufacturing footprint planning.

This thesis focuses on the topic: *"Evaluation model and decision-making tool for manufacturing footprint decisions"* and it is carried out as an assignment for Metso Finland Oy (later referred to as "Metso" or the "Target company"). The objective of this research is to develop an evaluation tool capable of scoring and analysing a range of factors relevant to manufacturing location decisions specifically within the Aggregates product portfolio. By systematically incorporating variables such as cost structures, supply chain logistics, market proximity, and workforce capabilities, this tool will enable stakeholders to make balanced and strategic choices. The proposed decision-making tool will serve as a practical guide to assist Metso in optimizing its manufacturing footprint for the Aggregates portfolio while aligning with both strategic business goals and operational constraints. This model is expected to make decision-making at Metso more efficient and provide a well-rounded way to evaluate manufacturing locations. By connecting theory with practical use, this research aims to add valuable insights to both academic studies and industry practice.

1.1 Structure of the thesis

The thesis begins with an overview of the research background, outlining the context and significance of the topic. This section explains why it is important to define and study the factors that affect the manufacturing footprint and how the increasing complexity of global supply chains affects cost, efficiency and balancing with customer satisfaction. In addition, this section discusses the motives for choosing the research area and why the topic is important in general and for the target company. The target company itself is also examined in more detail and what kind of operating environment the company works in.

Following this, the thesis framework and key concepts are briefly introduced. This part includes an in-depth explanation of the manufacturing footprint concept and what kind of solution the target company currently has. The next section introduces the research objectives and research questions, providing a clear focus for the study. Additionally, the scope and limitations of the topic are discussed to define the boundaries of the research and ensure a targeted approach.

Following the Introduction section, the thesis moves into the theoretical framework. This section provides a comprehensive examination of the manufacturing footprint, exploring the various factors that influence it based on different theoretical perspectives. Additionally, the multi-criteria decision-making (MCDM) theory is reviewed, along with its potential application in achieving the objectives of the thesis.

After the theoretical framework, the thesis moves to the empirical research section. This part begins with an explanation of why interviews were selected as the primary research method and outlines the structure of the interview content. Next, the criteria for choosing the interview participants are detailed. Finally, the results of the interviews are analysed, and the key factors identified as significant influences on manufacturing footprint decisions are compiled and discussed.

The empirical section concludes with the presentation of a tool designed to facilitate the comparison of various factors across different scenarios related to the manufacturing footprint. This tool provides a practical way to visualize and assess the impact of each factor, supporting informed decision-making. Additionally, the tool highlights interdependencies between factors, providing a more comprehensive understanding of their combined effects.

In the final section, the conclusions are drawn, summarizing the key findings of the study. Additionally, potential topics for future research are suggested, offering directions for continued exploration and development in the field. This section emphasizes how the findings can be built upon and highlights areas where further investigation could yield valuable insights.

1.2 Background to the research

The topic of this thesis is to create an evaluation model and decision-making tool for manufacturing footprint decisions. This research explores the various factors that influence these critical decisions and investigates how these factors may differ, for example, when comparing decisions for new products versus standardized products. A comprehensive understanding of these differences is vital for strategic planning and operational efficiency.

The topic was chosen in collaboration with the target company, Metso Finland Oy, which has extensive global operations and is recognized for its expertise in the aggregates and mining industries. The research specifically focuses on the manufacturing footprint within the existing factories in the Aggregates segment. It is important to note that this study does not include the mapping or commissioning of new production sites; these aspects are intentionally excluded to maintain a targeted scope on optimizing current manufacturing distribution.

The selection of this topic was driven by the author's day-to-day professional experiences and the challenges regularly encountered in her role. Requests for changes related to manufacturing footprint decisions occur on a weekly basis, but these requests often lack a structured approach and consistency. The justifications for these changes can vary widely, leading to decisions that prioritize only one perspective and fail to address the broader implications. This narrow focus often results in the same issue reappearing from different angles, creating a repetitive cycle of analysis and re-evaluation that consumes valuable time and resources.

One significant challenge highlighted in this research is the absence of a definitive, standardized tool for making these critical manufacturing decisions. Without such a tool, the decision-making process can be fragmented and unclear, leading to potential misunderstandings among stakeholders. Each stakeholder may approach the issue with a different priority in mind, adding to the complexity of the situation. For instance, a product manager may focus on achieving the lowest possible manufacturing cost to meet budget goals, while the sales team might emphasize the importance of shorter delivery times and logistical arrangements to meet customer expectations. These differing priorities can create tension and misalignment within the decision-making process.

The proposed evaluation model and decision-making tool aim to address these challenges by providing a comprehensive and structured approach that balances the various factors and perspectives involved. By integrating multiple variables such as cost structures, supply chain logistics, market proximity, workforce capabilities, and more, this model seeks to enable stakeholders to make well-rounded and strategic choices. The ultimate goal is to create a framework that enhances transparency, supports consistency, and facilitates more effective decision-making within the Aggregates product portfolio at Metso.

By developing this model, the thesis hopes to streamline processes, reduce repetitive cycles, and foster better communication among stakeholders. Additionally, the tool will serve to bridge the gap between different perspectives, ensuring that decisions are made with a holistic view of all relevant factors. This will not only support more informed decision-making but will also contribute to a better alignment of business goals with operational realities. Through this research, the author aims to provide valuable insights and practical solutions that can be applied to improve manufacturing footprint strategies at Metso, benefiting the organization’s overall strategic and operational framework.

The manufacturing footprint plays a crucial role in strategic decision-making and significantly affects factors such as factory capacity and sales margins. It largely determines the production volume at each factory and the market regions that each facility serves. Additionally, it controls which products and standard options the factories need to be prepared to offer in their normal production plan.

A stable manufacturing footprint helps maintain balance in the factories by minimizing changes to the production plan and maintaining steady material predictability. When the manufacturing footprint is well-balanced across market areas, it results in improved delivery times, reduced shipping costs, and an enhanced ability to meet customers' evolving needs due to optimized factory capacity. Overall, a strategic manufacturing footprint supports a company’s operational goals, financial performance, and long-term competitiveness.

Clear decision-making processes and a tool that helps visualize the overall situation would enhance decision-making and provide transparency for other stakeholders involved in the same area. This would hopefully reduce the number of similar change requests, or at least speed up their processing, when the overall picture would be better understood.

When all influencing factors are considered in decision-making, rather than focusing solely on a single aspect, it leads to more sustainable and well-rounded decisions. This comprehensive approach not only ensures that the outcomes are more resilient over the long term, but it also sets a foundation for a consistent decision-making framework. By developing a holistic mindset, it becomes easier to anticipate future challenges and apply the same principles to adapt to new situations, fostering continuous improvement and strategic growth in various contexts. Additionally, this approach helps align different perspectives, creates a shared understanding, and facilitates the smoother implementation of decisions.

1.2.1 Target company

Metso is a global leader in sustainable technology, solutions, and services, specializing in industries such as aggregates, mineral processing, and metals refining. Headquartered in Helsinki, Finland, Metso has a long history dating back to 1915, evolving over time through mergers, acquisitions, and innovations. (Törmä 2021). Today the company operates worldwide, with a strong presence in key markets across Europe, North America, South America, and Asia-Pacific (About us n.d.)

The company's offerings encompass a wide range of products and services aimed at improving efficiency, productivity, and sustainability. These include equipment for crushing, screening, grinding, and conveying, as well as automation and control systems for optimizing industrial processes. Metso's solutions are designed to help customers lower their operational costs, reduce environmental impact, and enhance safety, all while maintaining high performance standards. (Our business n.d.).

Aggregates is a segment of Metso that offers solutions for the production and processing of aggregate materials like crushed stone, sand, and gravel, which are used in construction projects such as roads, bridges, and buildings. The segment's offerings include machinery for crushing, screening, and conveying aggregates, as well as mobile and stationary equipment for quarrying and recycling applications. Metso Aggregates has over ten product families, each containing a range of products that can vary from as few as two to more than ten different products. (Aggregates n.d.).

Product Group + Product	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7	Location 8	Location 9	No Supply
Product group 1	X						X			
Product group 2	X						X			
Product group 3					X	X	X			X
Product group 4					X		X			X
Product group 5					X					X
Product group 6				X			X		X	
Product group 7				X			X			
Product group 8				X			X			
Product group 9	X				X		X		X	X
Product group 10					X		X		X	
Product group 11	X			X			X		X	X
Product group 12				X			X			
Product group 13				X						
Product group 14								X		
Product group 15							X	X		
Product group 16		X					X			X
Product group 17							X			
Product group 18			X				X			
Product group 19			X				X			
Product group 20					X		X			

Figure 1 Complexity of products and manufacturing locations

Figure 1 illustrates the existing distribution of manufacturing locations for each product group within the Aggregates segment. Each row in the figure corresponds to a specific product group, while the columns represent various factory locations. The presence of an 'X' indicates that a particular product group is manufactured at the corresponding site. There is significant variation in the distribution of manufacturing sites across different product groups. Furthermore, not every location necessarily produces all the products within a given product family.

1.3 Thesis framework and key concepts

The thesis is comprised of two main components: a theoretical framework and interviews conducted within the target company. The theory section outlines the key factors that have been previously identified as influencing the creation of the manufacturing footprint and the decision-making process. The interviews provide valuable insights from the perspective of the target company, offering practical perspectives. Together, these two data sets contribute to the development of the factors incorporated into the decision-making matrix. This tool simplifies the evaluation of various factors as part of the broader context, reducing the need for focusing on individual elements. Figure 2 shows the framework of the thesis:

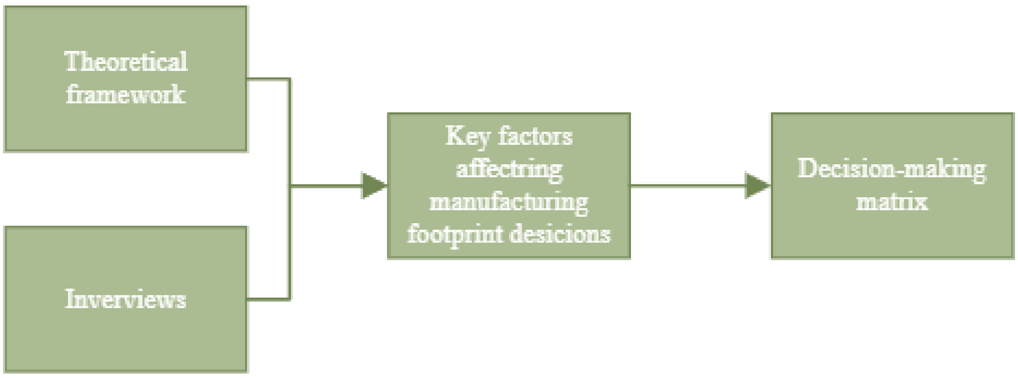

Figure 2 Thesis framework

The factors identified by the target company that influence the development of the manufacturing footprint, as shown in Figure 3, serve to strengthen both the theoretical framework and the interviews. These factors help streamline the theoretical framework, as the formation of the manufacturing footprint is influenced by a broad range of variables. By narrowing the focus to key areas, the complexity of the topic becomes more manageable. Furthermore, predefining the subject areas allows for more targeted and insightful interviews, ensuring that the data gathered is both relevant and practical. This focused approach not only enhances the quality of the interviews but also ensures that the theoretical framework is closely aligned with the company's real-world decision-making processes.

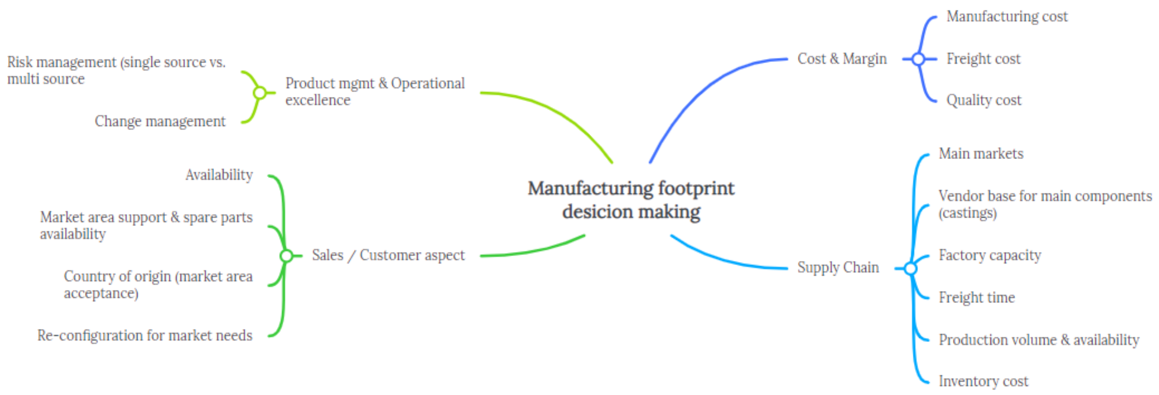

Figure 3 Different aspects in manufacturing footprint desicion-making

Factors affecting the manufacturing footprint decision-making process are divided into four different categories:

1. Cost and margin
2. Supply Chain
3. Sales / Customer aspect
4. Product Management and Operational Excellence

Cost & Margin involves assessing manufacturing costs, freight costs, and quality costs across different production sites. These financial factors directly influence the overall cost-effectiveness and profit margin of production operations. Analysing these costs helps to identify the most economically advantageous production locations, which enables their impact to be considered in decisions regarding for example, in product pricing and margins.

Supply Chain considerations include factors like the main markets served, vendor base for critical components (e.g. castings), factory capacity, freight time, production volume and availability, and inventory costs. This category aims to ensure that supply chain logistics and production capacity are optimized to meet market demands efficiently.

The Sales / Customer aspect centres on providing strong market support by guaranteeing spare parts availability, adapting to evolving customer needs with flexible configurations, and taking country-of-origin acceptance into account. By focusing on these elements, this category aims to boost customer satisfaction by ensuring that products are accessible, adaptable, and aligned with local expectations.

Product Management & Operational Excellence includes managing risks, especially around single vs. multi-source production strategies, and change management capabilities. A strong focus on operational excellence ensures resilience and adaptability to changing conditions, supporting long-term stability and quality.

These various factor categories are carefully weighted and assessed collectively to create a "final result," which serves as a balanced model for making manufacturing footprint decisions. The scoring system, potentially based on a predefined template, can assign "points" to each factor, quantifying the relative strengths of different manufacturing locations. This structured approach supports a data-driven, holistic view that aligns production decisions with broader strategic goals.

The most important concept of the thesis is the manufacturing footprint. A manufacturing footprint refers to the geographic distribution and configuration of a company's production facilities and operations. It encompasses the locations, capacities, and roles of factories, plants, and other manufacturing sites around the world. The manufacturing footprint determines where products are made, how production is allocated across different facilities, and which regions or markets each site serves. (Christodoulou 2007).

A default manufacturing location has been defined for each of the products manufactured by Metso's Aggregates business based on the destination country. Metso's division of market areas varies based on the specific purpose (such as finance or sales), leading to the manufacturing footprint being organized by country. This approach simplifies the management of the footprint, as it allows for multiple default manufacturing locations for the same products within same market areas. Figure 4 provides an example of how the manufacturing footprint is visualized for a specific product.

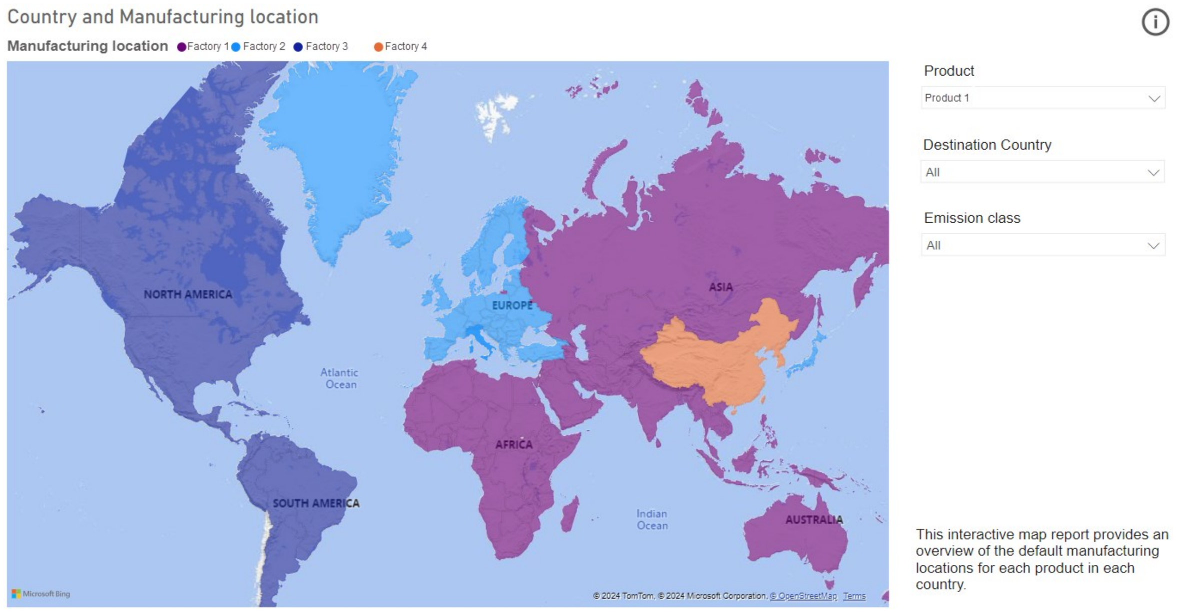

Figure 4 Destination country-specific manufacturing footprint

In the visualization, different colours represent specific factories, with each country assigned based on the delivery responsibility of a particular factory. When the product selection is changed, the map visualization dynamically updates to reflect the manufacturing footprint associated with that specific product. This allows users to quickly understand the distribution of production responsibilities and how they vary for different products, providing a clear overview of the manufacturing network and its geographic coverage.

The manufacturing footprint is utilized by a diverse range of users, including sales teams, product managers, and order handlers. Each group relies on the footprint for different purposes, such as determining optimal production sites, managing logistics, and coordinating customer orders. This widespread usage ensures that the footprint plays a critical role in decision-making across various functions, supporting efficient operations and strategic planning.

1.4 Research question and limitations

Because the manufacturing footprint tool is used by several different users with different needs, change requests or suggestions also come frequently. These requests typically aim to boost sales, but the reasons can vary. Sometimes, it's too challenging to arrange shipping to the destination country from the default factory, or the transit time is too long or expensive. In other cases, the delivery time offered by the factory is too far out, resulting in lost sales if a quicker delivery cannot be arranged. There are also cases where the price is not competitive with competitors, leading to a search for lower manufacturing costs at a different factory to provide a larger discount while still preserving the profit margin. Sometimes the terms of sale may have a limiting factor that requires, for example, a machine manufactured in Europe (EU-funding).

The objective of this study is to identify all the critical factors that influence decision-making related to the manufacturing footprint. By examining various elements involved in this process, the research aims to provide a comprehensive understanding of the underlying dynamics. Specifically, it seeks to answer the question, "*What are the main factors that impact the decision-making process regarding the manufacturing footprint?*". This inquiry will cover a diverse array of aspects, including economic, logistical, and strategic factors. By highlighting these elements, the research hopes to offer valuable insights that can aid in decision-making and clarify how different factors influence the process. This knowledge will facilitate better-informed choices that align with broader objectives.

In addition to the fact that there are many influencing factors, their impact can also differ significantly depending on whether the product is new or already part of the standard production line. In new products, aspects such as market demand, production costs and know-how to build complex machines can be more important. On the other hand, for products that are already in standard production, the focus can shift to optimizing efficiency, managing supply chains and responding to customers' existing needs. This difference highlights the complexity of decision-making processes, as strategies must be adapted to accommodate the unique circumstances surrounding each product type. As a result, the thesis will address the additional question, *"How do these factors differ between standardized products and new products?"*.

The topic of the thesis is limited to the use of existing manufacturing locations and does not cover the exploration of new sites, as decisions regarding new locations involve more significant strategic considerations. Focusing on current facilities allows for a more in-depth analysis of optimizing the existing manufacturing footprint without the complexities associated with establishing new production sites.

The thesis also only briefly touches on aspects related to procurement and sourcing, such as supplier capacity or networks. These topics are so extensive that they have been intentionally excluded from the scope of this study. By narrowing the focus, the research can concentrate more effectively on the other key factors influencing the manufacturing footprint.

Leaving out these aspects can impact the reliability or credibility of the thesis in several ways. For instance, procurement-related factors such as supplier capacity and networks can be significant in deciding the manufacturing location. Ignoring these factors might result in some important considerations being overlooked, potentially leading to an incomplete or one-sided overall picture. On the other hand, these limitations can also enhance the clarity and depth of the research by focusing solely on well-defined questions.

2 Global supply chains

This chapter provides a clear and practical overview of global supply chains, focusing on their structure, purpose, and importance in today's business world. It starts by explaining supply chain management (SCM), including its main goals and principles, and looks at how SCM is used in the manufacturing industry to improve efficiency and stay competitive.

The chapter also discusses common challenges that global supply chains face. Managing supply chains that span across countries comes with many difficulties, such as coordinating operations over long distances, dealing with sudden changes in customer demand, running out of raw materials, transportation delays, and handling differences in cultures and business practices. These challenges require creative and flexible solutions to keep supply chains running smoothly, even when unexpected problems occur.

Lastly, the chapter explores ways to make supply chains more resilient and better prepared for risks. It highlights the need for careful planning to identify potential risks, building strong capabilities to adapt to changes, and having clear strategies to respond quickly to disruptions. By covering these topics, the chapter gives readers an easy-to-follow understanding of how global supply chains work and why they are so important in the manufacturing industry.

A supply chain (SC) encompasses all entities, both directly and indirectly, involved in meeting a customer's needs. This network includes not only manufacturers and suppliers but also warehouses, transporters, retailers, and even the end customers. Each organization within the supply chain, such as a manufacturer, integrates various functions working collaboratively to process and fulfill customer requests. These functions may include marketing, new product development, finance, distribution, operations, and customer service. (Chopra & Meindl, 2016.)

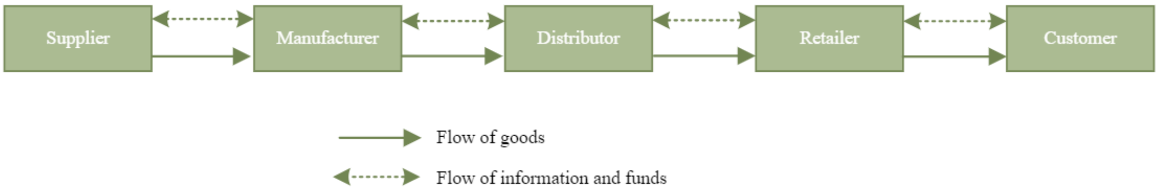

Figure 5 Basic supply chain (Chopra & Meindl, 2016)

The flow of materials, information, and funds between these entities is critical to the smooth operation of the supply chain. Figure 5 illustrates a simplified structure of a supply chain, showing the flow of goods, information, and funds. In this system, the flow of goods progresses from the supplier through the manufacturer, distributor, and retailer before reaching the customer. This unidirectional flow represents the movement of raw materials, components, and finished products. At the same time, the flow of information and funds moves in both directions along the chain. Suppliers, manufacturers, distributors, and retailers exchange information about demand, inventory levels, and order statuses, while funds move backward from customers to retailers and eventually to suppliers. (Chopra & Meindl, 2016.)

A global supply chain extends this concept beyond domestic borders, connecting entities and processes across multiple countries. It integrates suppliers, manufacturers, logistics providers, and retailers worldwide to deliver products and services to customers in different regions. In such system, raw materials may be sourced from one country, production carried out in another, and distribution spanning several continents before reaching the end customer. This interconnected network leverages the comparative advantages of various regions, such as cost efficiency, specialized expertise, or access to specific resources. (Christopher, 2011.)

Designing an efficient and resilient supply chain involves critical decisions, such as determining the number and placement of production facilities, allocating capacity at each site, assigning market regions to specific locations, and selecting suppliers for sub-assemblies, components, and raw materials. Furthermore, supply chain design must account for factors such as cost optimization, risk management, and compliance with regulatory standards. Effective design ensures the supply chain not only meets current demands but is also prepared for future challenges. (Chopra & Meindl, 2016.)

To thrive in today’s competitive landscape, companies must integrate into global supply chains. Effective management of these networks requires continuous refinement of activities and processes. Success depends on improving the flow of raw materials, finished goods, finances, and information. Additionally, optimizing logistics costs and enhancing satisfaction levels for both shareholders and consumers are essential for achieving long-term success. (Milovanovic, Milovanovic & Radisavljevic, 2017.)

An efficient and effective supply chain is critical for achieving a sustainable competitive advantage, helping companies secure their position in the global market. However, managing global supply chains is inherently challenging due to their complexity and uncertainty, which can hinder companies from fully capitalizing on their potential advantages. (Drake, 2012.) To remain competitive, supply chains must be cost-effective, responsive, flexible, and agile, ensuring the right products are delivered in the right quantity, at the right time, and in the right place (Milovanovic et al., 2017).

Koberg and Longoni (2019) emphasize the critical role of sustainability in the management of global supply chains, while Hallikas, Immonen, and Brax (2021) identify digitalization and big data as transformative forces reshaping supply chain management. According to Milovanovic et al. (2017), China has emerged as the preferred hub for major manufacturers, whereas India has become a focal point for the service sector. These examples underscore the diverse approaches and considerations involved in managing global supply chains, illustrating the complexity of this field.

2.1 Supply chain management

Supply chain management (SCM) has evolved since the 20th century, transitioning from a primarily domestic activity to a globalized phenomenon. This shift requires managers to address the complexities of cross-border operations, such as navigating diverse regulatory environments, managing longer lead times, mitigating geopolitical risks, and responding to fluctuating currency exchange rates. (Meixell & Gargeya, 2005.) Modern global supply chains face additional challenges stemming from geopolitical, technological, and economic uncertainties, which increase the complexity of their networks (Chang, Iakovou & Shi, 2020).

Supply chain management plays a vital role in enhancing competitiveness by optimizing inventory levels, streamlining process cycles, and mitigating risks and uncertainties to meet customer demands and maximize profitability (Park, Shin, Chang & Park, 2009). Recognizing this, executives and managers at all levels increasingly prioritize effective supply chain management as a key driver of their organization’s overall performance and competitive edge (Drake, 2012).

Supply chain management involves efficiently organizing the flow and storage of materials, in-process inventory, finished products, and associated information from their origin to the final point of consumption to meet customer demands. Its primary objective is to transform a company’s supply chain into a highly efficient, customer-focused system, prioritizing the performance of the entire supply chain over the effectiveness of individual departments or units. (Prater & Whitehead, 2013.)

Global supply chain design broadens the concept to encompass the selection of facilities in international locations, considering the unique factors associated with globalization. These design decisions can either be decentralized, allowing individual managers at each facility to make independent choices, or centralized, ensuring decisions are coordinated across all facilities. Ideally, these decisions align with the company's overarching supply chain strategy to maintain consistency and achieve strategic goals. (Meixell & Gargeya, 2005.) SCM emphasizes the integration and optimization of key business processes, including product design, planning and forecasting, order management, inventory management, order fulfilment, and return management (Prater & Whitehead, 2013).

2.2 SCM in manufacturing industry

A manufacturing strategy can be described as a unified set of decisions that influence a company's capability to achieve its long-term goals, meet market demands, and fulfil manufacturing responsibilities. Selecting the optimal manufacturing strategy is challenging due to the extensive range of options and limitations that businesses encounter. (Olhager &

Feldmann, 2017.) A manufacturing network, which is an aggregation of plants located in different places, offers significant advantages to companies. Manufacturing companies with multiple plants can benefit greatly by managing them as part of a connected manufacturing network, gaining valuable insights into markets, products, and processes. (MacCormack, Newman, and Rosenfield, 1994.)

With increasing global competition and the growing complexity of business environments, managing an integrated international network has become a key priority for managers (Ferdows, 1997). In these networks, strategic decisions must consider both the broader network and individual plant operations. This makes developing the right manufacturing strategy far more complex than for single-plant operations. This challenge is made even more difficult by trends like distributed manufacturing, involving more actors and where manufacturing takes place at multiple locations. (Olhager & Feldmann, 2017.)

Supply chain management is typically structured into three distinct phases: the strategic phase, the planning phase, and the operational phase (Figure 6). Each phase plays a crucial role in ensuring the efficiency and responsiveness of the supply chain. Together, these three phases ensure that supply chain management is aligned with both long-term goals and immediate operational needs, balancing strategic vision, planning execution, and operational efficiency. (Chopra & Meindl, 2016.)

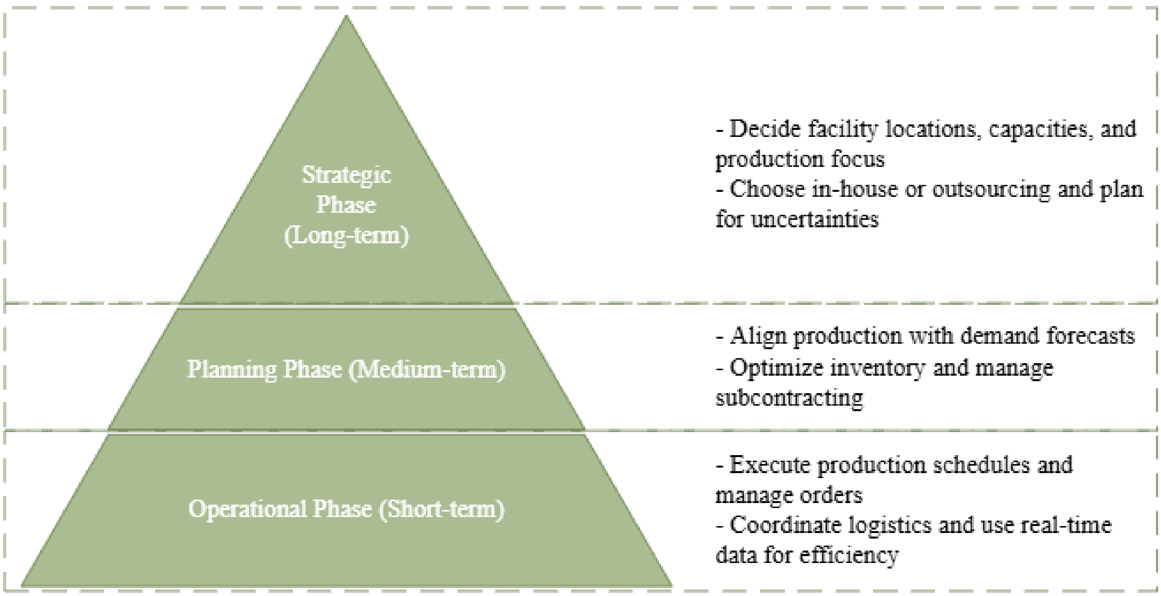

Figure 6 Supply chain management phases

In the strategic phase of supply chain management, companies define the structure of their supply chain for the long term, often spanning several years. From a manufacturing perspective, this involves decisions about whether production processes should be kept in-house or outsourced, which impacts cost structures, quality standards, and supply chain flexibility. A key consideration is the type of production facilities: flexible facilities can handle diverse products but are less efficient, while dedicated facilities are more efficient but limited to specific products. Companies must also decide whether facilities will focus on a single product or specific functions. Product-focused facilities handle all processes for one product, promoting expertise but limiting flexibility, while functional-focused facilities specialize in specific tasks for multiple products. These choices are critical in balancing efficiency and flexibility in the supply chain. (Chopra & Meindl, 2016.)

An essential aspect of supply chain strategy is selecting facility locations and determining their capacities. These decisions depend on factors such as access to raw materials, skilled labour, and infrastructure, which influence efficiency and costs. Equally important is assessing a facility’s capacity to balance efficiency and responsiveness. (Prater & Whitehead, 2013). Excess capacity enables flexibility to handle demand fluctuations but increases operational costs, while minimal excess capacity boosts efficiency per unit but limits adaptability. High-utilization facilities maximize efficiency but often lack the flexibility to respond to sudden demand changes. Companies must carefully balance these trade-offs to ensure their supply chain remains both cost-effective and agile. (Chopra & Meindl, 2016.)

Companies also decide which products to manufacture or store at specific sites, identify appropriate transportation modes, and implement information systems to ensure coordination throughout the supply chain. These decisions are expensive to alter and must consider uncertainties like market demand shifts and raw material availability over the planning horizon. (Chopra & Meindl, 2016.)

During the planning phase, supply chain design constraints are fixed, and the focus shifts to a medium-term horizon of about a quarter to a year (Chopra & Meindl, 2016). Manufacturing decisions center on aligning production schedules with demand forecasts, optimizing inventory levels, and managing subcontracting for specific production needs (Cristopher, 2011). Companies determine which markets will be served from which production facilities, define policies for inventory management, and schedule promotions to influence demand patterns (Chopra & Meindl, 2016). With better forecasts and shorter time frames, this phase emphasizes efficient use of capacity and minimizing costs, leveraging flexibility built into the strategic phase to adapt to unforeseen changes (Prater & Whitehead, 2013).

In the operational phase, decisions focus on short-term activities, often on a daily or weekly basis, to handle individual customer orders and manage production workflows (Chopra & Meindl, 2016). For manufacturers, this includes running production schedules, releasing shop floor orders, and ensuring the seamless execution of tasks to meet specific customer demands. Real-time data and reduced demand uncertainty allow firms to allocate inventory and production efficiently, prioritize customer orders, and manage logistics. (Fang, Huang & Li, 2013) Tasks include sequencing production activities, managing quality control, and coordinating transportation schedules to meet delivery commitments promptly. By aligning short-term execution with broader planning and strategic goals, manufacturing functions contribute to an efficient and responsive supply chain that meets customer expectations while optimizing costs and resources. (Chopra & Meindl, 2016.)

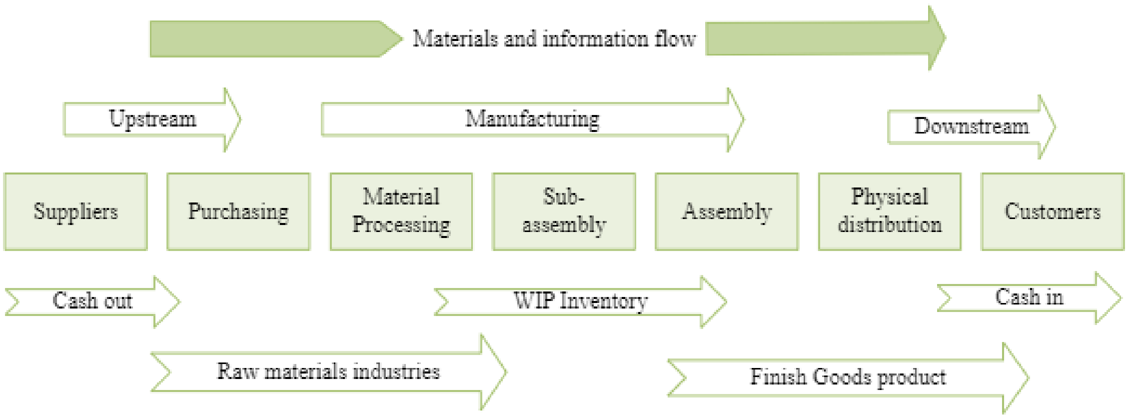

Figure 7 The flow of SCM in the manufacturing industry (Karim & Habib, 2022)

Figure 7 illustrates the flow of supply chain management (SCM) in the manufacturing industry, highlighting key stages: upstream, manufacturing, and downstream. In the upstream phase, raw materials are sourced and processed. Manufacturing involves adding value to these materials through sub-assembly and assembly to create finished products. Downstream focuses on distributing the end products to customers. (Karim & Habib, 2022.)

In the process of manufacturing illustrated in Figure 7, which involves turning raw materials into finished goods to meet consumer demand, SCM functions across both upstream and downstream phases. The intensified global competition presents challenges for manufacturers, including waste elimination, technology innovation, improving supplier-customer relations, complying with regulations, and adopting efficient inventory management. These challenges impact operational efficiency and overall performance. (Karim & Habib, 2022.)

Mishra, Singh & Subramaniam (2021) classified disruptions in supply chains caused by the COVID-19 pandemic into three main categories: supply disruptions, logistics disruptions, and demand disruptions. Demand disruptions may manifest as customer hoarding tendencies, infrequent purchasing patterns, or a reduced customer base, all of which destabilize the predictability of demand and complicate inventory management. On the supply side, disruptions like raw material shortages and supplier failures hinder production schedules and create bottlenecks in the supply chain. Logistics disruptions, including delivery failures and delays, further compound these issues by impeding the timely flow of goods between nodes in the supply chain. (Mishra et al. 2021.)

Similarly, Habermann, Blackhurst & Metcalf (2015) identified supply-side disruptions, internal or process-related disruptions (as noted by Parast and Subramanian, 2021), and customer-side disruptions. A common theme emerges from these studies: disruptions can occur at any stage of a company's supply chain, whether at the beginning (upstream supply chain), within internal processes, or at the end (downstream supply chain). This categorization is comprehensive, as it effectively encompasses the entirety of the supply chain. (Habermann et al., 2015.)

Moreover, these disruptions do not occur in isolation but are influenced by the broader macro environment, often amplifying one another. For instance, the bullwhip effect demonstrates how small uncertainties or fluctuations in customer demand can magnify as they move upstream in the supply chain, creating significant instability in production and inventory levels (Chopra & Meindl, 2016). Understanding the multifaceted nature of these disruptions is critical for developing effective risk mitigation strategies and ensuring the resilience of supply chain networks.

The increasing complexity of supply chains, driven by global sourcing and fluctuating demand, further complicates the task of balancing cost, quality, and delivery times (Kottala & Herbert, 2020). Manufacturers must continuously adapt to disruptions, such as raw material shortages or transportation delays, by implementing more resilient and flexible SCM strategies (Chopra & Meindl, 2016).

2.3 Issues in global supply chains

In recent years, managers have increasingly turned to international manufacturing sources, whether through company-owned facilities or external suppliers, to capitalize on reduced costs, higher revenues, and enhanced reliability. Establishing foreign factories offers several advantages, including tariff and trade concessions, access to low-cost labour, capital subsidies, and lower logistics expenses when serving foreign markets. (Ferdows, 1997.) Additionally, manufacturers benefit from direct access to overseas markets, opportunities for organizational learning by staying close to customers, and improved reliability due to proximity to key suppliers (Meixell & Gargeya, 2005).

Experts argue that managing global supply chains is more complex than handling domestic ones (MacCarthy & Atthirawong, 2003). The significant geographical distances involved not only increase transportation costs but also complicate decision-making due to inventory tradeoffs caused by longer lead times (Christopher, 2011). Differences in local cultures, languages, and business practices further hinder the efficiency of critical processes like demand forecasting and material planning. Additionally, developing countries often face infrastructural challenges in transportation and telecommunications. They also encounter issues such as limited worker skills, supplier shortages, inconsistent quality, and outdated equipment and technology. These challenges, which are less common in developed nations, can undermine the competitive advantages of a global supply chain. (Meixell & Gargeya, 2005.)

Global supply chains face unique risks that can disrupt performance, such as fluctuations in currency exchange rates, economic and political instability, and shifts in regulatory policies (Milovanovic et al., 2017). Currency variations, for instance, directly impact the cost of goods purchased in foreign currencies, affecting both purchasing strategies and overall financial outcomes (Drake, 2012).

MacCarthy and Atthirawong (2003) conducted a study that identified numerous challenges associated with the international location decision process. They emphasized the complexity of decision-making, highlighting key difficulties such as the involvement of numerous factors in the decision process, challenges in obtaining accurate information and engaging the right personnel, management-related issues, and the need to align new locations with existing manufacturing resources and technology.

Moreover, the study underscored the importance of balancing cost considerations, such as labor and logistics, with strategic factors like access to new markets and proximity to suppliers. Effective decision-making also requires firms to evaluate the long-term sustainability of a location, including its infrastructure, political stability, and environmental impact. Misalignment between a chosen location and existing operations can lead to inefficiencies, higher operational costs, and disruptions in supply chain flows (Christopher, 2011; Meixell & Gargeya, 2005).

To navigate these challenges, MacCarthy and Atthirawong (2003) suggested adopting a structured, multi-criteria decision-making approach that integrates both quantitative and qualitative factors. This enables firms to assess not only the financial implications of location decisions but also their broader strategic and operational impacts. Recent studies have built on these insights, advocating for the use of advanced tools like scenario analysis and predictive modeling to improve the accuracy of location assessments and mitigate risks associated with international expansions (Paul, Agarwal, Sarker and Rahman, 2023; Milovanovic et al., 2017).

Paul et al. (2023) classifies supply chain risks into four categories: environmental, economic, technical, and operational, and human-related risks. Environmental risks arise from uncontrollable external factors such as natural disasters, unreliable suppliers, shifting customer preferences, competitor actions, and rapid technological changes, all of which disrupt supply, demand, production, and overall network management. Economic risks include inflation, global recessions, and domestic financial losses that impact the entire supply chain. Technical and operational risks involve issues like production failures, insufficient expertise, and capacity shortages, which hinder the ability to meet demand surges and drive-up costs. Human-related risks stem from poor decision-making, lack of coordination, inadequate logistics management, and delays or inefficiencies in top-management actions. These risks collectively pose significant challenges to supply chain stability and performance. (Paul et al., 2023.)

Global supply chains offer significant advantages, such as cost efficiency, access to new markets, and improved learning opportunities, but they also present considerable challenges and risks (Pagano & Gyimah, 2017). The complexity of managing global operations arises from factors like geographical distances, cultural differences, and varying levels of infrastructure, particularly in developing regions (Khan, Ahmed & Waseem, 2023). These challenges, compounded by environmental, economic, technical, and human-related risks, can disrupt supply chain performance and reduce reliability (Paul et al. 2023). To succeed, companies must navigate these uncertainties by adopting robust strategies, leveraging technology for better decision-making, and fostering resilience in their supply chain networks. The ability to balance these opportunities and risks is critical to maintaining competitiveness in the global market. (MacCarthy & Atthirawong, 2003.)

2.4 Resilience and risk management

In today's highly competitive business landscape, companies face numerous risks and uncertainties within their supply chains. To navigate these challenges, they are adopting strategies aimed at both managing disruptions and building resilience into their operations. (Sultana, Paul, Tasmin, Dutta & Khan, 2024.) A resilient supply chain is essential for maintaining flexibility and adapting to the ever-changing dynamics of global markets. It is not sufficient to design and operate supply systems that are merely efficient and effective; they must also possess the ability to withstand, respond to, and recover from disruptions while maintaining steady-state operations at an acceptable cost and within a reasonable timeframe. (Ribeiro & Barbosa-Povoa, 2018.)

Resilience means being ready for disruptions, responding quickly during a crisis, and recovering effectively to keep things running smoothly. Supply Chain Risk Management (SCRM) plays a key role in this process. It focuses on identifying, assessing, and managing risks tied to global distribution, information flow, and communication systems. (Sultana et al., 2024.)

SCRM goes beyond merely anticipating unexpected events and disruptions; it also focuses on ensuring that supply chains operate at the desired level during such situations (Trkman, Oliveira & McCormack, 2016). Risk management is utilized to prevent disruptions from impacting the continuity of supply chain flows and operations while minimizing their overall effects (Scheibe & Blackhurst, 2018). Therefore, effective strategies for mitigating supply chain risks require thorough preparation, the ability to respond to disruptions, and ensuring flexibility within supply chains (Trkman et al., 2016).

Supply chain disruptions are defined as events that interfere with the regular movement of goods and materials within a supply chain (Parast & Subramanian, 2021). Supply chain disruptions can affect the entire supply chain, impacting upstream, internal, and downstream operations (Habermann et al., 2015). For instance, disruptions in upstream supply can lead to delays within internal processes, which then affect the ability to meet customer demands on time (Parast & Subramanian, 2021). Similarly, sudden changes in downstream demand, such as sharp increases or decreases, can create challenges for upstream suppliers in planning and fulfilling orders (Singh, Kumar & Kumar, 2023). Additionally, internal disruptions related to capacity often arise when demand fluctuates. For example, firms may struggle to cope with surges in demand, or conversely, face underutilized capacity and excess inventory when demand decreases. (Paul et al., 2023.)

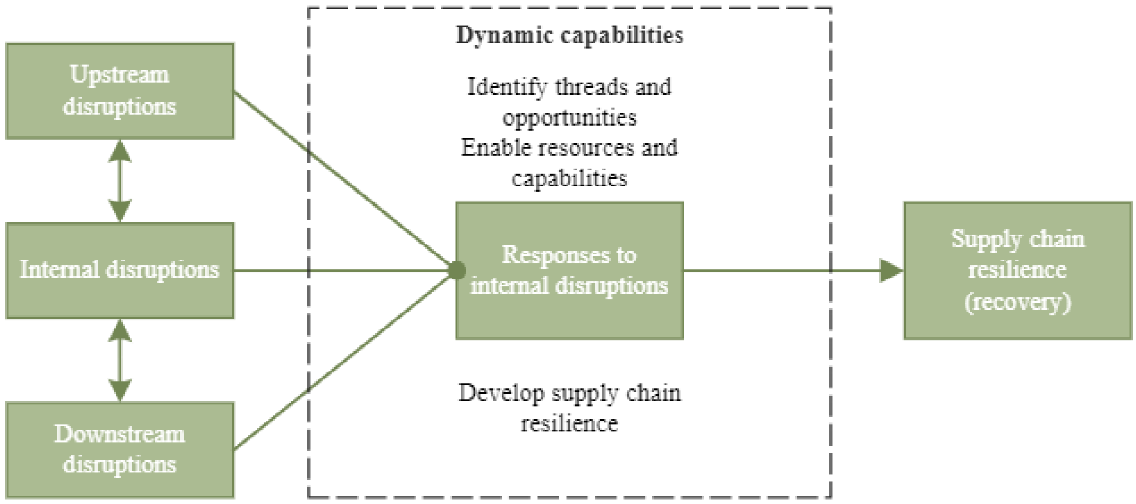

Figure 8 Supply chain disruptions (Nel, 2024)

Figure 8 illustrates a framework for building supply chain resilience by addressing disruptions through dynamic capabilities. The model identifies three types of disruptions: upstream, internal, and downstream. Upstream disruptions originate from suppliers and include challenges such as raw material shortages or delays in delivery. Downstream disruptions occur closer to the end customer, such as fluctuations in demand, customer hoarding tendencies, or logistical failures. Internal disruptions are related to inefficiencies or failures within the company's operations, such as production breakdowns or process-related issues. (Habermann et al., 2015.)

The framework highlights the role of dynamic capabilities in managing these disruptions. Dynamic capabilities allow organizations to identify threats and opportunities, as well as mobilize resources and develop the skills required to respond effectively. These capabilities enable the development of strategic responses to internal disruptions, which in turn enhance the overall resilience of the supply chain. (Nel, 2024.)

The outcome of this process is supply chain resilience, shown on the far right of the diagram, which refers to the ability to recover and maintain stability after disruptions. Figure 7 emphasizes that resilience is not achieved in isolation but through coordinated efforts to address and mitigate disruptions across all levels of the supply chain. (Nel, 2024.)

Several strategies have emerged to enhance resilience in the face of disruptions. Diversifying suppliers and manufacturing locations reduces reliance on a single source, thereby spreading the risk of potential failures. This approach ensures that if one part of the supply chain is disrupted due to factors such as natural disasters or political instability, other parts of the network can absorb the impact. (Bhatnagar & Sohal, 2005.) Nearshoring, or relocating manufacturing closer to key markets or core suppliers, helps reduce risks associated with long lead times, customs challenges, and logistical inefficiencies often linked to long-distance supply chains (Piatanesi & Arauzo-Carod, 2019). Additionally, relying on multiple suppliers for critical components or materials, known as multi-sourcing, provides extra security by ensuring that the failure of any single supplier will not disrupt production (Wu, Wang & Shang, 2019).

To further enhance risk management, companies are increasingly relying on predictive analytics and scenario planning. Predictive tools help forecast potential disruptions by analyzing data patterns and identifying vulnerabilities within the supply chain. For example, real-time data on geopolitical events or economic shifts can provide advanced warning of disruptions, enabling companies to adjust their strategies before issues arise. Scenario planning, on the other hand, allows businesses to simulate different risk scenarios, evaluate the impact of these disruptions, and develop response strategies for each. (Paul et al., 2023.)

These risk mitigation strategies are critical not only for protecting against disruptions but also for maintaining the efficiency and competitiveness of a company's supply chain (Christopher, 2011). Firms that strategically manage their supply chain networks, through diversification, nearshoring, multi-sourcing, and advanced planning tools, are better positioned to respond to unforeseen challenges, ensuring continuity of operations and safeguarding their market position. As global markets become more volatile and supply chains more complex, integrating these resilience-building strategies will be essential for companies aiming to stay competitive and sustainable in an increasingly uncertain world. (Paul et al., 2023.)

3 Manufacturing footprint

The decision regarding plant location is one of the key factors influencing supply chain performance (Bhatnagar & Sohal, 2005). Choosing the right locations for product manufacturing is crucial for strategic and logistical planning in manufacturing firms. Ideal locations can provide a competitive edge and significantly impact the success of a business. (MacCarthy & Atthirawong, 2003.) Decisions regarding the manufacturing footprint are critical to several key aspects of a firm's supply chain performance, including lead time, inventory levels, responsiveness to demand fluctuations, flexibility, and quality. As efficient supply chain management increasingly becomes a competitive advantage, the importance of facility location decisions is further amplified. (Bhatnagar & Sohal, 2005.)

Adjusting the manufacturing footprint is a common practice of doing business in many industries (Christodoulou, 2007). The term *manufacturing footprint* refers to the geographic distribution of a company's manufacturing facilities and operations, encompassing the locations, capacity, and specialization of plants, as well as their integration within the supply chain. It reflects strategic decisions about where and how a company produces its goods to optimize factors such as cost, lead time, and responsiveness to market demands. (Friedli, Lanza & Remling, 2021.)

Decision-making regarding the manufacturing footprint involves numerous other strategic considerations. These include adopting new technologies and leveraging big data across different production locations, managing risks in a decentralized manufacturing setup, enhancing the resilience of the network, and transferring production expertise within a global operational framework. These strategic objectives are implemented through operational tasks such as managing the allocation of resources and products to various plants, embedding lean practices and operational excellence across the global network, and monitoring the performance of individual facilities. (Friedli et al., 2021.)

The manufacturing footprint is often described as the allocation and geographic distribution of production facilities, designed to support a firm's overall operational strategy (Shi & Gregory, 1998). This concept encompasses factors such as production capacity, supply chain integration, and the coordination of operations across global locations. A well-structured manufacturing footprint plays a strategic role in supply chains by aligning production sites with key customer markets. This alignment not only reduces logistics costs but also enhances the firm's agility in responding to fluctuations in demand. (Ferdows, 1997.)

In the era of globalization, designing an effective manufacturing footprint requires careful evaluation of various cost factors, including labor, materials, and transportation, as well as considerations of regulatory environments and proximity to innovation hubs (Cheng et al., 2015). Moreover, the manufacturing footprint significantly influences a firm's ability to manage risks and navigate disruptions. Flexibility and resilience emerge as essential qualities, enabling companies to adapt and sustain operations in an increasingly volatile global environment (Christopher & Peck, 2004).

The manufacturing footprint plays a crucial role in optimizing key supply chain performance measures. Factors such as lead time, inventory levels, time to market, quality, customer service, and flexibility are all directly impacted by how the manufacturing network is structured. A well-designed footprint ensures that these performance measures are aligned with business objectives, creating a more efficient and responsive supply chain. (Bhatnagar & Sohal, 2005.)

3.1 Manufacturing strategy and networks

Each production plant plays a specific role within the manufacturing footprint, shaped by the overall manufacturing strategy. To simplify understanding and provide a clearer structure, Ferdows (1997) categorized plants into six distinct roles, offering a framework to visualize how different plants contribute to the manufacturing network. These roles include the Offshore Factory, which is primarily focused on low-cost production for export, typically located in regions with inexpensive labor and fewer production complexities. The Source Factory is similar in its focus on cost efficiency, but it also adds value by leveraging specialized skills, technology, or processes, often contributing to higher-quality output or specific technical expertise. The Server Factory, on the other hand, is designed to supply particular local markets with customized products that meet regional needs, ensuring responsiveness and flexibility in the supply chain. (Ferdows, 1997.)

The Contributor Factory goes a step further by not only handling production but also playing a significant role in product design, process development, or continuous improvement. These factories contribute to the overall innovation of the manufacturing network and help optimize processes. The Outpost Factory serves as a hub for gathering critical information, such as market trends, technological advancements, or valuable skills that are then shared across the network. Lastly, the Lead Factory is the flagship of the manufacturing network, driving innovation, setting technological and operational standards, and influencing best practices across all plants. It serves as the primary source of knowledge and development for the entire network, ensuring that the manufacturing footprint remains competitive and adaptive to changes in the industry. (Ferdows, 1997.)

Ferdows' classification dates back nearly thirty years, and further research has indicated that the topic still requires more exploration (Olhager & Feldmann, 2017). Nonetheless, it remains valuable in demonstrating that not every factory is designed to be the same or serve the same function. This understanding is key when developing an effective manufacturing footprint, where each plant plays a unique role in optimizing the overall supply chain.

In addition to the six different factory roles, Olhager and Feldmann (2017) emphasize several key factors that influence decisions within manufacturing strategy. These factors play a crucial part in shaping how different plants within a network operate and complement each other. For instance, process decisions involve selecting the right manufacturing technologies and processes that align with the overall strategy, ensuring that production is efficient and adaptable across the network (Miltenburg, 2005). Capacity decisions are about determining how much production capacity each plant needs, considering demand fluctuations and the timing of capacity investments (Dekkers, 2002). These decisions are vital for coordinating production across multiple locations, preventing underutilized or overwhelmed plants (Miltenburg, 2005).

When it comes to facilities, each plant may focus on specific tasks or specialize in particular areas to contribute to the network’s strength. This kind of specialization allows the network as a whole to perform more efficiently by leveraging the strengths of each individual plant. (Miltenburg, 2005.) Vertical integration involves deciding whether to produce components in-house or outsource them, which impacts the selection of suppliers and affects the flow of materials within the network (Dekkers, 2002).

The organization and workforce factor looks at how plants are structured and the importance of developing a skilled workforce. A well-organized network of plants with competent employees ensures that manufacturing operations run smoothly and can meet strategic goals. Similarly, quality systems ensure that each plant adheres to high standards, using quality tools and continuous improvement programs to maintain consistency across the network and meet customer expectations. (Hayes & Wheelwright, 1984.)

Finally, planning and control systems help coordinate the long-term goals of the network with the day-to-day operations of each plant. This includes balancing long-term strategic planning with short-term adjustments, ensuring that the entire network operates efficiently, even as market conditions change. (Miltenburg, 2005.)

All these factors help shape the structure and coordination of manufacturing networks, ensuring that plants not only specialize according to their strategic priorities but also work together seamlessly to optimize production across the entire network. By carefully considering these elements, companies can build a manufacturing network that is agile, efficient, and capable of meeting customer demands on a global scale. (Olhager & Feldmann, 2017).

The figure 9 illustrates Ferdows' expanded research, which evolved from focusing solely on the roles of individual factories to examining the roles of entire manufacturing networks. In their 2016 study, Ferdows, Vereecke, and De Meyer introduced a framework to categorize a firm's plant network into different subnetworks based on two key dimensions:

a) The complexity and proprietary design of the products being manufactured, and

b) The complexity and proprietary design of the production processes used.

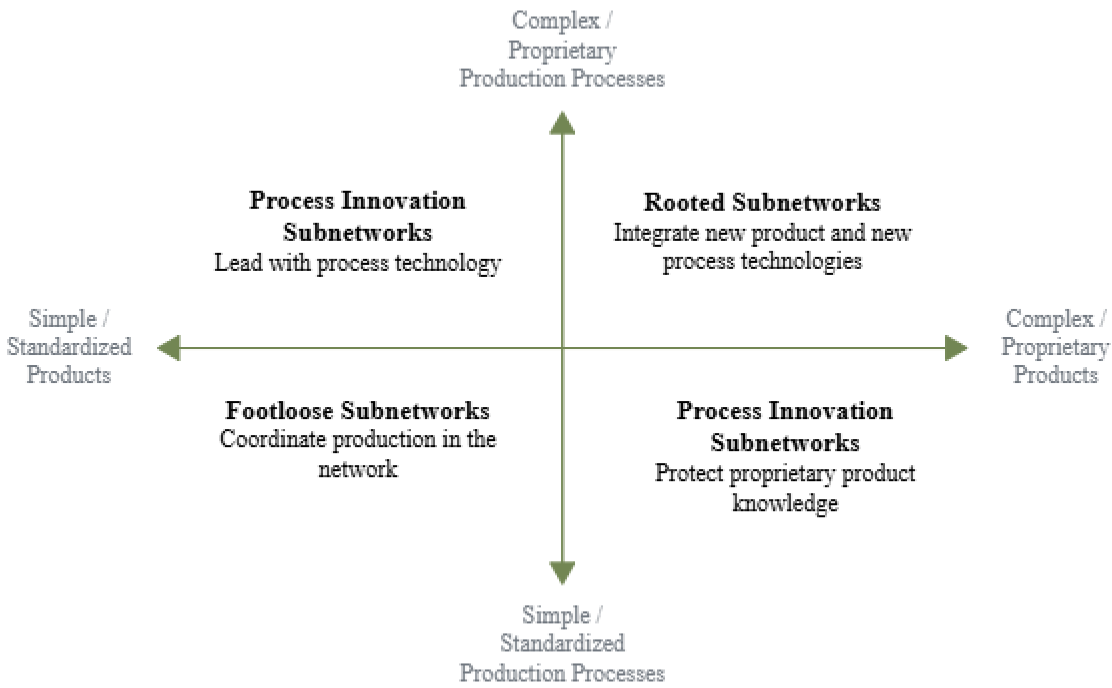

Figure 9 Framework for gauging plant subnetworks (Ferdows, Vereecke & De Meyer, 2016)

This framework, depicted in Figure 9, highlights four distinct types of subnetworks: Rooted Subnetworks, Process Innovation Subnetworks, Footloose Subnetworks, and Low Investment Subnetworks. It provides a practical tool for analyzing the global plant network at varying levels of granularity, whether for a division, a business unit, or an entire organization, depending on strategic needs (Ferdows, Vereecke & De Meyer, 2016).

Manufacturing networks that focus on specific outputs generally perform better than those trying to manage multiple, often conflicting objectives. By dividing these networks into subnetworks, firms can reduce complexity and streamline management and coordination efforts. The position of each subnetwork within the framework offers valuable insights into its manufacturing mission and the level of resources required to fulfil it. (Friedli et al., 2021.) Global production networks can typically be segmented into distinct subnetworks, each occupying a specific position within the framework based on the complexity and proprietary nature of the products or processes involved. Furthermore, a single plant may belong to more than one subnetwork if it produces a variety of products or employs different production processes, each with varying levels of complexity and specialization. (Ferdows et al., 2016.)

The framework categorizes plant subnetworks based on their roles and strategic focus within a manufacturing network. Rooted Subnetworks, located in the top-right quadrant, focus on producing advanced, uniquely designed products that require continuous research and frequent upgrades to both product and process technologies. Plants in these subnetworks, often referred to as "centers of excellence," play a key role in developing new production capabilities that can benefit the entire network. Building expertise in these areas requires stability, as the tacit knowledge essential for innovation develops locally through close collaboration between engineering and production teams. (Ferdows et al., 2016.)

Footloose Subnetworks, found in the bottom-left quadrant, focus on commodity-type products using standardized production processes. These plants prioritize minimizing production costs while maintaining quality and meeting delivery requirements, making cost-efficiency their primary mission. Process Innovation Subnetworks, situated in the top-left quadrant, employ sophisticated and proprietary production processes to manufacture relatively simple, commodity-type products. These subnetworks capitalize on advanced process technologies to enhance operational efficiency and maintain competitiveness. Low Investment Subnetworks, positioned in the bottom-right quadrant, produce mostly proprietary products using standard production processes. These plants generally play a less significant role in the company's competitive strategy and are not a primary source of competitive advantage. (Ferdows et al., 2016.)

By dividing manufacturing networks into these subnetworks, firms can effectively align plant capabilities with strategic goals, ensuring a more focused and efficient approach to production. A well-designed footprint integrates these subnetworks in a way that reflects the company's priorities, such as cost optimization, product innovation, or process excellence, enabling firms to compete effectively on a global scale. (Friedli et al., 2021.)

3.2 Factors affecting manufacturing footprint decisions

Footprint planning plays a crucial role in shaping the supply chain network and involves various approaches that consider total costs and investments (Melo, Nickel & Saldanha-da-Gama, 2009). A well-designed footprint should align with the company's value-creation process from both a supply chain and business perspective (Chopra & Meindl, 2010). To effectively define the footprint planning challenge, several key criteria must be considered. Integrating footprint decisions into the overall supply chain configuration is essential to ensure a network that operates efficiently in daily operations while also supporting long-term strategic goals. When evaluating different locations and supply chain setups, the resilience of a footprint scenario should be assessed across multiple factors, including cost, responsiveness, reliability, agility, and asset utilization. (Sprenger, Parlings & Hegmanns, 2014.)

While various skills are essential to address current and future challenges, cost pressure continues to be a constant concern, regardless of whether a manufacturing strategy is primarily cost focused. In manufacturing firms, productivity improvements can yield benefits for multiple stakeholders: customers may gain through lower prices, employees through higher wages, and shareholders through improved margins. This highlights the relationship between productivity and costs. As a result, many manufacturers seek to locate production in regions that provide access to cost-efficient labor. Ultimately, reducing costs remains one of the key factors influencing decisions about production capacities. (Friedli et al., 2021.)

The Sand Cone Model (Figure 10) offers a useful perspective on how manufacturing priorities, including cost, should be approached (Gold, Schodl & Reiner, 2017). While cost efficiency is often the driving force behind manufacturing footprint decisions, the model emphasizes that it should not come at the expense of other critical capabilities (Ferdows & De Meyer, 1990). According to the Sand Cone Model, sustainable competitive advantage in manufacturing is achieved by building capabilities in a specific sequence: quality forms the foundation, followed by dependability, then flexibility, and finally cost efficiency (Friedli et al., 2021).

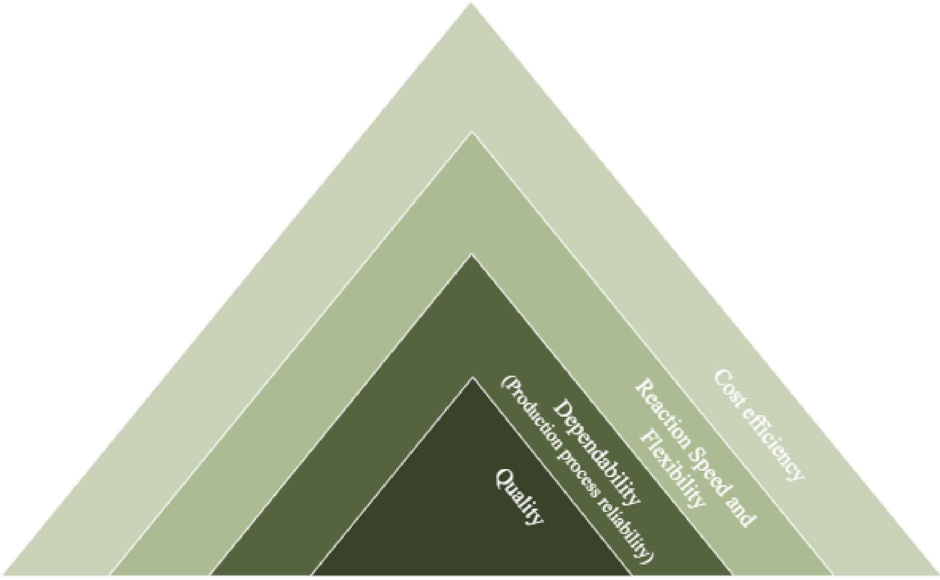

Figure 10 The sand cone model (Friedli et al., 2021)

This hierarchy shows that cost reductions work best and last longer when they are built on strong foundations like quality, reliable processes, and the ability to adapt to changes in the market (Friedli et al., 2021). For example, if quality systems are not in place, trying to save money with cheaper labour could lead to more defects, which might cancel out the savings and upset customers. In the same way, being dependable by ensuring smooth production and on-time deliveries is important to avoid problems that could ruin the benefits of focusing on lower costs. Flexibility is equally important, helping manufacturers quickly adapt to changes in demand or supply chain issues. This improves efficiency and strengthens the network. (Ferdows & De Meyer, 1990.)

Using the Sand Cone Model in footprint planning helps balance cost-saving goals with maintaining quality, dependability, and flexibility. This approach ensures cost savings are sustainable and keeps manufacturers competitive in a fast-changing global market. (Friedli et al., 2021.)

In MacCarthy and Atthirawong's (2003) study, panel members were asked to rate the importance of the major factors and their sub-factors generally in international location decisions. The factors were costs, infrastructure, labor characteristics, government and political factors, economic factors, legal and regulatory framework, proximity to markets/customers, proximity to suppliers, quality of life, characteristics of a specific location and social and cultural factors (Figure 11).

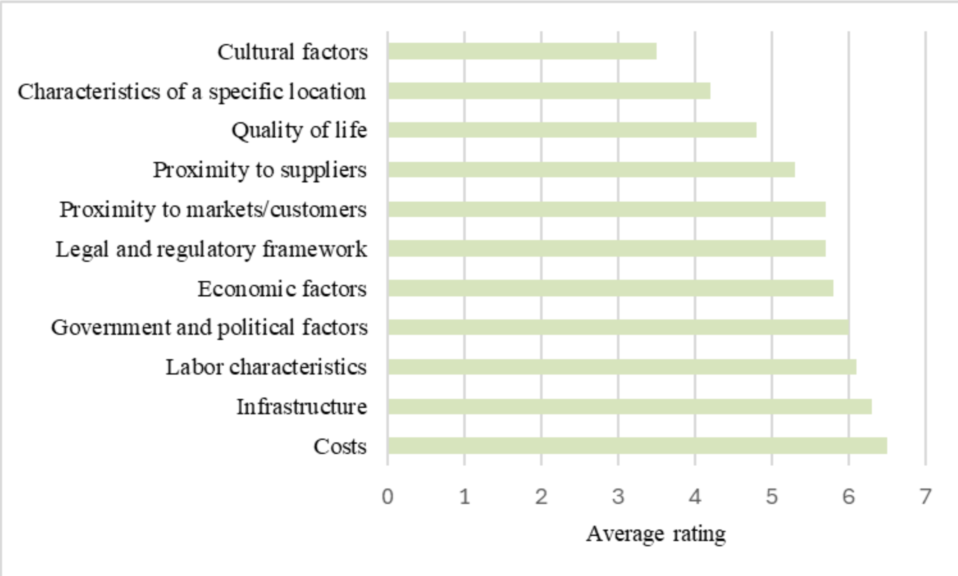

Figure 11 Key factors affecting international location decisions (adapted from MacCarthy and Atthirawong, 2003)

The study found that cost emerged as the most important factor influencing international location decisions. Costs included wage, transportation, fixed, energy, land, construction, and other costs. (MacCarthy & Atthirawong, 2003.) Milovanovic et al. (2017), Chopra & Meindl (2016) and Friedli et al. (2021) have also emphasized the impact of costs in creating supply networks and manufacturing footprints in their own studies.

While cost is a major factor in international location decisions, other aspects related to the manufacturing country itself also play a key role. Infrastructure, government stability, economic conditions, and legal regulations all shape the attractiveness of a location. Factors like the quality of transportation systems, government structure, tax policies, customs duties, and rules on moving profits abroad can significantly impact business operations. (MacCarthy & Atthirawong, 2003.) For instance, Paul et al. (2023) emphasized how the manufacturing country's environment directly affects the trade of goods produced there. Global economic challenges such as inflation, recession and geopolitical tensions can disrupt supply chains (Cavalcante, Frazzon, Forcellini & Ivanov, 2019). The COVID-19 pandemic in particular has highlighted that flexible, dynamic, and strategically managed supply chains are key to adapting to external changes (Paul et al. 2023).

Labor, quality of life, and cultural factors are all integral to the socioeconomic environment. The availability and quality of the workforce, community attitudes toward business and industry, the education system, and cultural aspects are all interconnected. (MacCarthy &

Atthirawong, 2003.) Prater & Whitehead (2013) highlight not only the importance of a skilled workforce but also the availability and reliability of suppliers. They also consider market access as a key competitive priority in global locations. The size and nature of the market, such as demand fluctuations and delivery time to market, are factors that must also be weighed when creating a manufacturing footprint (MacCarthy & Atthirawong, 2003).

Figure 12 presents all the major factors and sub-factors found by MacCarthy & Atthirawong. Their study found that the weight and importance of various factors are influenced by elements like the company’s strategy. Each location decision is unique, differing from others, so the significance of each factor can vary depending on the situation, industry, or market type. They also noted that these factors can sometimes be contradictory, while at other times complementary, making it challenging to establish general guidelines, as they are highly dependent on the specific company. (MacCarthy & Atthirawong, 2003.)

Costs
- Wage rates
- Transportation costs
- Fixed costs
- Energy costs
- Other costs
- Land costs
- Construction costs
- Other manufacturing costs

Infrastructure
- Existence of models of transportation
- Quality and reliability of modes of transporation
- Quality and reliability of utilities
- Telecommunication systems

Labor characteristics
- Quality of labour force
- Availaibility of labour force
- Motivation of workers
- Attitudes towards work and labour turnover
- Workforce management
- Lavour unions
- Unemployment rate

Government and political factors
- Record of government stability
- Consistency of government policy
- Attitude of government to inward investment
- Government structure

Economic factors
- Tax structure and tax incentives
- Custom duties
- Tariffs
- Financial incentives
- Strenght of currency against US dollar
- Business climate
- Interest rates/exchange controls
- GDP/GNP growth, income per capita
- Inflation
- Country's debt

Legal and regulatory framework
- Industrial relation laws
- Bureaucratic red tape
- Legal system
- Regulations concerning joint ventures/mergers
- Regulations on transfer of earnings out of country
- Compensation laws
- Environmental regulations
- Insurance laws
- Requirements of setting up local corporations

Proximity to markets/customers
- Size of market that can be served
- Responsiveness and delivry time to market
- Proximity to demand
- Population trends
- Nature and variance of demand

Proximity to suppliers
- Speed and responsiveness of suppliers
- Quality of suppliers
- Alternative suppliers
- Nature of supply process
- Competition for suppliers

Quality of life
- Community attitudes towards business and industry
- Standard of living
- Quality of environment
- Education system
- Climate, schools, churched, hospitals, recreation opportunities
- Crime rate

Characteristics of a specific location
- Quality of raw materials/resources
- Location of suppliers
- Availaiblity of space for future expansion
- Attitude of local community to a location
- Proximity to raw materials/resources
- Physical conditions

Cultural factors
- Culture
- Language
- Different norms and customs
- Customer characterictics

Figure 12 Factors and sub-factors affecting manufacturing footprint decisions

The motivations for decisions can range from the desire to achieve low production costs, the ability to access markets, tax incentives, or benefits from the host government. Motivations depend on the type of business and the nature of the operating environment. (MacCarthy & Atthirawong, 2003.) There can also be conflicts between motivations, such as when high quality is desired but low manufacturing costs are a priority. Evaluating these trade-offs can make it difficult to assess different criteria. (Friedli et al., 2021.) Therefore, a process or tool that simultaneously considers multiple criteria can help clarify decision-making (Thakkar, 2021).

4 Multi-criteria decision-making

Today's market dynamics are constantly changing with the rise of new technologies. Factors such as mass customization strategies, the need for highly complex parts, shorter product development cycles, a wide range of available materials, diverse manufacturing processes, and high costs related to production have made it essential to evaluate various criteria comprehensively as part of the manufacturing decision-making process. (Zaman, Rivette, Siadat & Mousavi, 2018.)

No decision can be made without considering the process of decision-making. Decision-making is a complex mental process used to solve problems and achieve a desired outcome by taking different factors into account. This process can be logical or based on instinct, and it may rely on either clear or hidden assumptions. Various factors, such as physical and biological conditions, culture, and social influences, can shape these assumptions. Additionally, elements like authority and risk levels can impact how complex the decision-making process becomes. (Taherdoost & Madanchian, 2023.)

Decision makers rely on intuition when handling problems with a single criterion, as the solution is straightforward, simply choosing the most preferred alternative. However, decision making becomes significantly more complex when multiple conflicting criteria with varying weightages must be considered. This complexity necessitates the development of methods that can balance tradeoffs between criteria and alternatives while addressing real life challenges and concerns of decision makers. (Thakkar, 2021.)

Multi-criteria decision-making (MCDM) methods have proven to be valuable in addressing complex problems that involve multiple criteria or conflicting perspectives (Rojas-Zerpa & Yusta, 2015). The primary goal of MCDM, also known as multi-criteria decision analysis (MCDA), is to systematically assign weights to various factors, ensuring a logical evaluation process. By establishing relationships between different factors, MCDM enables decision-makers to rank available alternatives based on their preferences, leading to well-informed and balanced choices (Kim, Shah, He & Kim, 2022).

The factors are usually conflicting, making the solution highly dependent on the preferences of the decision-maker and requiring a compromise. In most cases, multiple groups of decision-makers are involved in the process, each bringing different criteria and perspectives. These differences must be resolved within a framework of understanding and mutual compromise. (Pohekar & Ramachandran, 2004.) Selecting a set of potential and promising solutions from a non-dominated set is a complex task that requires a systematic approach. MCDM analysis ensures that the proposed solution is acceptable to the individuals or organizations affected by it. Additionally, the trade-offs evaluated through critical analysis in MCDM techniques help guarantee that the chosen solution will have an overall positive impact on the system, without optimizing one part of the system at the expense of another. (Thakkar, 2021.)

Decision-making is a structured and methodical process that consists of four key stages (Thakkar, 2021). The process begins with recognizing the problem, where decision-makers identify and define the issue that needs to be addressed. Understanding the context, determining stakeholders, and acknowledging constraints are crucial in ensuring that the problem is accurately framed. (Munier, Hontoria, Jiménez-Sáez, 2019.)

Once the problem is recognized, the next step is establishing preferences. This involves determining priorities and defining the criteria that will guide the evaluation of potential alternatives. (Thakkar, 2021.) Preferences may be influenced by factors such as cost, efficiency, sustainability, or stakeholder interests, helping to ensure that decisions align with the desired outcomes (Zaman et al., 2018).

Once preferences are established, decision-makers move on to selecting the appropriate MCDM method to evaluate various alternatives. This step involves generating and analyzing different options based on the predefined criteria. (Thakkar, 2021.) By choosing the right decision-making tools and methodologies, such as specific MCDM techniques, decision-makers can systematically assess the strengths and weaknesses of each alternative (Munier et al., 2019).

The final stage is selecting the most suitable option. Decision-makers compare the evaluated alternatives and choose the one that best meets the defined objectives and constraints. A structured selection process ensures that the decision is rational, well-informed, and aligned with organizational or personal goals. (Thakkar, 2021.)

By following these four key stages, recognizing the problem, establishing preferences, assessing alternatives, and selecting the best option, decision-makers are able to breakdown complex decisions into manageable steps (Thakkar, 2021). This structured approach provides a clear framework for evaluating the situation, prioritizing objectives, and considering various options. As a result, decision-makers can navigate through the uncertainties and trade-offs inherent in complex scenarios with greater clarity and confidence. Ultimately, this methodical process helps ensure that the chosen solution is the most effective and aligned with the desired goals, leading to more informed, balanced, and optimal outcomes. (Munier et al., 2019.)

4.1 MCDM methods

MCDM approaches are highly valuable in situations where policymakers need to prioritize and resolve conflicting objectives (Thakkar, 2021). Over the past few decades, various MCDM methods have been developed or refined by different researchers. The key differences between these methods lie in factors such as the complexity of the algorithms, the weighting techniques used for criteria, how preferences are represented and evaluated, the handling of uncertain data, and the types of data aggregation employed (Taherdoost & Madanchian, 2023).

MCDM methods are broadly classified into two main categories: Multi-Objective Decision-Making (MODM) and Multi-Attribute Decision-Making (MADM). MODM methods are typically used for design-related problems, while MADM techniques select the most suitable alternative from a given set. (Soltanifar, Tavana, Santos-Arteaga & Sharafi, 2023.)

MODM approaches focus on solving optimization problems that involve multiple objective functions. These methods are widely applied across various fields, including engineering, management, economics, medicine, and social sciences, to achieve balanced and efficient solutions. MADM methods are used when decision-makers need to evaluate and compare different alternatives. This process includes defining potential solutions, identifying key evaluation attributes, determining their significance, measuring performance across alternatives, and integrating the results to establish a ranked list of options for decision implementation. (Soltanifar et al., 2023.)

Examples of MODM methods include linear programming, goal programming, LINMAP, and the lexicographic approach, all of which are used to optimize multiple objective functions and find balanced solutions across various decision-making scenarios (Thakkar, 2021).

Several widely used MADM methods have been developed to assist in decision-making by evaluating and ranking alternatives based on multiple criteria. The Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) help structure complex decisions by breaking them down into hierarchical relationships (Taherdoost & Madanchian, 2023). Techniques such as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Elimination and Choice Translating Reality (ELECTRE) focus on comparing alternatives to an ideal solution or eliminating less favourable options (Thakkar, 2021).

Other prominent methods include VIsekriterijumska optimizacija KOmpromisno Resenje (VIKOR), which balances conflicting criteria (Rojas-Zerpa & Yusta, 2015), and the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), which ranks alternatives based on preference flows (Munier et al., 2019). Additionally, methods such as Simple Additive Weighting (SAW), Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA), and Complex Proportional Assessment (COPRAS) provide systematic approaches for weighting and evaluating criteria. More advanced techniques are Complex Proportional Assessment with Grey Relations (COPRAS-G) and Stepwise Weight Assessment Ratio Analysis (SWARA). (Thakkar, 2021.)

The Weighted Sum Model (WSM) is a widely used and the simplest MCDM method for evaluating multiple alternatives based on multiple criteria, particularly in single-dimensional problems (Pohekar & Ramachandran, 2004). Given *M* alternatives and *N* criteria, where all criteria are benefit criteria (higher values indicate better outcomes), WSM calculates the total importance of each alternative as the sum of the weighted performance values across all criteria. The best alternative, A_{WSM}, is determined by the formula:

$$A_{WSM} = \sum_{j=1}^{N} a_{ij} w_j, \qquad \text{for } i = 1, 2, 3, \dots, M$$

where a_{ij} represents the performance value of alternative A_i for criterion C_j, and w_j is the weight of importance for C_j, and M is the number of alternatives. The alternative with the highest WSM score is considered the best. (Zaidan, Zaidan, Hussain, Haiqi, Mat Kiah & Abdulnabi, 2015.)

However, WSM faces limitations in multi-dimensional decision-making problems, as it assumes all criteria are comparable on the same scale. Despite its simplicity WSM is closely related to other MCDM methods, such as the Simple Additive Weighting (SAW) method, which refines the approach by introducing a normalization step to handle different measurement units across criteria. (Zaidan et al., 2015.)

SAW, also known as the weighted linear combination or scoring method, determines priorities for each alternative by multiplying the scaled values assigned to the alternative by the weights of relative importance set by decision-makers for each criterion and then summing these weighted values. As a weighted averaging approach, SAW provides a simple yet effective way to compare alternatives with varying measurement units, making it a preferred choice in many practical applications. (Thakkar, 2021.)

A straightforward approach to applying WSM or SAW method involves several key steps. First, the relevant decision criteria, such as cost, lead time, sustainability, capacity, and risk, must be defined. Each criterion is then assigned a weight based on its relative importance in the decision-making process. Following this, the available alternatives are evaluated and scored according to these criteria. The final step involves calculating the SAW or WSM scores by summing the weighted values for each alternative, after which the alternative with the highest score is selected as the most optimal choice. (Thakkar, 2021.)

WSM and SAW are two of the most widely used MCDM methods, particularly in scenarios requiring a straightforward yet effective evaluation of multiple alternatives based on multiple criteria. Both methods rely on assigning weights to criteria based on their importance and computing a final score by summing the weighted values for each alternative. (Thakkar, 2021.) While WSM assumes that all criteria are on the same scale, SAW refines this approach by normalizing the values, making it suitable for cases where criteria have different units of measurement (Pohekar & Ramachandran, 2004; Zaidan et al., 2015).

These methods are particularly useful in decision-making scenarios where factors like cost, time, sustainability, capacity, and risk must be carefully balanced. Their ease of use and adaptability make them valuable for both small-scale decisions, such as selecting between two competing options, and larger strategic choices, such as evaluating multiple alternatives across different contexts. By systematically incorporating key priorities into a weighted scoring framework, WSM and SAW support data-driven, consistent, and repeatable decision-making across a wide range of applications. (Thakkar, 2021.)

The limitations of WSM and SAW lie in their inability to handle real-life problems, which are often structured hierarchically with multiple layers of criteria and sub-criteria. Such problems require a more advanced MCDM technique, like the Analytic Hierarchy Process (AHP). AHP effectively manages multiple layers of hierarchy and evaluates alternatives by conducting pairwise comparisons of both criteria and alternatives. (Thakkar, 2021.)

AHP is a decision-making method used to solve complex problems by structuring them into a hierarchy. It involves pairwise comparisons of criteria and alternatives, helping to prioritize and make decisions based on their relative importance. (Zaidan et al., 2015.) It requires breaking down the problem into multiple levels of criteria, sub-criteria, and alternatives, which can be quite detailed and complex. While AHP is effective for handling multi-criteria problems, creating and managing the hierarchical structure can be time-consuming and complex, requiring careful judgment and organization. (Thakkar, 2021.)

5 Empirical study

Empirical research was conducted to support the theoretical framework. The empirical part of this thesis explores the research question through a qualitative approach, more specifically by conducting themed interviews. This method was chosen to gain in-depth insights into the perspectives and experiences of professionals operating in different business functions. Thematic interviews allow for a flexible yet structured discussion, enabling the collection of rich and detailed data while ensuring consistency across participants (Lätti, Eskola & Vastamäki, 2018.)

For this study, six individuals were interviewed from the target company, each representing one of four business functions: supply chain, sales, product & business management, and finance. Two sales representatives were selected to represent both direct sales and distributors. Experts in product & business management, specializing in unit crushers and mobile products, were interviewed to ensure that perspectives from different product families were considered.

The selection of these business functions was intentional, as they collectively provide a comprehensive understanding of the topic from multiple functional perspectives within an organization. By engaging professionals from different domains, the study aims to capture a diverse range of viewpoints, challenges, and best practices related to the manufacturing footprint.

5.1 Data collection

To gain a comprehensive understanding of the manufacturing footprint process, representatives from key business functions, meaning supply chain, sales, product & business management, and finance, were selected for interviews. These functions were chosen because they each play a distinct yet interconnected role in shaping and executing manufacturing footprint decisions. Their perspectives provide valuable insights into both the strategic and operational considerations that influence footprint optimization. In addition, each interviewee has been with the target company for a long time and has extensive knowledge of its industry and operating methods.

Supply chain was selected because of its central role in ensuring the efficiency and feasibility of manufacturing decisions. Supply chain professionals oversee the operational side of the footprint, including logistics, supplier management, production planning, and distribution. Their insights help assess the practical implications of different manufacturing locations, including transportation costs, lead times, and supply chain resilience. The selected interviewee provided expertise on how footprint decisions impact day-to-day operations and long-term supply chain strategies.

Sales was included in the interviews because of its direct connection to customers and market demand. Sales teams ultimately experience the impact of manufacturing footprint decisions through product availability, delivery reliability, and regional competitiveness. A sales representative was chosen to provide insight into how manufacturing locations affect customer satisfaction, order fulfillment, and market responsiveness. Additionally, sales teams gather valuable feedback from customers that can influence future footprint adjustments.

Product & business management was selected as a key function due to its responsibility for overseeing the entire product life cycle. Manufacturing location is a crucial factor in product planning, affecting cost structures, time-to-market, and regional supply alignment. The product & business management representative contributed by explaining how footprint decisions influence product development, portfolio strategy, and long-term competitiveness. Their role ensures that manufacturing decisions align with both current and future product needs.

Finance was included in the interviews because of its role in assessing the economic impact of footprint decisions. Financial professionals analyze cost structures, capital investments, tax implications, and overall profitability when evaluating manufacturing locations. A finance representative was selected to provide insights into how financial assessments shape footprint strategies and ensure that manufacturing decisions align with the company’s long-term financial goals.

By interviewing representatives from these four areas, a holistic view of the manufacturing footprint process was obtained. Their combined expertise highlights the complex interplay between operational feasibility, market responsiveness, product strategy, and financial viability, all of which are essential for making informed and sustainable footprint decisions.

The questions and topics of the thematic interview were constructed based on intuition, utilizing the information accumulated in the theoretical framework and the researcher's own experience with the topic. The interview covered six main topics, with an opportunity for additional questions and comments at the end. The outline was as follows:

1. Overview of the interviewee's role
2. Connection to the manufacturing footprint process
3. Impact on the manufacturing footprint process
4. Influence on decision-making
5. Key factors in manufacturing footprint decision-making
6. Clarity and transparency of criteria
7. Additional comments or thoughts

Support questions were prepared to guide the interview topics, but the interviews remained semi-structured, allowing for a natural flow of conversation. Additional questions or clarifications were asked as needed during the discussion. However, all topic areas were thoroughly covered with each interviewee.

The functionality of the interview framework was reviewed with both the thesis supervisor and the company representative, and based on these discussions, the number of interviewees was increased from four to six to ensure comprehensive representation from sales and product & business management.

Interviewees received the questions in advance at the same time when they received interview invitations, giving them plenty of time to prepare. Since the topic was diverse and complex, they appreciated the chance to organize their thoughts beforehand, making the interviews more efficient. Many interviewees found this approach helpful. That said, everyone was already knowledgeable about the subject, so discussions on the manufacturing footprint flowed smoothly without the need for any extra materials.

The interviews were conducted one-on-one online, where they were recorded and transcribed using automation. The remote meeting enabled efficient use of time as transcription was mostly automatic and the interview materials (recordings and transcriptions) were easily accessible. Conducting the interviews individually also allowed each interviewee to focus on their area of expertise while ensuring equal attention and consideration for all.

5.2 Interview analysis

This section presents the analysis of the themed interviews conducted with professionals involved in the manufacturing footprint process. The analysis follows the key themes explored in the interviews, starting with an overview of the interviewees' roles and their connection to the process. Each theme is examined in detail, with a particular focus on aspects that emerged as most significant, such as key factors influencing decision-making and the clarity and transparency of criteria. By structuring the analysis around these themes, this section aims to provide a deeper understanding of the interviewees' perspectives and the critical factors shaping manufacturing footprint decisions.

5.2.1 Role and connection to manufacturing footprint

First, each interviewee was asked about their current job role and how long they had been working at the target company. The interviewer already knew that each interviewee had been with the company for several years. Table 1 provides an overview of the business function each expert (A–F) represents, their key tasks, and their years of experience at the company.

Table 1 Overview of interviewees

Interviewee	Business Function	Key responsibilities	Years in target company
Expert A	Supply Chain	Decision-making on production volumes, locations, and distribution to meet demand across markets and brands.	Total 15 years in various positions, 5 years in current position
Expert B	Finance	Financial advisor to the business area president, leading the finance team and overseeing strategy, budgeting, and M&A activities.	17 years total, 9 years as VP Finance in AGG
Expert C	Sales	Growing equipment sales through market-driven strategies, campaigns, and distributor development.	6 years in various sales support roles, 2 years in current role
Expert D		Leading sales support, technical support, and product safety teams, focusing on both strategy and daily operations.	Almost 20 years at the target company, 5 years in current position
Expert E	Product & Business management	Driving growth and profitability, ensuring competitiveness, and developing products based on customer feedback.	Total 17 years, where 10 years in product management
Expert F		Managing product lifecycle competitiveness and profitability, supporting sales and marketing, and developing the product portfolio.	16+ years in AGG segment, 9+ years in current role with changing responsibilities

Expert A represents Supply Chain and works specifically in Planning and Manufacturing Strategy. His role involves decision-making regarding production volumes and locations, including proposal, preparation, and implementation. A key responsibility is ensuring that availability aligns with demand by proposing how much should be produced and which market areas each factory should serve. Additionally, Expert A is involved in the manufacturing planning of sister brands in AGG factories. In the manufacturing footprint process, he is involved in several stages, including preparing and presenting proposals (sometimes on behalf of another stakeholder), as well as implementing and monitoring changes as part of the monthly meetings. Additionally, planning starts with strategy, ensuring that the company has the necessary readiness and capabilities for future changes.

As Finance VP, Expert B is involved in the annual budgeting process and the development of the business area strategy. His team contributes financial insights and suggestions to the development of the manufacturing footprint. Identifying and presenting these opportunities to the executive team is a crucial part of the initial phase of the manufacturing footprint process, after which the proposal moves on to the next organizational level.

In the customer interface, changes in the manufacturing footprint are visible and impact on both the distributor and direct sales sides. Expert C, who works closely with distributors, emphasizes how these changes affect the end-user, such as delivery times and freight costs. Expert D, on the other hand, works together with the supply chain to handle specific cases where deviations from the standard manufacturing footprint are required, such as delivering products from an alternative factory. Both experts see the concrete impact of the manufacturing footprint as an important part of the sales process.

Expert F summarizes the role of product & business management very well:

> “We set the direction for the business and then track how it performs.” (Expert F)

However, this is only one side of product & business management's responsibilities, as they also play an active role in ensuring product profitability and competitiveness. The manufacturing footprint serves as an important tool in this process. Product & business management is involved in deciding which factories will produce the products and which markets each factory will serve. Considering the overall impact is a key part of ensuring the product’s competitiveness and the product line strategy. Expert E also adds that product development based on customer feedback, is a crucial aspect of growth and profitability."

5.2.2 Impact on the manufacturing footprint and decision-making process

The interviewees have varying levels of involvement in the manufacturing footprint process. Experts C and D feel that their role comes at the end of the process, when the manufacturing footprint is in use in sales. For instance, they provide sales with information on footprint changes or manage exception requests in collaboration with the supply chain team. Experts E and F feel that they are involved in the process at the beginning, for example, as providers of ideas, impulses, and information. Expert B also feels involved as a provider of impulses but additionally plays an important role in reviewing and supporting the 'intermediate steps' as well as in the decision-making phase itself. Expert A influences every stage of the process, which is expected since monitoring the manufacturing footprint process is part of his responsibilities.

Experts A, B, E and F involved at the beginning of the process feel that they also have influence in decision-making. Sales experts C and D, on the other hand, see themselves as having little influence on the manufacturing footprint itself but may play a greater role in supporting the sales approach in individual cases where a deviation from the default footprint is needed. Such a case could, for example, be a sales offer where the seller wants to offer the same product from another factory to achieve a better delivery time.

When it comes to managing the manufacturing footprint, interviewees agree that representatives from supply chain and product & business management play a key role in brainstorming and negotiating alternatives. The finance team needs to be more actively involved as the impacts of change grow, for example when risks increase or when larger investments are under discussion. However, many smaller transfers are made without analysing the final outcome, for example when responsibility for a single country or market area of a product already manufactured at both factories is shifted to another factory.

In addition to the interviewees' roles and influence, the sources of impulses for change in the manufacturing footprint were discussed. Each interviewee receives impulses for change in a slightly different way, with sales, product & business management, and supply chain being the most frequently mentioned sources of change requests. Expert A mentioned that change requests also come from factories, primarily from a capacity perspective, when they are willing to increase volume. Expert B, on the other hand, highlighted external factors such as competitors' movements or following megatrends. Expert F added that the current management is highly proactive in exploring alternative footprint solutions driven by megatrends. Expert E noted that he reviews the deals in his area of responsibility monthly, analysing their profitability and assessing whether won deals offer potential for doing things differently. Experts C and D shared that change requests from the sales typically come from the target company's own salespeople or distribution managers and are often driven by a real need or specific case.

> "Could we improve our competitiveness if we produced the product for this market at a different factory?" (Expert E)

When looking at the change requests themselves, many interviewees say that the perspective of costs is a driver. Expert A emphasizes that focusing solely on the cost often overlooks the overall impact of the change, such as how it affects the factory's capacity or the other effects of the transfer. Additionally, changes in regulations and rules in the target country (such as emission class) significantly affect the manufacturing footprint, and timely information on these should be obtained from the market area.

The interviewees were also asked whether there is more manufacturing footprint change requests for new or standard products, and how they differ from each other. All interviewees agreed that there are more change requests for products that have been on the market for a long time compared to new products. For new products, the definition of the manufacturing footprint is part of the new product process, meaning the layout has already been planned. Therefore, questions regarding new products are not typically related to the manufacturing footprint itself, but rather to the interest and curiosity surrounding the launch phase, such as whether the product is available in a specific market area.

The target company's products have a long-life cycle, meaning that many factors can impact demand and supply over time. New demand for a product may emerge from a previously quieter market area, triggering the need to adjust the manufacturing footprint. On the other hand, exchange rate fluctuations could make it advantageous to use a different manufacturing location in order to realize cost benefits. These are just examples of how the market lives during a product's life cycle and how reacting to changes can affect the profitability of the entire product.

During the discussions about the strengths and weaknesses of the current decision-making process, several common themes emerged. Table 2 summarizes the key insights from all interviews. The strengths mentioned most often were flexibility, adaptability, and system support. On the other hand, the main weaknesses included a lack of an end-to-end approach, limited transparency in decision-making, and not enough focus on market perspectives. The existing tool for visualizing the manufacturing footprint was seen as neutral; it’s useful but could be improved to better support users.

Table 2 Strengths and weaknesses of current process

Strengths:	Weaknesses:
- Flexibility	- Lack of end-to-end or process-based approach
- Resilience	- Lack of transparency in decision-making
- Adaptability	- Lack of market/customer perspective in decision-making
- System support	

Neutral:
- Existing tool for factory selection, but needs further development

According to the interviews, the decision-making process for the manufacturing footprint emphasizes flexibility, both in adapting to changing situations like demand fluctuations and in managing supply chain disruptions. Many products have alternative manufacturing locations, enabling adjustments ranging from small changes, such as shifting a default factory within a target country, to larger-scale decisions like balancing market demand across multiple factories. Expert B also highlighted that the target company has fostered a culture of change where employees are prepared to act efficiently and respond quickly.

The ERP system, which is used across all AGG factories, was also highlighted as a strength. Having a unified system streamlines order processing throughout the entire chain and makes it easier to manage complex product structures by supporting both ordering and manufacturing.

The visual tool for the existing manufacturing footprint itself is a positive improvement, but its overall execution was considered neutral since there is still significant potential for further utilization and development. For example, displaying product availability only from the default factory in the target country could add value for sales. The target company has a large and diverse sales organization, with responsibilities ranging from global roles to individual country salespeople and distributors. Awareness and understanding of the manufacturing footprint also vary across the organization, although notable progress has been made in recent years.

The interviewees mentioned a few weaknesses in the process. One major issue is that there isn't a clear, set process in place. Important factors like freight prices, availability, customs duties, tariffs, and requirements for the destination country aren't consistently reviewed when making decisions. Instead, decisions tend to be influenced by individuals and external pressures. Also, sensitivity analyses aren't done, which could help understand how different factors might affect the outcome and make the decision-making process more reliable.

Decisions regarding our manufacturing footprint ultimately impact the customer experience, yet market area insights are rarely sought during the decision-making process. Additionally, it was noted as an area for improvement that the tracking of initial deliveries from new manufacturing locations should be more closely monitored, all the way to the customer. This would help ensure that the product consistently meets the promised quality, preventing any potential customer disappointments or issues.

The interviews also brought up some useful points about the decision-making process. One challenge is finding the right balance between flexibility and securing product availability, which often means tying up money in material inventories, especially for low-volume products. While involving more people in decisions could be helpful, it can also slow things down. Additionally, when changing the manufacturing footprint, it can be hard to know when involving extra stakeholders truly adds value. It was also mentioned that using numerical metrics, like inventory turnover, could be more helpful in decision-making. On a positive note, Expert A shared that when deciding where to manufacture new products, there's now a better focus on choosing the most competitive location from the start, ensuring the product is made there right away.

5.2.3 Prioritizing factors in manufacturing footprint decisions

After an initial general discussion on the factors affecting the manufacturing footprint, the interviewees were asked to identify the key factors they considered most important. All interviewees highlighted the customer perspective and the profitability or efficiency perspective as the most important factors. The overall impact on the customer was emphasized, particularly in terms of customs costs and clearance time, landed cost, and end-to-end lead time. Meeting customer needs was also considered a crucial factor. On the financial side, profitability, overall efficiency, competitiveness, and growth were all seen as key considerations. Interviewees pointed out that these perspectives can, however, encompass many different factors.

Expert B highlighted the importance of risk from several perspectives, including political risk, geographic risk, and business continuity. He emphasized the need to secure operations against potential political instability and geographic disruptions. Ensuring business continuity, particularly for critical functions, was also stressed as a key consideration in risk management, helping businesses remain resilient in the face of external challenges.

Interviewees were then presented with a pre-compiled list of six factors: price/cost, quality, logistics, market area preference, factory capacity and capability, and an open category for any additional factors. These five factors were selected based on the theoretical framework and the author's own experience as key influencing factors. The five main factors covered nearly all the key considerations that the interviewees had initially highlighted as the most significant.

The price/cost perspective included for example manufacturing costs, customer pricing, and total landed cost. While each of these represents a slightly different viewpoint, they all ultimately address the financial value from different angles. The quality perspective encompassed product durability, defect rates, and compliance with industry standards. While these aspects differ slightly in focus, they all ultimately reflect the overall reliability and performance of the product. The logistics perspective includes factors such as shipping schedules, transportation frequency, and the availability of suitable routes from the manufacturing site to the destination country.

The market area perspective, or more specifically the customer viewpoint, considers how the manufacturing location aligns with customer preferences and requirements. Key factors may include smoother customs clearance when shipping from a specific factory or trade restrictions imposed by the destination country. For example, tenders involving EU funding may require that the product be manufactured within the EU, directly influencing footprint decisions. All market area requirements, regardless of their underlying reasons, are considered under this factor.

The factory capacity and capability factor encompass all aspects that influence a factory’s ability to operate efficiently. This includes the skill level of employees, the physical capabilities of the manufacturing equipment, capacity management, and overall production flexibility. In essence, this factor considers both the technical and operational aspects that determine how well a factory can meet production demands.

The interviewees were asked to distribute a total of 100% among these five predefined factors and any additional factors they felt were important but missing from the list. The pie chart (Figure 13) illustrates the average weighting of these factors in influencing the manufacturing footprint. Price/cost received the highest weight (31%), followed by quality (22%), factory capacity and capability (14%), market area preference (13%), and logistics (12%). An additional 8% was allocated to "Something else," which includes risk and cultural impacts, identified as additional factors by two interviewees.

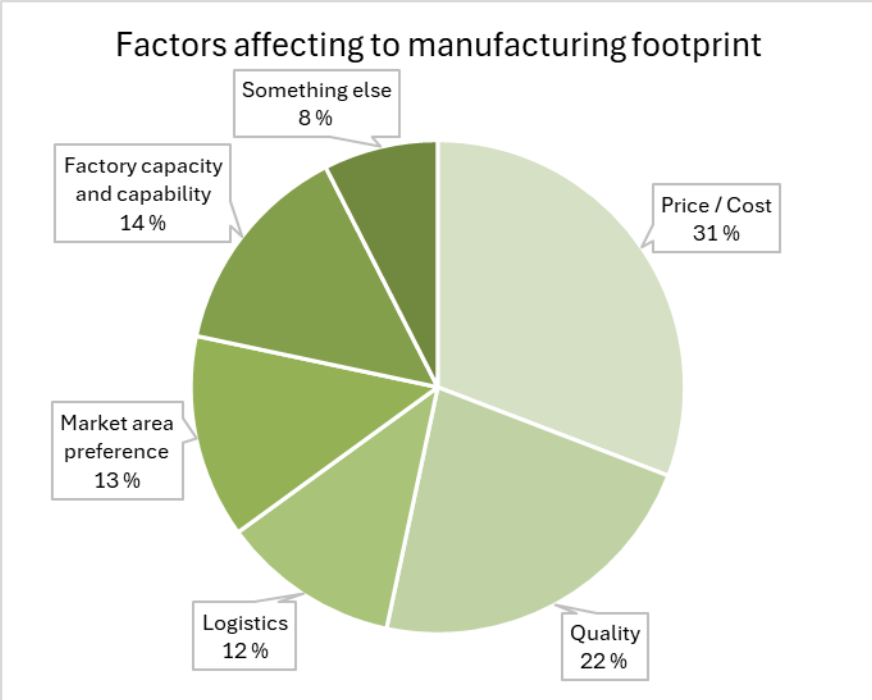

Figure 13 Average weighting of factors influencing the manufacturing footprint

In addition to these factors, the interviewees identified so-called "gateway factors," which function more as pass/fail criteria. While these factors primarily determine whether a proposal advances to the stage of evaluating other factors, they can also influence decision-making later in the process. One such factor is risk, as highlighted by Expert B. Even if other factors indicate that a proposal should proceed, an excessive level of risk can halt it. For example, while moving the production of a high-runner product to the factory with the lowest manufacturing cost may seem beneficial from a cost perspective, the risk of relying on a single facility for a strategically important product could prevent the decision from moving forward. Expert D also mentioned the factory as a gateway factor because not all products are available from all factories, or for some other reason an alternative manufacturing location is not available.

Expert A also highlighted the importance of a product's annual volume in determining the significance of a change. If the product has a high volume and the change would lead to major impacts, it requires greater consideration. In contrast, adjustments to the manufacturing footprint of a low-volume product with less strategic importance may not require as in-depth analysis.

The importance of price/cost as the most crucial criterion aligns with other discussions throughout the interviews, particularly from the perspective of profitability. All interviewees shared this view, with many also highlighting the significance of quality. However, price/cost remained the main driver. Expert E noted that while price/cost is the primary factor, he considered all five factors to be equally important. Expert C was the only one who ranked market area preference as more important than price/cost. However, he combined market area and logistics into the same factor, as he mentioned logistics is strongly tied to the destination country and what the overall experience to the customer is.

According to Expert A, a factory’s capacity and manufacturing capability are determined by the overall strategy, including how the workload is balanced between factories and how existing capacity is utilized. He also emphasized that quality is not just a factor but a prerequisite. Expert F, on the other hand, views cultural issues as a factor in itself, noting that understanding their impact is essential to the manufacturing footprint. He highlighted the importance of considering tax issues, language, and local competence in the decision-making process. While Expert F acknowledged the significance of market area preference, he pointed out that if factors like price and quality are in place, the weight of market area preference diminishes.

The interviewees were asked whether the weighting of different factors depends on the product, factory, or destination country. All agreed that the combination of these factors does have an impact. However, Expert F emphasized that if all elements are aligned, the product, factory, or country should not significantly affect the weighting.

Other interviewees provided various examples of how these factors influence decision-making. These included considerations such as exchange rates, customs and tariffs, product complexity, and the importance of pricing and availability. Different customer groups value different factors, with some prioritizing quality while others emphasize fast delivery times. While the operating factory should ideally not influence the purchasing decision, it realistically must be considered for certain customers.

Logistics can also vary significantly between products, depending on whether the product fits in a container or requires flat-rack or RoRo shipping. Shipping schedules between the manufacturing site and the destination country can also be a limiting factor, influenced by the chosen mode of transport. Additionally, the business value of the product plays a role, particularly if the product is intended to be a single-source product.

Expert E clarified the manufacturing footprint process, explaining that it typically starts with evaluating market area preference. Next, competitors in the market are analysed, including the types of machines they offer and their pricing. This is followed by assessing the company's own comparable machines and shaping the product strategy accordingly. After that, cost factors and logistical aspects, such as freight costs, are considered to see how they fit into the overall picture. According to him, the final decision is usually based on these factors, assuming that quality meets the required standards and the factory has the necessary capabilities.

The interviewees were also asked to consider how the weightings might change if the product were new. Figure 14 illustrates the average weightings in manufacturing footprint decisions for new products. There was little change in the percentages, with price remaining the most important factor (28%) and quality following closely as the second most important (24%). Factory capacity and capability (14%), market area preference (13%), and logistics (12%) remained almost the same, while "something else" had the lowest weighting at 8%.

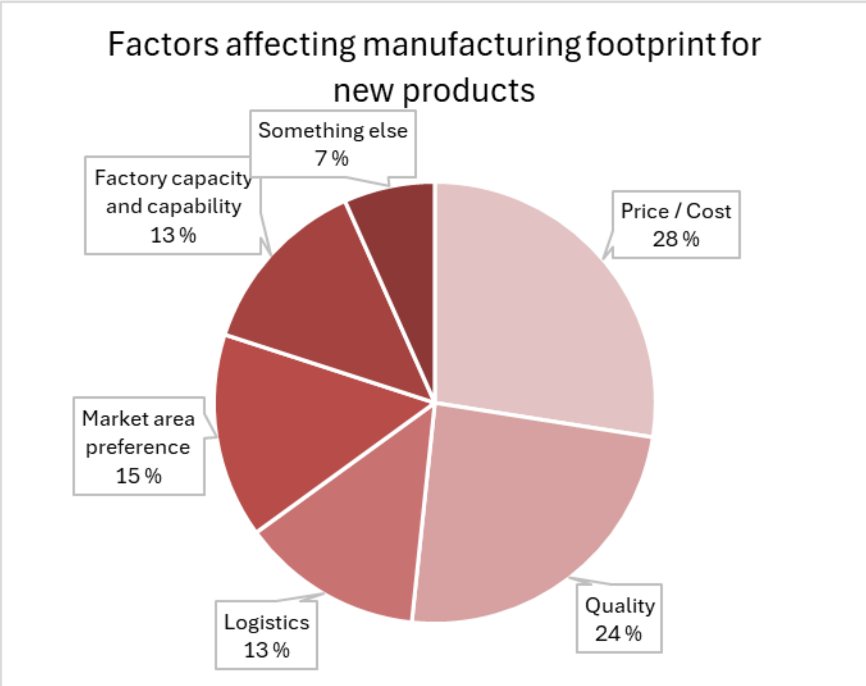

Figure 14 Average weighting of factors for new products

There were no dramatic changes between the factors; the weighting of price/cost dropped slightly, while the weightings of quality and market area increased. This shift was also reflected in the interviewees' comments. Four out of six interviewees maintained their emphasis on the same factors for a new product, while two felt that the focus on price/cost decreased and the importance of other factors grew.

For new products, the interviewees also highlighted the importance of the new product development process in shaping the manufacturing footprint. During the development phase, the footprint is often examined and refined in greater detail. Expert E emphasized that for a new product, it is crucial to first ensure quality and demand are aligned before focusing on cost optimization. While cost should not be the primary driver initially, it can be optimized throughout the product's lifecycle, especially since manufacturing costs are typically higher at the start. Other interviewees also stressed that quality is a key consideration during the early stages of a new product.

The role of the factory was also mentioned, with a focus on its ability to produce a high-quality product at a competitive price. The connection between the market area and the manufacturing facility was highlighted as well, as references for a new product are essential.

The closer the demand is to the manufacturing site, the faster the factory can receive feedback and improve its processes.

Expert A highlighted that sharing technology and design drawings with suppliers poses a significant risk, especially for new products. These elements represent the company's core expertise and are fundamental to its competitive advantage. Therefore, safeguarding them is crucial, particularly in the early stages of a product's lifecycle, when intellectual property and know-how are most vulnerable. This risk must be carefully weighed when defining the manufacturing footprint.

The target company has a predefined manufacturing footprint guideline that assigns a default factory for each product and target country combination. However, requests for exceptions are common, and the reasons for them vary widely. When asked about what an acceptable reason would be to deviate from the default factory, all interviewees agreed that the manufacturing footprint can be flexible if there is a risk of losing the deal. This reason can apply to a variety of scenarios.

Delivery time is one of the most common criteria, but customs processes, fees, or trade conditions, such as those related to EU funding, can also play a role. Customer preferences, shaped by prejudices or past negative experiences with a particular factory, can also be decisive factors. Since customer relationships are typically long-term at the target company, it is important to consider and value the customer's perspective, making them feel valued. However, this doesn't mean customers should be directed in a specific way, and the product's origin shouldn't be the main factor in the purchasing decision. As Expert F noted, customer preferences can be influenced when other factors are properly addressed.

The interviews reveal the same insight as the theoretical framework: while it is possible to categorize the factors, narrowing them down is challenging because many are interconnected. It is also impossible to establish simplified conclusions, as the number of influencing factors is vast, and each case is unique. Additionally, the relative importance of these factors often varies depending on the specific context, making it even more difficult to generalize. Each decision is shaped by a complex interplay of factors that require careful consideration and a tailored approach.

5.2.4 Clarity and transparency of manufacturing footprint decision criteria

After discussing the factors influencing decision-making, interviewees were asked about the decision-making process itself and the criteria involved. The goal was to gather insights from different stakeholders on their experiences with the process and whether they see opportunities for improvement. Interviewees were asked to assess three aspects of the decision-making process:

a) Whether the criteria are clear, meaning the factors leading to a decision are well-justified and understandable.

b) Whether the criteria are consistent, ensuring that similar cases are evaluated using the same standards.

c) Whether the process is transparent, meaning they know who made the decision and the reasoning behind it.

All interviewees agreed that the criteria for decision-making are not clearly defined. Several experts mentioned that decisions often seem to rely more on intuition than structured analysis. Expert F emphasized that without a well-defined process, maintaining a systematic approach is challenging. In contrast, Expert D, who is not involved in the early stages of the manufacturing footprint process but instead reviews individual cases and their underlying reasons, felt that he could identify the criteria. In his view, they have at least become clearer over the years and are now more understandable.

When it comes to the consistency of decision-making criteria, all interviewees agreed that there is room for improvement. Expert A shared an example where production was moved to a more expensive manufacturing site closer to the market due to delivery time being a key factor. However, as a result, the product can no longer compete on price as initially expected. Expert D noted that while the standard manufacturing footprint is logical and well-justified, individual cases clearly show how different factors are prioritized depending on the situation.

Only Expert A felt that the decision-making process was transparent, but he explained that this was because he is involved in nearly every stage. He acknowledged that for many others, the process is likely not as clear. This view was shared by all other interviewees. Experts C and D mentioned that decisions sometimes feel predetermined and expressed a desire for better communication and information-sharing about the supply chain with relevant stakeholders.

The interviewees agreed that all decision-making criteria should be considered together, taking a holistic approach. However, Expert A pointed out that the options should also be narrowed down, for example, only viable factories should be included in the evaluation. This makes sense, as some options can already be ruled out early on without deep analysis (for instance, if a factory does not manufacture the specific product, it wouldn't be considered). A thorough yet focused review would improve efficiency, and modeling could provide valuable insights into strengths and key priorities.

Based on the discussions, all interviewees agreed that a decision-making tool would be helpful and add value by listing all relevant factors and allowing for their simultaneous assessment. Expert A explained that such a tool would bring process consistency, repeatability, and transparency. Since changes to the manufacturing footprint are part of an ongoing process, Expert B highlighted that a standardized approach would also make the decision-maker's role easier. A documented and structured method would enhance efficiency and consistency in decision-making. Expert D agreed, noting that simply listing the factors would streamline the process, as currently, each case requires starting from scratch and considering the criteria independently.

> "A decision-making tool would bring process-likeness, repeatability and transparency" (Expert A)

Expert C believed that a standard tool would provide much-needed transparency, while Expert E appreciated the potential for clearer approval processes. Expert F emphasized that the tool would enable a thorough examination of various factors, risks, and opportunities, providing a final outcome that helps prioritize the right aspects.

Based on the interviews, it is clear that a multi-criteria decision tool is needed to effectively evaluate the various factors influencing the manufacturing footprint. Interviewees emphasized that such a tool would allow for a comprehensive assessment of all relevant criteria simultaneously, improving decision-making efficiency and consistency. By providing a structured framework, the tool would help decision-makers balance competing factors like cost, quality, logistics, and market preferences while also identifying potential risks and opportunities. The tool's ability to clarify the decision-making process, ensure repeatability, and enhance transparency would be a significant asset to the organization.

5.2.5 Key findings

The interviews highlighted that changes to the manufacturing footprint have a broad impact across the entire supply chain. Adjustments affect factories and suppliers through increased production volumes, while distributors and end customers may experience changes in freight costs or overall delivery times.

The interviewees represented various stages of the process, from initiating the need for change to decision-making and assessing the effects on customer interactions. This diverse perspective provided a comprehensive understanding of how manufacturing footprint decisions are made and their consequences.

Initiatives for manufacturing footprint changes can arise from different sources, including sales teams, internal analyses, or external factors such as competitor movements. However, most proposals typically originate from sales, where each case is evaluated individually to determine whether deviating from the default manufacturing location is necessary. It can generally be said that if there is a risk of losing a deal, flexibility in the manufacturing footprint is considered to support business opportunities.

One key finding from the interviews is that the end-to-end manufacturing footprint process lacks clarity. Responsibilities and decision-making authority are not always well defined, leading to inconsistencies in how decisions are made. Without a clear framework, different stakeholders may have varying interpretations of the criteria, which can result in misalignment and inefficiencies.

A notable weakness identified is the reliance on gut feeling or intuition rather than a structured, data-driven approach. Additionally, too much emphasis is often placed on manufacturing costs, while other crucial factors such as logistics, quality, and market needs can be overlooked. This can lead to short-term cost savings at the expense of long-term strategic benefits, potentially affecting competitiveness in certain markets.

On the other hand, flexibility emerged as a strength, as there are typically alternative manufacturing locations available for most products. This adaptability is further supported by an organizational culture that encourages agility in decision-making. The ability to shift production when necessary, provides resilience against supply chain disruptions and allows the company to respond quickly to changes in demand.

Another advantage is the system support in place, as all Metso AGG factories operate within the same system, ensuring a level of consistency across manufacturing locations. A unified system simplifies coordination between factories, enhances visibility across the supply chain, and enables smoother decision-making processes when evaluating manufacturing footprint changes.

The prioritization of decision-making factors was largely consistent among the interviewees, with most ranking them in a similar order. However, there were some variations in emphasis. One sales representative prioritized market area and quality over cost, highlighting the importance of proximity to customers and product reliability. In contrast, one product manager considered all factors equally important, emphasizing the need for a balanced approach rather than focusing on a single dominant criterion. These differing perspectives reflect the diverse priorities of various stakeholders involved in manufacturing footprint decisions.

When it comes to new products, the general emphasis on decision-making factors remained similar, but there was a slight decrease in the weight of cost. Instead, quality became more critical, as ensuring a product meets required standards before optimizing costs was seen as essential. This shift in priority aligns with the natural lifecycle of new product introduction, where early-stage investments in quality and stability help secure long-term success.

The interviewees also identified "gateway factors" as go/no-go criteria that influence whether a manufacturing footprint alternative is even considered. Risk was frequently mentioned as a key factor, highlighting the importance of assessing potential downsides before committing to a decision. Certain risks, such as supply chain disruptions, capacity limitations, or vendor reliability, must be carefully evaluated to avoid costly mistakes. Additionally, understanding these risks helps ensure that the chosen footprint supports long-term stability and business growth.

A shared understanding among all interviewees was that if there is a risk of losing a deal, deviating from the default manufacturing footprint is acceptable. Flexibility in such cases is considered necessary to secure business opportunities, ensuring that customer demands can be met even if it requires a shift in production location. This reinforces the idea that while predefined footprint guidelines provide structure, they should not be overly rigid when business viability is on the line.

Another widely agreed point was that all influencing factors should be considered simultaneously in decision-making, rather than in isolation. Interviewees emphasized the need for a dedicated tool that would support this process by allowing a structured evaluation of all relevant criteria. Such a tool would enhance transparency, improve consistency, and ensure that decisions are based on a comprehensive analysis rather than intuition alone.

5.3 Decision-making tool

Based on both the theoretical framework and interviews, it is clear that numerous factors influence manufacturing footprint decision-making. These factors can be interdependent or interconnected. For example, lower manufacturing costs often allow for reduced customer prices. However, in some cases, they may also conflict, such as when balancing low costs with high-quality requirements.

Strategic factors such as proximity to key markets, supply chain resilience, and legal requirements set by governments, including labour laws, environmental policies, taxes, and trade regulations, further complicate the decision-making process. Understanding these trade-offs is essential for making informed and effective manufacturing footprint decisions.

Since manufacturing footprint changes range from small adjustments to large transformations, influenced by numerous factors. Therefore, the criteria for a tool designed to simplify decision-making were clear: it needed to be user-friendly and adaptable to different situations, without being overly complex or difficult to maintain.

Since the target company has not previously used any decision-making tools and has instead relied on existing knowledge and experience, the tool does not need to provide an absolute outcome. Instead, it should offer directional guidance, supporting holistic decision-making by considering all relevant factors Given that this type of tool is new to the company, the initial version can be lightweight, with room for growth and refinement based on actual usage and experience. This iterative approach will allow the tool to better align with the company’s evolving decision-making needs over time.

Several multi-criteria decision-making tools seemed suitable for the target company's needs. After a thorough evaluation, the Weighted Sum Model (WSM) was chosen as the most practical option for manufacturing footprint decision-making.

The WSM is one of the most user-friendly multi-criteria decision-making tools, ideal for both small adjustments and larger-scale changes. It allows the simultaneous consideration of multiple criteria, which can be grouped into broader categories or examined in detail, depending on the level of precision needed. Additionally, WSM serves as a directional aid, highlighting the most favourable options based on the weighted factors. This functionality supports comprehensive decision-making, especially if the results need further validation.

Furthermore, the WSM can be developed into more advanced tools, such as the SAW (Simple Additive Weighting) method, if there is a need for more precise measurement of different factors. This could be particularly useful in comparing prices or costs between factories, where using actual numerical values instead of predefined scales would allow for more accurate assessments. Such an enhancement could improve transparency and provide clearer justification for selecting a particular alternative.

There is also potential for future development toward the Analytic Hierarchy Process (AHP). However, this requires a detailed definition of hierarchical criteria, which can be challenging to maintain across different cases. While AHP can improve decision accuracy by structuring complex decisions, its complexity may limit its practicality for frequent use. Over time, as the tool is utilized, the hierarchy of criteria may become clearer, allowing for more advanced development, particularly in refining factor weighting. A step-by-step enhancement approach ensures that the tool remains user-friendly while gradually increasing its analytical depth.

While WSM is widely used for its simplicity and ease of implementation, this can also be a limitation. WSM assumes that all criteria contribute independently to the decision and can be summed with weighted values. In reality, trade-offs between for example cost, quality, and lead time are often nonlinear, making it difficult to fully capture the dynamics of complex decision-making.

A key challenge of WSM is the subjectivity in assigning weights to different criteria. If the weighting process is not based on objective data, biases or inconsistencies may affect the outcome. It also lacks a built-in mechanism for analyzing how input changes impact the final decision. Small variations in the assigned weights can significantly alter rankings, leading to potential instability

WSM is effective for a limited number of criteria and alternatives but becomes more difficult to manage as complexity increases. More advanced methods, such as AHP, may offer greater accuracy and scalability. Despite its limitations, WSM should not replace expert judgment. Over-reliance on numerical outputs without considering the broader business context could lead to misguided decisions. Instead, WSM should serve as a supporting tool, complementing other decision-making approaches.

5.3.1 Structure and use of the weighted sum model tool

The weighted sum model tool developed for the target company was built on key concepts from the theoretical framework and various educational resources on WSM construction. Excel was chosen as the platform due to its familiarity among users, making the tool easy to adopt, share, and implement. The tool features a structured layout where users can input criteria, assign weights, and evaluate alternatives based on predefined scoring. Its flexibility allows for adjustments over time, ensuring it remains relevant as decision-making needs evolve.

Figure 15 provides an overview of the tool. In the upper left corner, users can enter details about the product and its target country or market area, allowing for customization based on the specific case. These fields are freely editable. On the upper right, a concise instruction box guides users in assigning criteria weights and ratings, which should be entered in the light-blue highlighted cells. This section ensures clarity in the input process, helping users maintain consistency in evaluations. The structured format of the upper section enhances usability by keeping key information easily accessible while preventing errors in data entry.

Instructions:
Insert weights and rates
Scale: 1=low, 5=high

Product: **Product X**
Destination country / market area: **Market area X**

Criteria	**Weight (%)**	**Factory**											
		Factory 1		Factory 2		Factory 3		Factory 4		Factory 5		Factory 6	
Price / Cost	31 %	1	0,31	2	0,62	5	1,54	5	1,54		0,00	3	0,93
Quality	23 %	5	1,13	3	0,68	2	0,45	2	0,45		0,00	2	0,45
Logistics	12 %	3	0,35	3	0,35	2	0,23	3	0,35		0,00	3	0,35
Market area preference	13 %	4	0,53	2	0,27	1	0,13	1	0,13		0,00	5	0,67
Factory capacity and capability	14 %	5	0,71	5	0,71	2	0,28	4	0,57		0,00	2	0,28
Something else	8 %	1	0,08	3	0,23	3	0,23	3	0,23		0,00	3	0,23
TOTAL	**100 %**	**3,10**		**2,84**		**2,87**		**3,27**		**0,00**		**2,90**	

Figure 15 Overview of the WSM tool

On the left side of the tool, users can define the criteria they want to include in the decision-making process. In this example, the same criteria used in the interviews have been applied: price/cost, quality, logistics, market area preference, factory capacity and capability, and something else. Next to each criterion, users assign a weight based on their assessment of its importance in the manufacturing footprint decision. The weight for each criterion can range from 0% to 100%, with the total sum equaling 100%. This flexibility allows the tool to adapt to different decision-making priorities. The example weights used in Figure 15 are the same as the average weights of the factors based on the interviews.

Since the tool is designed to support decision-making while remaining easy to use, the weighting of criteria should be based on the users' own judgment. Overcomplicating the weighting process with excessive analysis would make the tool cumbersome and limit its ability to provide quick, directional guidance. One of the tool's primary objectives is to encourage a holistic perspective, ensuring multiple factors are considered rather than focusing solely on individual aspects.

To simplify this process, the weighting column provides a clear and structured format, helping users assign appropriate values while ensuring that the total always sums to 100%. This layout enhances usability by preventing errors and maintaining consistency across different cases. The tool's visual design also makes it easy to compare weightings at a glance, reinforcing a balanced approach to decision-making.

The tool allows users to compare various alternatives, such as different factories. If a user wishes to exclude certain factory options from the comparison, perhaps because relocating production of that product to a new factory would require substantial investment or the factory is logistically unsuitable for the target market area, they can mark the respective column in grey, removing it from the comparison. For example, in Figure 15, Factory 5 is greyed out and has not been assigned any ratings.

For the factories included in the comparison, a rating is assigned to each factor on a scale from one to five, where one represents low and five represents high. Since even minor rating adjustments can significantly impact the final results, user assessment plays a crucial role.

However, this also presents a valuable opportunity, as adjusting different criteria and assessments allows users to explore the outcomes of various alternatives. This flexibility helps users evaluate their decision-making process, offering insights into which factors are prioritized and highlighting when decisions may be influenced more by intuition, potentially signaling the need for further research.

Based on the assigned values, the tool calculates a weighted sum for each option, highlighting the two highest-scoring factories in green. In Figure 15, the top-ranked factories are Factory 1 and Factory 4. This visual representation helps users quickly identify the top options, making it easier to evaluate the overall results and focus on the most promising alternatives. By clearly marking the highest-scoring factories, the tool enables users to focus on alternatives that best align with their criteria and strategic objectives.

One of the key features of the tool is its ability to consider a wide range of factors. To simplify this process, related sub-factors are organized into separate tabs. For example, the price/cost category has its own tab, which includes specific factors such as manufacturing cost (MFC), transportation cost, landed price, total price, customs duties, and exchange rates. As shown in Figure 16, this illustrates how the sub-factors are listed under the price/cost category.

Price / Cost

This list provides a standardized reference for all sub-factors included in the **Price/Cost** category. It ensures consistency in evaluation by defining key cost-related elements to consider when making manufacturing footprint decisions. **No weights or scores are assigned here**—this is purely a checklist to guide decision-makers.

Sub-factors:

Manufacturing cost (MFC)
Transportation cost
Landed price
Total price
Customs duties & trade agreements affecting cost
Exchange rate

Figure 16 Example of sub-factors in price/cost category

Each category derived from the interviews has its own dedicated tab to help streamline the evaluation process. This structured categorization enhances transparency and enables a more detailed review of individual factors influencing the decision. While the tool groups the many factors into main categories, it also allows for a detailed review of each individual factor.

Overall, the tool provides a robust framework for evaluating and comparing various manufacturing alternatives by considering a wide range of factors. By organizing these factors into clear categories and sub-factors, it allows users to assess each option in a structured and comprehensive manner. The flexibility to adjust weights and evaluate different criteria enhances decision-making, enabling users to tailor the tool to their specific needs and priorities. Through the use of visual aids the tool simplifies complex data, making it easier for users to identify the most promising alternatives. Overall, this tool offers valuable support in making informed decisions, providing both a detailed analysis and a flexible approach to evaluating different manufacturing scenarios.

Conclusions

This thesis explored manufacturing footprint decision-making and the key factors influencing it. The objective was to develop a tool that enhances the decision-making process by providing a more comprehensive approach and ensuring all relevant factors are considered. The tool was designed to accommodate both major and minor changes, offering a holistic perspective to support well-informed decisions.

The research question of this thesis, *"What are the main factors that impact the decision-making process regarding the manufacturing footprint?"*, was explored through both a review of existing theoretical frameworks and interviews with six experts from the target company. The findings revealed a wide range of influencing factors, from smaller considerations like customer preferences to larger, more complex issues such as transportation costs and shipping times, as well as trade restrictions affecting the choice of manufacturing location.

Given the wide range of factors influencing manufacturing footprint decisions, they were grouped into six main categories to improve clarity and streamline the evaluation process. These categories include price/cost, quality, logistics, market area preference, factory capacity and capability, and an additional category for other relevant factors.

Each category is further broken down into detailed sub-factors, providing a more structured and specific view. The purpose of these sub-factor listings is to help users see the broader picture while ensuring all key considerations are accounted for, reducing the need to repeatedly identify relevant factors from scratch during decision-making.

Based on the interviews, price/cost was identified as the most influential factor in manufacturing footprint decisions, followed by quality. The remaining factors, logistics, market area preference, and factory capacity and capability, were considered important but ranked lower. Additionally, interviewees highlighted cultural influences and the role of risk in decision-making, which were categorized under "Something else."

The interviews also introduced the concept of "gateway factors," which are critical considerations that determine whether a manufacturing footprint alternative is even viable.

For example, risk was frequently mentioned as a factor that could immediately exclude certain options from consideration.

The additional question in the thesis, *"How do these factors differ between standardized products and new products?"*, did not reveal a significant difference in the final results. While the importance of quality increased slightly for new products, price/cost remained the most important factor overall. The interviewees noted that for new product projects, the manufacturing footprint and its associated impacts are typically evaluated more thoroughly. In contrast, the manufacturing footprint for standardized products is not regularly reassessed, as it tends to remain stable over time.

As part of the decision-making process, a tool was developed for the target company to simplify the evaluation of various factors and provide a comprehensive overview, ultimately making decision-making easier. The tool is based on a weighted sum model, where different criteria are given weights according to the user's own assessment. Different alternatives, in this case factories, are then rated on a value scale and as a result, the weighted sum of these assessments highlights the alternatives with the highest scores.

The study excluded the impact of procurement on manufacturing footprint decision-making, which could serve as an interesting area for future research. Exploring how procurement strategies influence the selection of manufacturing locations could provide valuable insights and enhance the decision-making framework further.

This thesis was also limited to comparing existing manufacturing locations for the manufacturing footprint, excluding the consideration of new location possibilities. While the focus was on evaluating and optimizing current manufacturing sites, future research could expand the scope by exploring the potential of new locations. This could include assessing factors such as emerging megatrends, technological advancements, labour availability, infrastructure development, and shifting geopolitical dynamics. Additionally, examining how the transition to new manufacturing sites may impact supply chains, costs, and environmental sustainability could provide valuable insights into the broader concept of manufacturing footprint.

References

About us, n.d. Metso. [Web page]. [Cited 2024-10-25]. Available: https://www.metso.com/corporate/about-us/

Aggregates, n.d. Metso. [Web page]. [Cited 2024-10-25]. Available: https://www.metso.com/aggregates/

Bhatnagar, R. & Sohal, A.S. 2005. Supply chain competitiveness: measuring the impact of location factors, uncertainty and manufacturing practices. Technovation. Vol 25, no. 5, p. 443-456.

Cavalcante, I., Frazzon, E., Forcellini, F. & Ivanov D. (2019) A supervised machine learning approach to data-driven simulation of resilient supplier selection in digital manufacturing. International journal of information management. Vol. 49, p. 86-97.

Chang, Y., Iakovou, E. & Shi, W. 2020. Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of-the-art, challenges and opportunities. International Journal of Production Research. Vol. 58, no. 7, p. 2082-2099

Cheng, L., Farooq, S., & Johansen, J. 2015. Manufacturing network evolution: A manufacturing plant perspective. Journal of Manufacturing Technology Management. Vol. 26 no. 7, p. 1053-1082.

Chopra, S. & Meindl, P., 2010. Supply Chain Management: Strategy, Planning, and Operation, 4th edition. Upper Saddle River, New Jersey, Person Education.

Chopra, S. & Meindl, P. 2016. Supply Chain Management: Strategy, Planning and Operations. 6th edition. Harlow, Pearson Education Limited.

Christodoulou, P. 2007. Manufacturing footprint strategy. University of Cambridge. [e-publication]. ISSN= 1755-9898. Cambridge; Institution for Manufacturing. [Cited 26.10.2024]. Available: https://www.ifm.eng.cam.ac.uk/uploads/Resources/Briefings/cim_briefing_footprints.pdf

Christopher, M. 2011. Logistics & Supply Chain Management. 4th ed. Harlow, Financial Times Prentice Hall.

Christopher, M., & Peck, H. 2004. Building the resilient supply chain. International Journal of Logistics Management. Vol. 15 no. 2, p. 1-13.

Dekkers, R. 2002. Strategic Capacity Management: Meeting Technological Demands and Performance Criteria. International Journal of Production Research. Vol. 40, no. 15, p. 3895-3911.

Drake, M. 2012. Global Supply Chain Management. 1st ed. New York, Business Expert Press.

Fang, J., Huang, G.Q. & Li, Z. 2013. Event-driven multi-agent ubiquitous manufacturing execution platform for shop floor work-in-progress management. International journal of production research. Vol. 51, no. 4, p. 1168-1185.

Ferdows, K. 1997. Making the most of foreign factories. Harvard Business Review. Vol. 75, p. 73-88.

Ferdows, K. & De Meyer, A. 1990. Lasting Improvements in Manufacturing Performance: In Search of a New Theory. Journal of Operations Management. Vol. 9, no. 2, p. 168-184.

Ferdows, K., Vereecke, A., & De Meyer, A. 2016. Delayering the global production network into congruent subnetworks. Journal of Operations Management. Vol. 41, no. 1, p. 63-74.

Friedli, T., Lanza, G. & Remling, D. 2021. Global Manufacturing Management: From Excellent Plants Toward Network Optimization. Switzerland, Springer.

Gold, S., Schodl, R. & Reiner, G. 2017. Cumulative manufacturing capabilities in Europe: Integrating sustainability into the sand cone model. Journal of Cleaner Production. Vol. 166, p. 232-241.

Habermann, M., Blackhurst, J. & Metcalf, A.Y. 2015. Keep your friends close? Supply chain design and disruption risk. Decision Sciences. Vol. 46, no. 3, p. 491-526.

Hallikas, J., Immonen, M. & Brax, S. 2021. Digitalizing procurement: the impact of data analytics on supply chain performance. Supply Chain Management. Vol. 26, no. 5, 629-646.

Hayes, R. H., & S. C. Wheelwright. 1984. Restoring Our Competitive Edge – Competing through Manufacturing. New York, Wiley.

Karim, M.A., Habib, M.M. 2022. What to know about supply chain management. New York, Nova Science Publishers Inc.

Khan, N.A., Ahmed, W. & Waseem, M. 2023. Factors influencing supply chain agility to enhance export performance: case of export-oriented textile sector. Review of International Business and Strategy. Vol. 33, no. 2, p. 301-316.

Kim, B., Shah, B., He, T. & Kim, K. 2022. A survey on analytical models for dynamic resource management in wireless body area networks. Ad Hoc Networks. Vol 135, p. 1-20.

Koberg, E. & Longoni, A. 2019. A systematic review of sustainable supply chain management in global supply chains. Journal of cleaner production. Vol. 207, p. 1084-1098.

Kottala S.Y., Herbert, K. 2020. An Empirical Investigation of Supply Chain Operations Reference Model Practices and Supply Chain Performance: Evidence from Manufacturing Sector. International journal of productivity and performance management. Vol. 69, no. 6, p. 1925-1954.

Lätti, J., Eskola, J. & Vastamäki, J. 2018. Teemahaastattelu: Lyhyt selviytymisopas. In book: Ikkunoita tutkimusmetodeihin 1: Metodin valinta ja aineistonkeruu: virikkeitä aloittelevalle tutkijalle. PS-kustannus, Chapter 2, pp. 27-51

MacCarthy, B.L. & Atthirawong, W. 2003. Factors affecting location decisions in international operations - a Delphi study. International Journal of Operations & Production Management. Vol. 23, p. 794-818.

MacCormack, A. D., Newmann, L. J. & Rosenfield, D. B. 1994. The New Dynamics of Global Manufacturing Site Location. MIT Sloan Management Review. Vol. 35, no. 4, p. 69-80.

Meixell, M. & Gargeya, V. 2005. Global supply chain design: A literature review and critique. Transportation Research Part E: Logistics and Transportation Review. Vol. 41, no. 6, p. 531-550.

Melo M.T., Nickel, S. & Saldanha-da-Gama, S. 2009. Facility location and supply chain management - A review. European Journal of Operational Research. Vol, 196, p. 401-412.

Milovanovic, G., Milovanovic, S. & Radisavljevic, G. (2017) GLOBALIZATION - THE KEY CHALLENGE OF MODERN SUPPLY CHAINS. Ekonomika. Vol. 63, no. 1, p. 31-39.

Miltenburg, J. 2005. Manufacturing Strategy – How to Formulate and Implement a Winning Plan. 2nd ed. Portland, Productivity Press.

Mishra, R., Singh, R.K. & Subramaniam, N. 2021. Impact of disruptions in agri-food supply chain due to Covid-19 pandemic: Contextualised resilience framework to achieve operational excellence. The International Journal of Logistics Management. Vol. 33, no. 3, p. 926–954.

Munier, N., Hontoria E. & Jiménez-Sáez, F. 2019. Strategic Approach in Multi-Criteria Decision Making - A Practical Guide for Complex Scenarios. Switzerland, Springer.

Nel, D. 2024. The role of supply chain risk mitigation strategies to manage supply chain disruptions. Journal of Transport and Supply Chain Management. Vol. 18, no. 1, p. 1-12.

Olhager, J. & Feldmann, A. 2017. Distribution of manufacturing strategy decision making in multi-plant networks. International Journal of Production Research. Vol. 56, no. 1-2, p. 692-708.

Our business, n.d. Metso. [Web page]. [Cited 2024-10-25]. Available: https://www.metso.com/corporate/about-us/business/

Pagano, A.M., & Gyimah, M. 2017. Contemporary Issues in Supply Chain Management and Logistics. 1st ed. New York, Business Expert Press.

Parast, M.M. & Subramanian, N., 2021. An examination of the effect of supply chain disruption risk drivers on organizational performance: Evidence from Chinese supply chains. Supply Chain Management: An International Journal. Vol. 26, no. 4, p. 548–562.

Park, J., Shin, K., Chang, T. & Park, J. 2009. An integrative framework for supplier relationship management. Industrial Management & Data Systems. Vol. 110, no. 4, p. 495-515.

Paul, S.K., Agarwal, R., Sarker, R.A. & Rahman, T. 2023. Supply Chain Risk and Disruption Management. 1st ed. Singapore, Springer.

Piatanesi, B. & Arauzo-Carod, J-M. 2019. Backshoring and nearshoring: An overview. Growth and change. Vol. 50, no. 3, p. 806–823.

Pohekar, S.D. & Ramachandran, M. 2004. Application of multi-criteria decision making tosustainable energy planning—A review. Renewable and Sustainable Energy Reviews. Vol. 8, p. 365-381.

Prater, E. & Whitehead, K. 2013. An Introduction to Supply Chain Management: A Global Supply Chain Support Perspective. 1st ed. New York, Business Expert Press.

Ribeiro, J. P. & Barbosa-Povoa, A. 2018. Supply Chain Resilience: Definitions and quantitative modelling approaches - A literature review. Computers & Industrial Engineering. Vol. 115, p. 109-122.

Rojas-Zerpa, J. & Yusta, J. 2015. Application of multicriteria decision methods for electric supply planning in rural and remote areas. Renewable and Sustainable Energy Reviews. Vol. 52, p. 557-571.

Scheibe, K.P. & Blackhurst, J. 2018. Supply chain disruption propagation: A systemic risk and normal accident theory perspective. International Journal of Production Research Vol. 56, no. 1–2, p. 43-59.

Shi, Y., & Gregory, M. 1998. International manufacturing networks - to develop global competitive capabilities. Journal of Operations Management. Vol. 16, no. 2-3, p. 195-214.

Singh, S., Kumar, S. & Kumar, A. 2023. Identifying disruptions by COVID-19 and devising strategies to build robust supply chain – a case study illustration of India's energy storage sector. Benchmarking: an international journal. Vol. ahead-of-print, no. ahead-of-print.

Soltanifar, M., Tavana, M., Santos-Arteaga F. & Sharafi H. 2023. A hybrid multi-attribute decision-making and data envelopment analysis model with heterogeneous attributes: The case of sustainable development goals. Environmental Science and Policy. Vol. 147, p. 89-102.

Sprenger, P., Parlings, M. & Hegmanns, T. 2014. Planning Approach for Robust Manufacturing Footprint Decisions. Next Generation Supply Chains: Trends and Opportunities. Vol. 18, p. 29-50.

Sultana, S., Paul, N., Tasmin, M., Dutta, A. & Khan, S.A. 2024. Analyzing Supply Chain Risks and Resilience Strategies: A Systematic Literature Review. Engineering Proceedings. Vol. 76, no. 41, p. 1-9.

Taherdoost, H. & Madanchian, M. 2023. Analytic Network Process (ANP) Method: A Comprehensive Review of Applications, Advantages, and Limitations. Journal of Data Science and Intelligent Systems. Vol. 00, p. 1-7.

Taherdoost, H. & Madanchian, M. 2023. Multi-Criteria Decision Making (MCDM) Methods and Concepts. Encyclopedia. Vol 3, p. 77-87.

Thakkar, J. 2021. Multi-criteria decision making. 1st edition. Singapore, Springer.

Trkman, P., Oliveira, M. P. V. & McCormack, K. 2016. Value-oriented supply chain risk management: you get what you expect. Industrial Management & Data Systems. Vol. 116, no. 5, p. 1061-1083.

Törmä, M., 2021. 100 vuotta leukamurskaimia!. Helsinki, Metso Outotec Finland Oy.

Wu, J., Wang, H. & Shang, J. 2019. Multi-sourcing and information sharing under competition and supply uncertainty. European Journal of Operational Research. Vol. 278, no. 2, p. 658-671.

Zaidan, A., Zaidan, B., Hussain, M., Haiqi, A., Mat Kiah, M.L. & Abdulnabi, M. 2015. Multi-criteria analysis for OS-EMR software selection problem: A comparative study. Decision Support Systems. Vol. 78, p. 15.27.

Zaman, U. K., Rivette, M., Siadat, A. & Mousavi, S. M. 2018. Integrated product-process design: Material and manufacturing process selection for additive manufacturing using multi-criteria decision making. Robotics and Computer-Integrated Manufacturing. Vol 51, p. 169