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Trade-offs in Performance Objectives and Automation in Production

A case study for SKF Industrial Gothenburg

Bachelor’s thesis in Industrial Management and Production Engineering

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Cover: A close-up of a ball bearing in greyscale with SKF's logo overlaid in the centre.

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ABSTRACT

As manufacturing companies face increasing pressure to balance cost efficiency, flexibility, and technological advancement, decisions regarding production setup and automation level have become central to long-term competitiveness. This thesis investigates how different levels of automation and production setup influence operational performance in a large-scale industrial setting, using SKF's D-factory in Gothenburg as a case study.

The study is conducted through a combination of qualitative and quantitative methods, including semi-structured interviews with operators, production managers, and automation specialists, direct factory observations, and analysis of internal documentation and literature. The theoretical framework includes Hill's Manufacturing Strategy Framework, process design theory, levels of automation, manufacturing planning and control systems, and key performance indicators.

The findings reveal a gap between the maturity of physical automation on the factory floor and the cognitive and systems-level automation required to support it. Disruptions in system integration, incomplete data flows, and varying knowledge distribution among operators are identified as key operational challenges. Furthermore, the study shows that strategic decisions regarding automation must be derived from a clear alignment between corporate objectives, market strategy, and manufacturing strategy, approached from both a top-down and bottom-up perspective.

The thesis concludes that standardisation of processes, data structures, and automation frameworks is a prerequisite for SKF to achieve its 2030 strategic ambitions. Flexibility is identified as the primary performance objective, and the ability to adapt production strategy to evolving market requirements, including a shift toward smaller batch sizes, shorter lead times, and a postponed customer order decoupling point, is central to sustaining competitive advantage. The findings are intended to serve as a foundation for data-driven and context-aware decision-making in future automation projects at SKF Industrial in Gothenburg.

Keywords: automation, manufacturing strategy, production layout, cell production, system integration, KPI, SKF, Industry 4.0, flexibility, performance objectives, standardisation

SAMMANFATTNING

I takt med att tillverkningsföretag möter ett ökat tryck att balansera kostnadseffektivitet, flexibilitet och teknologisk utveckling har beslut om produktionsupplägg och automationsgrad blivit centrala för långsiktig konkurrenskraft. Denna uppsats undersöker hur olika nivåer av automation och produktionsupplägg påverkar den operativa prestandan i en storskalig industriell miljö, med SKF:s D-fabrik i Göteborg som fallstudie.

Studien genomförs med en kombination av kvalitativa och empiriska metoder, inklusive semistrukturerade intervjuer med operatörer, produktionschefer och automationsspecialister, direkta fabriksbesök samt analys av intern dokumentation och litteratur. Det teoretiska ramverket bygger på Hills Manufacturing Strategy Framework, processkonstruktionsteori, automationsnivåer, system för tillverkningsplanering och -styrning samt nyckeltal.

Resultatet visar en klyfta mellan mognadsgraden hos den fysiska automationen på fabriksgolvet och den kognitiva och systemövergripande automationen som krävs för att stödja den. Störningar i systemintegration, ofullständiga dataflöden och varierande kunskapsnivåer bland operatörer identifieras som centrala operativa utmaningar. Vidare visar studien att strategiska beslut om automation måste utgå från en tydlig koppling mellan företagets övergripande mål, marknadsstrategi och tillverkningsstrategi, och ses både uppifrån och ned (top-down) samt nedifrån och upp (bottom-up).

Slutsatsen blir att standardisering av processer, datastrukturer och automationsramverk är en förutsättning för att SKF ska kunna uppnå sina strategiska mål för 2030. Flexibilitet identifieras som det primära prestationsmålet. Att anpassa produktionsstrategin till förändrade marknadskrav där man går över till mindre batchstorlekar, kortare ledtider och en förskjuten kundorderkoppling, blir en central del för att upprätthålla konkurrensfördelar. Resultaten är avsedda att utgöra en grund för datadrivna och kontextmedvetba beslut i framtida automationsprojekt vid SKF Industrial i Göteborg.

Nyckelord: automation, tillverkningsstrategi, produktionslayout, cellproduktion, systemintegration, KPI, SKF, Industri 4.0, flexibilitet, prestationsmål, standardisering

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1. Introduction

In accordance with a directive from its investors, SKF is set to be divided into two separate entities: SKF Industrial and SKF Automotive. This transformation goes beyond a purely organisational realignment, as it also requires the separation of factories and operational systems, placing new demands on how production and automation are structured and managed across the company.

At SKF's Gothenburg office, a permanent team works continuously with the optimization and design of automation across the company's operations, addressing both technical aspects, such as machinery and system infrastructure, and the broader strategic question of what automation levels are appropriate given the complex environment in which the company operates. In light of the ongoing division of the company, this team has been given the important task of developing a framework for how automation should be optimized and structured going forward.

This thesis has been conducted in collaboration with SKF, and aims to examine how different factory designs and levels of automation influence operational performance. The goal is to contribute to a deeper understanding of how automation can be effectively applied in a large-scale industrial setting.

The study also includes a case study of SKF's D-factory in Gothenburg, one of the company's most highly automated production facilities. The case study provides a practical perspective on how a high degree of automation functions in reality, while also identifying potential gaps between intended and actual performance. It draws on interviews with a range of stakeholders, offering a broad view of the system and forming the basis for a root cause analysis of what is required for automation to be more effectively and cohesively implemented.

1.1 Problem Description

Over the course of its more than 100 years in operation, SKF has undergone repeated transformations with respect to both factory design and organizational structure (SKF, 2026). Production layouts have evolved from functional arrangements to line production, and subsequently to the cell-based configurations currently in use, according to what the company itself refers to as channels (Respondent 1, personal communication, Apr 8). In parallel, machinery has been continuously developed to meet higher standards of safety, ergonomics, and autonomous operation.

These developments have yielded considerable benefits within SKF's D-factory. Over a period of 30 years, the facility has transitioned from a loud and hazardous working environment to one that is near-silent (Respondent 1, personal communication, Apr 8). Despite the progress achieved through successive improvement initiatives, current production still has its shortcomings. A high degree of automation has introduced a new set of challenges that cannot be adequately examined through registered data alone (Respondent 3, personal communication, Apr 8). Understanding the full implications of automation therefore necessitates a study incorporating qualitative interview-based material. A case study is consequently well positioned to provide insight into the functioning of a highly automated operation.

It should be noted, however, that factory design involves a considerable number of interdependent variables, making it difficult to establish a standardized framework applicable to the optimization of any individual facility. Limited access to complete information, combined with continuously changing operational conditions, places substantial demands on a comprehensive understanding of the advantages and constraints involved, particularly in the context of capital-intensive investments such as automation.

1.2 Purpose

The purpose of this thesis is to develop a comprehensive understanding of how different levels of automation and production system design influence production performance. Drawing on both existing literature and an in-depth case study of SKF's D-factory in Gothenburg, the study examines how automation affects the five performance objectives and how different production setups shape operational outcomes.

Furthermore, the thesis evaluates the current implementation of automation in the D-factory, and the relationship between SKF's manufacturing strategy and market strategy. By analysing the performance implications of the current system and identifying areas where operational capabilities do not fully support strategic objectives, the study seeks to provide a clearer understanding of the opportunities and challenges associated with a high degree of automation.

The findings are intended to support more informed automation and investment decisions by highlighting the organisational and operational factors that should be prioritised to improve performance and reduce disturbances. Ultimately, the study aims to provide recommendations that not only support the continued development of SKF's production system but also contribute to the company's ongoing efforts to establish a more structured approach to automation decision-making.

1.3 Research Questions

Q1. What key input parameters affect the decision of production system design and automation level and what effect does the strategic decision imply on output parameters?

Q2. How does SKF Industrial in Gothenburg’s production system design relate to theoretical models within manufacturing and strategy?

Q3. Which requirements does SKF Industrial in Gothenburg have to fulfil to integrate a suitable level of automation, and prepare the organisation for modern technical advancements?

1.4 Limitations

Given the scope of the thesis, the study has been limited such that the case study and its analysis of production system design and automation level focuses specifically on the assembly operation, which is of particular interest as it represents the process step where a different level of automation could be considered, as well as being the most labour-intensive operation in the D-factory. That said, as the assembly cells operate within a broader system, the thesis also discusses implications at a more general level. Consequently, the findings would likely be applicable to the other processing cells within the factory as well.

Moreover, the case study is conducted at SKF's D-factory in Gothenburg, which contains four assembly cells operating within the channel concept. All four cells share the same production logic and operate under highly similar system infrastructures, with comparable layouts, automation levels, and system integration. Therefore, the findings and recommendations from the study are considered relevant and transferable across the assembly cells within the D-factory.

The study is further limited to examining and analysing selected factors related to automation and production system design, including the five performance objectives, production volume, product mix, and the operational and organisational implications associated with different levels of automation. In practice, there are numerous predictable and unpredictable factors that may influence a factory's optimal choice of setup and degree of automation. While it is not feasible to account for all such variables within the scope of this work, the thesis addresses the most central parameters and also discusses additional constraining factors relevant to these decisions.

2. Methodology

This section describes the work process of this thesis. The study is conducted by a collection of quantitative and qualitative data, followed by an analysis, and a discussion of the synthesised results. Finally, a conclusion and recommendation for SKF is designed to help management teams in decision-making regarding the production process.

2.1 Method Model

The methodology used consisted of multiple processes to divide the work into structured phases that fit into the given timeline. The chosen processes were formed to provide a deeper understanding of SKF's current situation, and to be able to analyse and transform the collected data into solutions based on the research questions of the study. The method model used is described by the illustration below.

Figure 1: *Method model for the project design*

2.2 Problem Identification

As an introduction to, and onboarding of the project, observations of the production process were made by factory visits with focus on the assembly of the roller bearings. Workshops together with the supervisors both at the institution and at SKF were conducted as well. Its' purpose was to visualize the assembly process and see firsthand how the production flow of the operation looked, to thereafter identify the problem.

2.3 Data Collection

The data collection can be divided into two categories, primary sources and secondary sources. The definition and difference between the two sources are described in this section.

2.3.1 Primary Sources

A primary source is original information collected firsthand by the researcher for the purpose, and in the duration of the research project (Crelin, 2024). Primary sources reflect how an event occurred and personal experiences as raw, unbiased data. Interviews, surveys, illustrations, and official documents are examples of primary sources. As primary sources generally aim to have objective means, they inevitably are an interpretation of the researcher or creator, which must be taken into account.

2.3.1.1 Interview Studies

The objective of the interviews was to identify the organisation's pain points, in order to determine their needs. To fully understand SKF's current situation, interviews with the stakeholders of the project were conducted, where relevant questions about the production setup within the assembly were discussed. It was also important to document which factors were measured, and how it affected the overall performance.

As previously stated, there is a high risk for bias from the researcher or creator since they are interpretations of the raw material (Crelin, 2024). In the case of interview design, one can argue that the question or formulation of the question can be steered to a specific result. The participants for the interviews must also have the correct role to be able to answer the research questions, but must be chosen at random to ensure unbias. The table below represents the number of respondents, their role in SKF, as well as the date the interviews took place.

Table 1: *The number of respondents, their role at SKF and date of interviews.*

Respondent	Role	Date
Respondent 1	Operator	8/4-2026
Respondent 2	Operator	8/4-2026
Respondent 3	Production Manager	8/4-2026
Respondent 4	Process Developer	10/4-2026
Respondent 5	Standardisation and	16/4-2026

	Automation Lead	6/5-2026
Respondent 6	Global Manufacturing Manager	22/4-2026
Respondent 7	Reliability Specialist	23/4-2026

The interview guide deemed best for the project is a semistructured interview, where specific but open-ended questions are asked and follow-up questions can be added when needed (Bryman, 2016). All participants thus received similar questions, but allowed the flexibility to expand their answers related to their specific role.

2.3.1.2 Factory observations

The empirical studies consisted of direct observations of the production environment at SKF's D-factory. The purpose was to understand how the channel concept functions in practice, and how different production setups and automation levels affect operational performance, flexibility and decision-making.

At the beginning of the study, a tour was conducted by the production manager, providing valuable insights into the channel concept and the production flow at the D-factory. The tour covered the cell layout and the transportation of material between cells, with particular focus on the assembly cell. Observations were also made regarding which parts of the operation were performed manually versus automatically. These factory visits were a key factor in being able to visualise and understand how the operation functions in practice, which provided a foundation to the current state analysis.

2.3.2 Secondary Sources

Secondary sources are information gathered from multiple primary sources, which in contrast to primary sources, are interpretations and analyses of situations or events (Tantawi, 2024). They can further be categorized into quantitative data, which includes numerical data such as statistics as well as financial statements, and qualitative data, for example literature studies and internet articles. In many cases, secondary data can give a broader perspective of a subject since they take multiple angles into account. However, this can be seen as a disadvantage as well since bias may be introduced into the primary sources.

2.3.2.1 Literature Studies

For the theory behind the concepts included in this thesis, thorough research through published books, articles as well as internet sources was done to support the results with facts. Previous articles of SKF were reviewed to take inspiration from, and compare to, regarding the strategies and patterns for their approach to the organisational changes happening today. Insights regarding their approach to risks, challenges and potential improvements were documented and taken into account.

The objective with the literature studies was for academic purposes, to achieve a deeper understanding of the concepts and strategies used in industries. Databases such as SCOPUS, Google Scholar and Chalmers Library were used for this study. The subjects relevant for the theoretical frame of reference include strategic parameters, production planning and control systems, automation levels, and KPIs.

2.3.2.2 Internal documentation

As a complement to the factory observations, documentation from SKF's internal database and other literature produced by SKF was analysed. The purpose was to compare practical insights from the observations with formally documented descriptions of the operation, and to complete the overall picture of the company. Material such as frameworks describing SKF's strategic goals and market strategy was also reviewed, in order to assess whether these aligned with how the manufacturing strategy appeared in practice.

2.4 Analysis

The results from the interviews, literature studies, and empirical studies were systematically analysed to identify the most suitable recommendations to help SKF through their transformation process.

The findings from the literature review established a theoretical foundation for the analysis, where key concepts such as manufacturing strategy, production layout, and automation levels were applied to interpret the empirical findings. The interview data and factory observations were then analysed in relation to this framework. Its' purpose was to identify and compare theoretical models of strategy with the operation in practice. Together, these inputs formed the basis for the trade-off analysis and the recommendations presented in the conclusion.

2.5 Recommendation and Conclusion

The recommendation and conclusion were developed through a triangulation of the interview findings, factory observations, internal documentation, and the theoretical framework. The strengths and limitations of the proposed recommendations were critically assessed throughout this process. The entire study was peer reviewed and reviewed by supervisors both at Chalmers and at SKF, and was finalised in the form of a report concluded with a presentation.

2.6 Validity and Reliability Analysis

Validity and reliability are two essential factors in determining the trustworthiness of a study (Nartgün & Şahin, 2015). Validity refers to the trustworthiness of the content itself. When using secondary data, it is important to identify relevant and correct information for the purpose of the research and critically evaluate it. It is also important to ensure that the data and researchers' opinions are unbiased. Reliability refers to the measurements or observations derived from secondary data, and to the extent to which they are consistent with findings from other sources.

2.6.1 Use of AI Tools

In this report, AI tools such as Chat GPT (version 5.2) and Claude (Sonnet 4.6) have been used as support to improve the language academically, formulate the interview questions correctly, and to structure the language flow of the text to ensure that it is easy to read and follow. Additionally, Chat GPT (version 5.2.) and Scopus AI were used as support to find relevant scientific articles used for the theoretical frame of reference.

All information in this report has been sourced from scientific sources that have been critically checked. If any additional information has been derived using AI tools, it has been reviewed and compared with multiple sources to validate its credibility.

3. Company Description

SKF is a global Swedish industrial company with operations and factories in over 40 countries worldwide (SKF, n.d). The company was founded in 1907 in Gothenburg and has since developed into one of the world's leading suppliers of solutions for rotating equipment (SKF, n.d). SKF is best known for its production of rolling bearings, which still constitutes the company's largest and most central industrial business (SKF representative, personal communication, Feb 10).

In addition to rolling bearings, SKF has in recent years broadened its offering to meet increased demands for operational reliability, energy efficiency and life-cycle costs among industrial customers (SKF representative, personal communication, Feb 10). The business now also includes industrial services such as maintenance and reliability solutions, lubrication systems, seals and digital solutions for condition monitoring and preventive maintenance (SKF, n.d). These services aim to reduce unplanned downtime and extend the service life.

SKF is currently undergoing a large-scale organisational restructuring where SKF will be divided into automotive and industrial on the encouragement of SKF:s investors (SKF representative, personal communication, Feb 10). The split of the company is implemented to provide investors with greater clarity, given that bearing revenues differ between the two sectors, and to better align systems and production within each field (Respondent 5, personal communication, Mar 25). The division will therefore provide clarity but may also result in higher costs. Some factories might need to purchase more of the same machines and hire more staff as machines and systems no longer will be shared (Respondent 5, personal communication, Mar 25).

SKF currently find themselves in a position where they also need to adapt their production to the ongoing electrification of automotives and the green transition (SKF representative, personal communication, Feb 10). This introduces new criteria for each division that also requires modifications in their production. For SKF automotive the electrification of vehicles implies less demand for bearings, since electric cars generally need fewer bearings to function, averaging 18 bearings in an electric car compared to 150 bearings in a car with a combustion engine (SKF representative, personal communication, Feb 10). However, there may also be a higher demand for customer specification and high quality; therefore, SKF's market share and turnover will not necessarily be negatively affected (SKF representative, personal communication, Feb 10). Automotive today stands for about one third of SKF's business.

The industrial segment accounts for approximately two thirds of SKF's revenue (SKF representative, personal communication, Feb 10). Unlike the automotive sector, this segment is characterized by a more stable and predictable demand. However, the industrial side is also influenced by the green transition. This has led to a higher demand for remanufacturing services, requiring SKF to expand its facilities and enhance its capacity to refurbish and reuse bearings to meet sustainability goals.

3.1 SKF's Product Range

Rolling bearings are used across a wide range of machinery to enable movement, transfer loads between components, and reduce friction and wear (SKF, 2019). They are manufactured in varying sizes and designs, found in everything from household appliances and bicycles to trains, aircraft, and wind turbines (SKF, 2019)

SKF offers a broad product portfolio, ranging from standardized bearings for mass production to highly specialized solutions tailored for demanding applications in sectors such as energy, mining, , marine, and transportation (SKF representative, personal communication, Feb 10). There are two fundamental types of rolling bearings, ball bearings and roller bearings, and they are distinguished by the type of rolling element used between the inner and outer rings (SKF, 2019). Ball bearings use spherical balls that make point contact with the rings, giving them low friction and making them well suited for high speeds, though with a limited load capacity. Roller bearings instead use cylindrical or profiled rollers that provide line contact, which increases load capacity but comes with slightly higher friction and a lower maximum operating speed (SKF, 2019). To handle this product diversity, SKF organizes its production facilities according to bearing size and product family (SKF representative, personal communication, Feb 10).

In the Gothenburg region, SKF produces bearings across a wide range of sizes in multiple facilities. One of these facilities is the D-factory, which focuses on mid-size bearings, primarily spherical roller bearings which stand for around 86% of the factory's output (SKF representative, personal communication, Feb 10). The factory is not only one of SKF's most highly automated facilities, but also stands out in the way it works by incorporating Industry 4.0 tools and lean practices as integral parts of its daily operations, making it one of SKF's most advanced production environments (SKF representative, personal communication, Feb 10) and a natural subject for this study.

3.3 SKF's Production Layout and Flow

Until the 1980s, SKF operated with a functional layout, where machinery and equipment were grouped according to their specific functions. While this arrangement offered flexibility, it resulted in high levels of tied-up capital due to large inventories and excessive work-in-progress. In response, SKF transitioned during the 1980s toward line-based production, introducing a channel concept in which each channel corresponded to roller bearings within a specific diameter range. This shift reduced inventory levels significantly, but introduced new challenges: the limited buffers inherent to line production meant that a single machine breakdown could halt the entire production flow. Line production also offered less flexibility and made customer-specific adaptations more difficult to accommodate (Respondent 4, personal communication, Apr 10)

Over the following decades, SKF observed that line production had also led to overcapacity in certain sub-processes. To address this, production was gradually restructured toward a more cellular orientation, with shared operations across cells to improve resource utilisation. Today, SKF's factories are organised around channels that integrate cells, lines, and individual workstations into a hybrid production structure. This has allowed SKF to maintain relatively low buffer levels while achieving greater flexibility, higher resource utilisation, shorter lead times, and earlier detection of quality defects. In parallel, the D-factory in Gothenburg has progressively moved toward higher levels of automation and digitalisation, in line with Industry 4.0 principles. This development has brought significant changes to the factory environment in terms of physical layout and equipment, and in working practices, processes, and the demands placed on the workforce (Respondent 4, personal communication, Apr 10).

The D-factory is structured around four channels, each containing assembly cells. However, the material flow between cells is not strictly linear. Components can move between channels during processing, meaning that the physical channel boundaries and the actual production flow do not always coincide (Respondent 3, personal communication, Apr 8). This has given rise to some confusion in how the channel concept is understood and communicated internally within SKF, and the question of how channels should be defined and potentially restructured is an active discussion within the organisation today. The term is used both to describe the physical grouping of cells and to describe the flow of materials through production (Respondent 6, personal communication, Apr 22). According to one interpretation used within the organisation, the channels are defined by the material flow between production cells, with the boundaries between channels determined by the intermediate buffers between them. Under this definition, breaking up a channel means introducing additional buffer points by splitting the activities handled within a cell, so that material is placed into intermediate storage more frequently. More buffers reduce the sensitivity of production to disruptions, as they allow other parts of the production to continue operating for a period despite a stoppage in one machine. Buffer sizes vary by product type and family, and are also constrained by incoming material deliveries and batch sizes. Since there is little practical difference between holding material in raw material stock or in intermediate storage, it is generally preferable to hold it as intermediate buffer stock closer to the point of use (Respondent 5, personal communication, May 6)

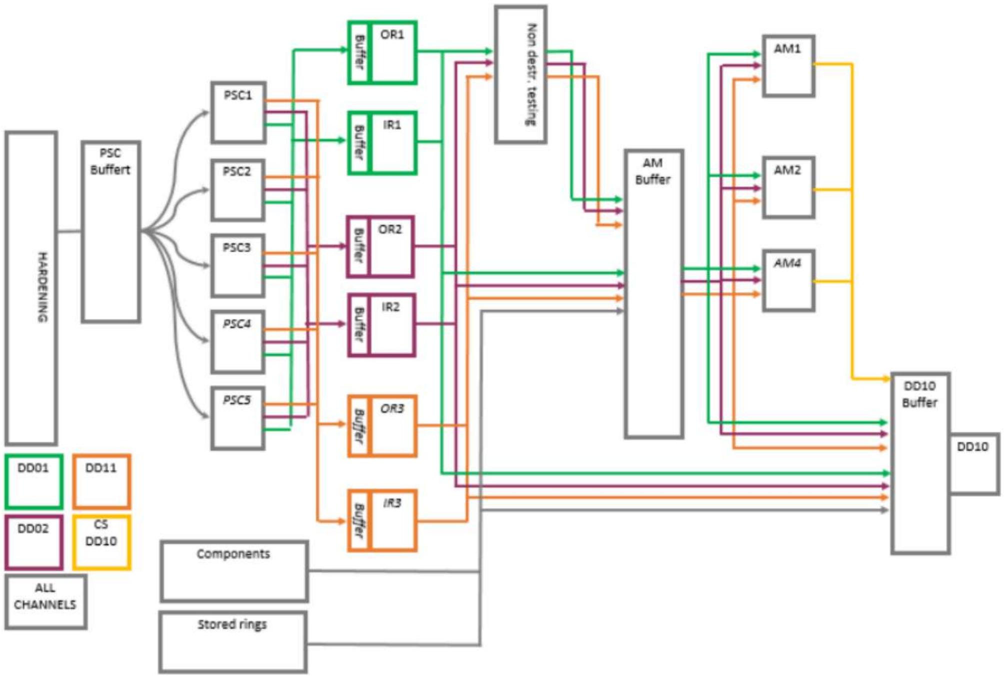

Figure 2: *Flow diagram between cells and channels at SKF’s D-factory (SKF, 2026).*

The figure illustrates the physical formatting of the ‘channels’ as well as the channel flow between cells and how this flow can cross the physical ‘channel’ boundaries. Material enters from the warehouse following the hardening process and proceeds to the flat grinding cell (PSC), which can handle rings from multiple product families. It then moves to the inner ring grinding (IR) and outer ring grinding (OR) cells, which can only process products belonging to their designated product family, before finally being assembled in the respective assembly cell (AM).

When it comes to strategic decision making regarding the detailed production setup and inventory levels, these decisions are taken locally and are primarily based on well-founded knowledge and are partially data-driven (Respondent 5, personal communication, Apr 16). However, there is still no general framework for optimizing production layouts and automation, nor for how these should be modeled under changing conditions. This gap highlights a significant challenge in modern manufacturing, as the lack of a standardized optimization model means that many layout transitions, such as the shift from functional to cellular structures, often rely on a combination of historical experience and specific case studies rather than a universal mathematical formula (Respondent 6, personal communication, Apr 22)

In the absence of such a framework, companies like SKF must continuously adapt their modeling techniques to account for variables like fluctuating market demand, product customization, and technological advancements. Without a robust, standardized method to simulate these changing conditions, the risk remains that a layout optimized for today's efficiency might become a bottleneck when production requirements shift tomorrow. This necessitates a more dynamic approach to industrial engineering, where flexibility is not just a feature of the physical machines, but a core component of the planning and modeling process itself.

3.3.1 Order Planning and Production Control at SKF

SKF operates a mixed order planning system combining both push and pull principles. For make-to-order products, depletion of finished goods inventory triggers a new production order in line with pull-based production planning. However, production is carried out in batches to reduce changeover times, which introduces a push element where output does not always directly mirror real-time demand. Production sequencing is also constrained by product family logic. When a given product family is scheduled for production, multiple variants within that family are produced together to avoid large and costly changeovers between fundamentally different setups (Respondent 5, personal communication, May 6)

3.4 Components and operations

Roller bearings are designed to enable rotation and movement with minimal friction. Although the overall design is largely similar across different bearing types, variations arise depending on the intended application, the type and magnitude of loads the bearing is expected to carry, and specific size requirements. These differences in performance requirements, materials, and dimensions result in a wide range of product variants offered by SKF (SKF representative, personal communication, Feb 10).

Despite these variations, roller bearings fundamentally consist of the same core components: an inner ring, an outer ring, rolling elements, a cage, and often seals and lubrication.

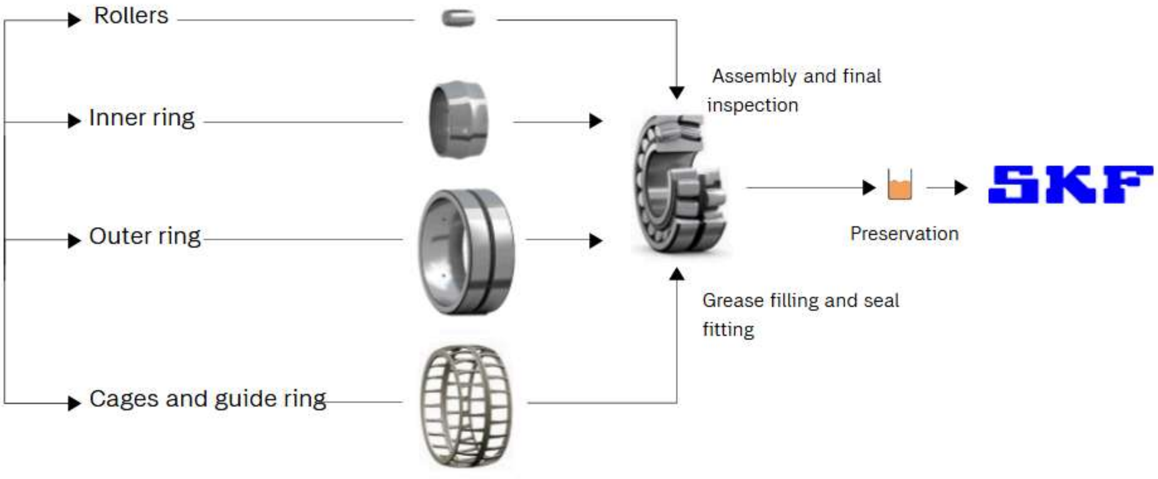

Figure 3: *Components in a Roller Bearing (SKF, 2025).*

In a production context, these components must be precisely synchronized to ensure structural integrity. While the rings provide the raceways, the rolling elements carry the load, and the cage maintains their alignment (SKF, 2019)

Each component of a ball bearing goes through several preparation and manufacturing steps before the final assembly. The outer ring, inner ring, and steel balls are produced separately through a sequence of processes such as forging, heat treatment, grinding, and finishing. These steps are necessary to achieve the required precision, strength, and surface quality. Because bearings operate under high loads and speeds, even very small imperfections can affect performance and durability. Therefore, each stage of the manufacturing process is carefully controlled to ensure consistent quality (SKF, internal, 2026)

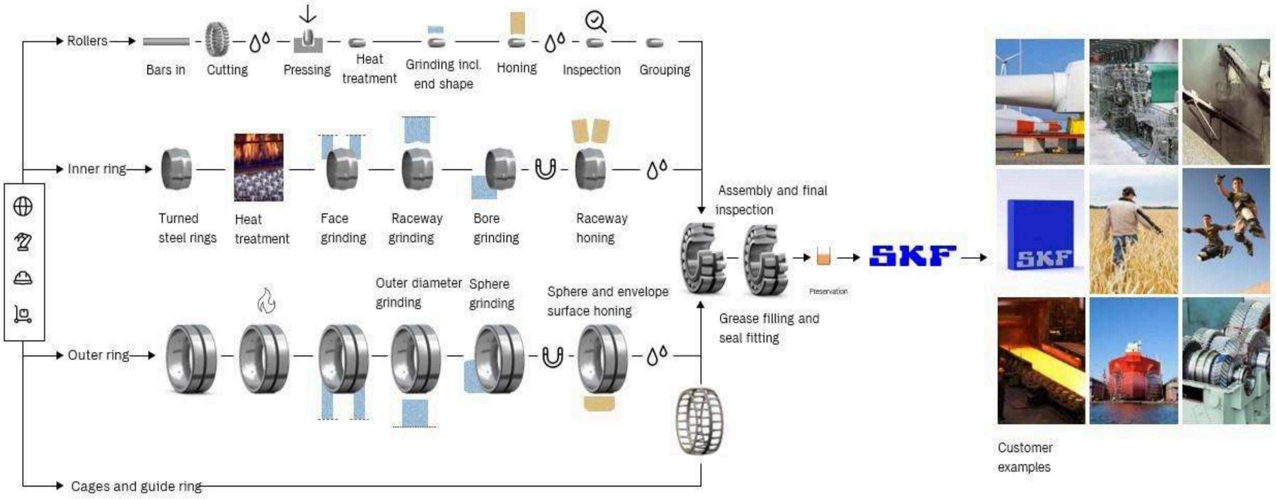

Figure 4: *Roller Bearing Manufacturing and Assembly (SKF, 2025).*

As shown in the figure, the components are processed individually before being assembled into the final bearing. A significant part of the desired product properties and customer-specific requirements is achieved during the heat treatment stage. During this process, the material's hardness, strength, and wear resistance are carefully adjusted to meet the operational demands of the bearing. This step is therefore crucial for ensuring long service life, reliability, and optimal performance in different applications.

3.5 The Gothenburg Factory

The Gothenburg factory is one of SKF's most advanced production facilities in terms of automation and digitalization. Most production tasks are automated, enabling a significant reduction in the number of operators required in the assembly cells. While the factory today requires approximately seven operators per shift in each assembly cell, the same production area previously required around 50 operators and was the most labor-intensive cell in the factory, accounting for roughly half of all operators (Respondent 4, personal communication, Apr 10)

The implementation of automation has not only enabled SKF to reduce staffing levels, but also to increase production output and achieve shorter cycle times (Respondent 4, personal communication, Apr 10). Today, operators primarily complement the automated processes by performing tasks that have not yet been fully automated, such as feeding rolling elements and handling pallets. In addition, they monitor the systems, manage disturbances, report errors, handle customer-specific orders, and ensure that production operates smoothly and efficiently (Respondent 1, personal communication, Apr 8)

The D-factory primarily produces spherical roller bearings, which account for approximately 86% of its total output. Inner and outer rings are supplied pre-turned by subcontractors, while the raw material for the rolling elements is delivered as steel bars. Depending on the required product characteristics, different raw materials may be used, particularly for larger bearings that often require additional alloying elements or stainless steel. The desired material properties are mainly achieved through heat treatment processes (Respondent 3, personal communication, Apr 8).

The manufacturing process begins with hardening, where the rings are heated to specific temperatures to obtain the required material properties. After heat treatment, the rings proceed to grinding operations to achieve the required tolerances and surface specifications. The first stage consists of face grinding, where the side surfaces of both inner and outer rings are processed within the same production cell. In the subsequent stage, the rings are separated, and the raceways and functional surfaces are ground and polished. Although grinding and polishing are performed within the same cell, each cell is dedicated exclusively to either inner rings or outer rings due to differences in geometry and process requirements (Respondent 3, personal communication, Apr 8)

Once the grinding and polishing operations are completed, approximately twenty measurements are performed on each ring to verify compliance with dimensional tolerances and relevant standards established by the International Organization for Standardization (ISO). SKF currently operates with a high process capability across its manufacturing processes and is considered as a capable and reliable production system (Respondent 5, personal communication, Mar 25).

3.5.1 Assembly of Medium Sized Roller Bearings

The assembly process of medium-sized roller bearings involves several key steps, including assembly, washing, inspection, preservation, and laser marking (Respondent 5, personal communication, Mar 25)

The first step is ring pairing, where each inner and outer ring is matched to ensure an optimal combination and adherence to the total permitted tolerances. This process is carried out using advanced algorithms, where the measurement data of each ring is saved and stored on an RFID tag, as well as the ring's position on the pallet (Respondent 5, personal communication, Mar 25)

The matched inner ring is then positioned inside the outer ring, allowing contact while still leaving space for the rolling elements. The required number of rolling elements is inserted and evenly spaced. Finally, the cage is attached from the top and bottom, and rivets are pressed to secure the bearing in place.

The assembled bearing then moves on to the washing stage, where it is cleaned before continuing to inspection, preservation, and finally laser marking (Respondent 6, personal communication, Mar 25). The laser marking is very important for traceability, as it helps prevent plagiarism and enables digital tracking of the bearing throughout its lifecycle (SKF representative, personal communication, Feb 10).

3.6. SKF Industrial's Corporate Strategy

SKF Industrial Gothenburg's corporate strategy, also known as the "Industrial More Progress" strategy is centrally about accelerating profitable growth and creating greater value by 2030 (SKF, 2025). The strategy is guided by the motto "Intelligent and Clean", which reflects not only what SKF does, but how it thinks and organises itself to solve complex industrial problems. The strategy is built around three core pillars, which is supported by seven strategic levers for execution.

Reignite growth

1 Leverage attractive high-growth industries and geographies
2 Scale recurring service and intelligent solution business
3 Accelerate Specialized Industrial Solutions
4 Explore value accretive bolt-on M&A

Innovation leadership

5 Differentiate through customer-centric innovation and AI

Business-driven value chain

6 Finalize ongoing regionalization and footprint optimization
7 Optimize supply chain for a pure Industrial play

Figure 5: *SKF Industrials strategy (SKF, 2025).*

The first pillar, *reignite growth,* aims to outgrow markets at improved margins (SKF, internal, 2025). SKF emphasises both market share expansion and stronger profitability. SKF aims to leverage global trends and capitalise on attractive high-growth industrial verticals such as aerospace, rail, food production and industrial transportation where it already holds a strong market presence. Growth is to be driven through a customer-centric approach, with a focus on selecting key customers and co-developing new applications rather than risking to become average by trying to serve everyone. This includes scaling recurring service and intelligent solution businesses, and exploring value-creating mergers and acquisitions.

The second pillar, *innovation leadership,* focuses on differentiating SKF’s products and services to maintain competitiveness in the market, by developing new technologies. As the global trends within industries go through changes, SKF recognises the need to integrate and follow these by developing their portfolio in robotics, automation, humanoids, and material sciences. Investment in intelligent research and customer-centric R&D is prioritised, with approximately 90% of developments being done for the most attractive industries and key customers. AI and digitalisation are also seen as central factors for increased flexibility and faster decision making.

Lastly, the third pillar, *business-driven value chains,* aims to simplify operations and establish a way of working towards customer demand (SKF, internal, 2025). This includes regionalisation and automation of high-volume production, which is a shift toward a pull-based supply chain planning to reduce lead times, optimise their portfolio through a 25% reduction in their product variants, and exit unprofitable contracts. Leaders emphasise that standardisation of manufacturing setups and the use of data models have to be done to accelerate digitalisation and AI implementation. The main goal here is a simplified and modernised IT landscape, cost management, and intelligent pricing in this pillar.

These pillars are designed to make SKF Industrial more profitable, more technologically advanced, more industrially skilled, and more globally standardised while remaining adaptable to local variations (SKF, internal, 2025).

4. Theoretical Frame of Reference

This chapter describes the theoretical frame of reference used in this thesis. It highlights the main concepts and ideas relevant to the analysis. By presenting these topics, it serves as a foundation to the discussion of the results.

4.1 Strategic Parameters

The table below is known as Hill's Manufacturing Strategy Framework, which shows the link between a corporation's objectives, the market strategy and the qualifications required on an operational level (Hill, 2000). They are thus not considered independently and each decision is followed by the insights gained from the previous dimension.

Table 2: *Corporate objectives to manufacturing strategy (Hill, 2000).*

Corporate objectives	**Marketing strategy**	**How do products qualify and win orders in the marketplace?**	**Manufacturing strategy**	
			Process choice	**Infrastructure**

Growth Survival Profit Return on Investment Other financial measures	Product markets and segments Range Variants Volumes Standardization versus customisation Level of innovation Leader or follower	Price Quality conformance Delivery: speed, reliability Demand increase Colour range Product design Brand image Technical support After-sales support	Choice of alternative processes Trade-offs embodied in the process choice Role of inventory in the process configuration Make of buy Capacity: size, timing, location	Function support Manufacturing planning and control systems Quality assurance and control Manufacturing systems engineering Clerical procedures Work structuring Organisational structure

4.1.1 Corporate Objectives

Firstly, the framework begins with corporate objectives, which are the organisation's goals and conditions required in a competitive environment (Hill, 2000). These include growth, survival, profitability and Return on Investment (ROI), and other financial objectives. These are the strategic logic that gives the manufacturing organisation its purpose and direction. Based on these measures, they predetermine the next steps that lead to which manufacturing strategy is deemed most suitable.

4.1.2 Market Strategy

The market strategy that follows is determined by the corporate objectives. This segment includes what is known as the 4 V’s: volume, variety, variation, and visibility (Slack et al., 2022). The trade-offs between them are substantial to later design the operation’s services, products, and processes.

To be able to determine which of the market requirements are most important, it is important to be able to distinguish *order-winners* from *order-qualifiers* (Hill, 2000). *Order-winners* are those factors which contribute to winning businesses, for example a unique product design. O*rder-qualifiers* are those factors which are required to be on the market, for example the price range.

There are five performance objectives to take into account in determining how well a firm meets these criteria: quality, speed, dependability, flexibility and cost (Slack et al., 2022). Each of these objectives can, depending on the market context, function as either an order-winner, and an order qualifier.

Quality refers to the degree of which a product or service meets the customers' expectations, which is a vital influence to customer satisfaction or dissatisfaction (Slack et al., 2022). The higher degree of satisfaction, the higher chance the customer will return or refer the company to others.

Speed is the amount of time between a customer placing an order and receiving the product or service (Slack et al., 2022). The faster the customer receives an order, the greater benefit they see with the specific product or service.

Dependability is to which content a firm consistently meets its promised delivery requirements (Slack et al., 2022). Dependability concerns how predictable and trustworthy the firm is. Regardless of price or speed, being able to receive the product on time or when they are needed is important to the overall performance. In most markets, dependability is not necessarily *an order-winner* but an *order-qualifier.*

Flexibility is the ability of an operation to change or adapt in some way to meet customer requirements, whether in terms of the introduction of new products, product variety, volume, or the timing of delivery (Slack et al., 2022). To be able to customize an order to customer needs can serve as a significant order-winner which differentiates the firm from less adaptable competitors.

Lastly, the cost is which expenses the firm has through producing and delivering a product or service, which directly affects the price (Slack et al., 2022). The cost and price in turn affect the organisation's margin, and so it is up to each organisation to decide how important the cost objective is to the operation. The cost is the foundation of all the other performance objectives.

4.1.3 Manufacturing Strategy

The most difficult task in determining the best manufacturing strategy is deciding which trade-offs are between the five performance objectives that are most valuable to the firm (Holweg, 2018). Since no operation can excel at all five simultaneously, the manufacturing strategy must prioritise those objectives that directly correspond to the firm's order-winning criteria in its target market (Slack et al., 2022).

Manufacturing strategy is divided into two dimensions: process choice and infrastructure (Hill, 2000). Process choice is the selection of an appropriate production system, which can range from highly flexible jobbing processes to standardised continuous flow production (Slack et al., 2022). The type of process is strategic, as different process types prioritise different performance objectives.

Infrastructure describes the systems, structures, and practices that support the chosen process. This includes manufacturing planning and control systems, quality assurance and control, work structuring, and so on (Hill, 2000).

Manufacturing planning and control systems concern how production is scheduled, how inventory levels are monitored, and whether production is driven by predetermined schedules or by actual customer demand (Slack et al., 2022). In practice, this is often managed through Enterprise Resource Planning (ERP) systems, which integrate planning, scheduling, and inventory control across the operation. Shop-floor oriented systems such as Programmable Logic Controllers (PLC) regulate and automate individual production processes.

Quality assurance and control involves decisions around how much investment is directed toward inspection versus prevention, and what types of quality improvement programs are relevant to the operation (Holweg, 2018).

Work structuring includes hiring practices, competence levels required, job content, training, and the degree of cross-training across different roles (Holweg, 2018).

Beyond these, infrastructure also includes decisions related to technology and facilities, such as the level of automation, capital versus labour intensity, and plant size and location (Holweg, 2018). Within organisational aspects, whether the decision-making is centralised or decentralised is also critical to the operation.

The structure and process choice must be well analysed for what the form needs to deliver in the marketplace.

4.2 Top Down versus Bottom Up

While Hill’s (1993) model suggests a largely top-down process, where market requirements shape manufacturing strategy, strategic reality is rarely this straightforward. Mintzberg (1994) argues that strategies seldom emerge as purely deliberate, top-down processes; instead, they are frequently influenced by operational realities, resource constraints and local adaptations. Applied to manufacturing strategy, this means that the translation from market requirements to production decisions is not always direct – internal limitations may constrain or alter the strategic options available to the firm.

This perspective is further supported by the work of Barney (1991), who uses the traditional SWOT analysis framework to explain the link between a firm's internal characteristics and its performance,. According to Barney (1991), firms obtain sustained competitive advantages by implementing strategies that exploit their internal strengths and avoid internal weaknesses, while simultaneously responding to environmental opportunities and neutralizing external threats,. Consequently, a firm's strategic choices are bounded by its actual resource endowments, as managers have a limited ability to manipulate all the attributes and characteristics of their firms. These resources -categorized as physical capital (e.g., technology, plants, and equipment), human capital (e.g., training, experience, and relationships), and organizational capital (e.g., formal structures and planning systems) - are not infinitely flexible. They represent both enablers and constraints in the formulation of manufacturing strategy, often being shaped by unique historical conditions and path-dependencies that make them difficult for competitors to duplicate.

Manufacturing strategy should therefore be understood as the outcome of both top-down market imperatives and bottom-up resource realities - where Hill’s (1993) framework provides the analytical structure, while Mintzberg (1994) and Barney (1991) account for the constraints and historical factors that shape strategic decision-making in practice.

4.3 Process Design

A production process is designed based on multiple factors, among others the process type, and the layout (Slack et al., 2022). The first decision is based on the process type, followed by the layout, and finally the detailed layout. The figure below describes a simplified model for a part of the decision making process.

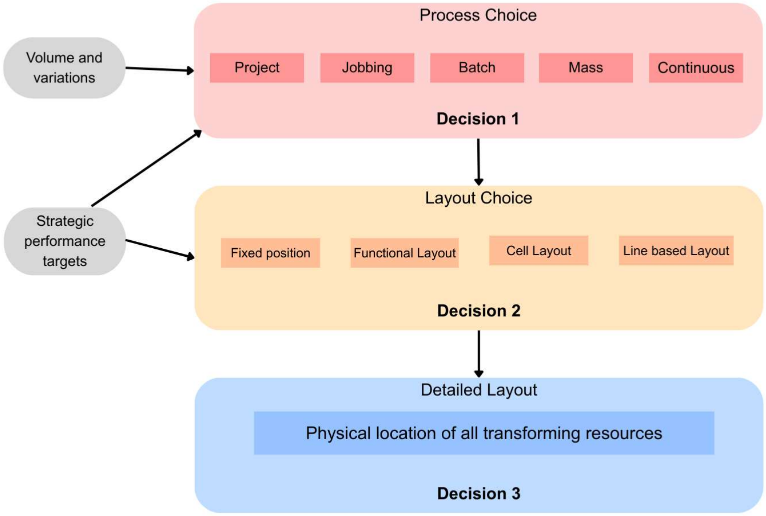

Figure 6: *Decisions concerning process and layout choices (Slack et al., 2022).*

4.3.1 Process Type

A production process contains multiple steps, and the decision of the layout and flow is followed by the first decision of choosing the process type (Slack et al., 2022). The different processes can be characterized by their varying range in the volume-variety continuum. The process types can be divided into five categories: project processes, jobbing processes, batch processes, mass processes, and continuous processes.

In both project and jobbing processes, the manufactured product usually is highly diversified, meaning that the number or variants are high and the volume is low (Slack et al., 2022). They differ in the fact that project processes are unique and have a defined start and finish, while jobbing processes are less complex and exclusive.

For batch processes the manufactured products are less diversified, and so enables batch production (Slack et al., 2022). The size of the batches and the product variety may vary, which means that batch processes can be used for a wide range of manufacturing situations.

For mass and continuous processes, the manufacturing process runs through a consecutive line from raw material to the finished product (Slack et al., 2022). The industries using this process usually manufacture in bulk, meaning high volumes and low variation between units. Although continuous flow produces at even higher volumes with a lower variety, usually being inseparable in an endless flow. They are often inflexible and highly automated due to the predictable flow. Water processing is an example of a continuous process.

The figure below illustrates the relationship between the process type volume in correlation to the design characteristics each type obtains.

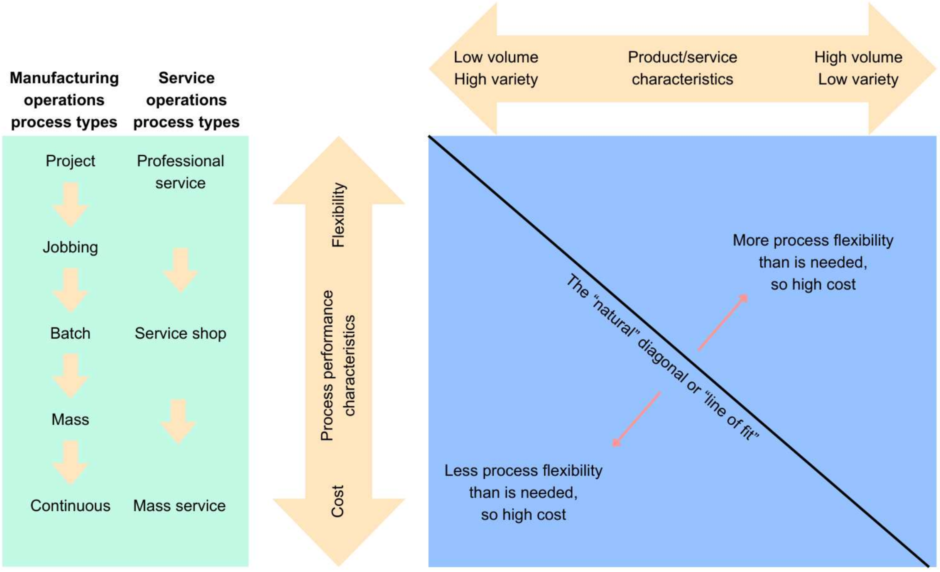

Figure 7: *The Hayes and Wheelwright product-process matrix (Slack et al., 2022)*

4.3.2 Process Layout and Flow

Choosing the correct layout in general is substantial to the customer satisfaction, flow, and efficiency in an operation (Slack et al., 2022). The choice of layout affects the ability to implement or adjust how the equipment is arranged, which in turn affects the organisation's flexibility to introduce new products, change existing products, and adapt to market fluctuations.

The different basic layouts are the following:

- Fixed-position layout
- Functional layout
- Cell layout
- Line layout

4.3.2.1 Fixed-position Layout

Fixed position production is often used for project processes. The product requires high customization and often is difficult to transport between different stations, thus placed in a fixed position (Slack et al., 2022). Furthermore, they require high physical labor and skilled personnel. Examples of products mostly used with fixed position layout include airplanes, highways, and buildings.

4.3.2.2 Functional Layout

Functional layout refers to grouping processes with similar functions in the same area, which can be used for project, jobbing, and batch processes (Slack et al., 2022). Many different types of products are manufactured in small volumes, and are transported to different parts of the production depending on which processes are needed. An important factor is to plan and coordinate when the machines are used to avoid bottlenecks in one station and downtime in another. Poor planning can result in inter alia, long throughput times, excess inventory which ties up assets, and low delivery precision which decreases customer satisfaction. Another disadvantage, as per lean principles, is the waste of time in transportation between machines, since it does not add any value to the total production (Liker, 2021). However, functional layout enables low barriers to introduce new products to the product assortment since the equipment is not arranged based on the product family.

4.3.2.3 Cell Layout

Cellular layouts can be applied in a range of production environments, particularly in medium-volume and medium-variety manufacturing where the advantages of both functional and line layouts are desired (Slack et al., 2022; Hyer & Wemmerlöv, 2002). In a cellular layout, machines and workstations are arranged according to the sequence of operations required to produce a family of similar products rather than grouping machines solely by function. This arrangement reduces material handling, work-in-process inventory, and throughput times while supporting smoother material flow (Hyer & Wemmerlöv, 2002).

Because cellular manufacturing often involves producing several product variants within the same cell, short set-up times and flexible operators are important to maintain flow efficiency and avoid excessive waiting between operations (Slack et al., 2022). Operators are commonly required to manage multiple machines and tasks within the cell, which increases the need for broader skills and cross-training. However, the effectiveness of a production cell depends heavily on how product families and processing sequences are designed. Incorrect grouping of products or poorly balanced workflows can lead to queues, idle time, and underutilization of resources (Hyer & Wemmerlöv, 2002). To support the design of manufacturing cells, Production Flow Analysis (PFA) can be used to identify products with similar routing requirements and determine which products are most suitable to group together (Hyer & Wemmerlöv, 2002).

When discussing cell design, a distinction can be made between intra-cell and inter-cell arrangements (Hyer & Wemmerlöv, 2002). Intra-cell arrangement refers to how machines, operators, and workstations are organized within an individual production cell, while inter-cell arrangement concerns how separate cells are positioned relative to each other within the factory. Common intra-cell configurations include straight-line layouts and U-shaped layouts. The U-shaped layout is widely used because it allows operators to move efficiently between consecutive operations and supports flexible staffing as production demand changes. Straight-line layouts organize operations sequentially in a linear flow and may be appropriate where material flow is stable and less operator flexibility is required (Hyer & Wemmerlöv, 2002).

Another intra-cell arrangement is the robot-centered cell, in which an industrial robot is positioned at the centre of the cell and serves as the primary material handler, transferring workpieces between peripheral process stations arranged around it (Groover, 2020). This layout minimises unnecessary transport, reduces handling time between operations, and enables a high degree of process integration within a compact footprint. Because the robot can be reprogrammed to follow different sequences or handle different part variants, the robot-centered cell also offers greater flexibility compared to fully fixed automated systems (Groover, 2015).

In practice, production cells are not always designed according to one strict geometric form. Hybrid arrangements are common, and cells may combine characteristics of different layouts as long as the material flow remains relatively continuous and manageable (Hyer & Wemmerlöv, 2002). At the inter-cell level, manufacturing cells are often separated and connected through material handling systems such as conveyors or forklifts rather than forming one uninterrupted production line. Parallel resources may also be used both within and between cells to increase capacity and improve flow balance when demand or processing times require it (Hyer & Wemmerlöv, 2002).

4.3.2.4 Line Layout

Line-based layout is mostly used for mass and continuous flow production where the focus lies on the product rather than the machines (Slack et al., 2022). The product itself follows a prearranged route through a sequence of workstations, not necessarily arranged in a straight line. Products are produced at high volumes, which often results in a lower unit cost. The processes are typically standardised and predictable, which makes them well suited for automation. However, line-based layouts can only accommodate a limited product mix and are generally less robust and flexible in response to disruptions.

Different physical configurations of line layouts exist, each influencing workflow, operator interaction, and space utilisation in different ways (Slack et al., 2022; Monden, 2011). A straight-line (I-shaped) layout arranges workstations sequentially in a single direction, enabling efficient material flow but offering limited flexibility in terms of space use and operator movement. U-shaped lines fold the line back on itself so that the entry and exit points are adjacent, which reduces walking distances, facilitates better communication between operators, and supports more flexible staffing since operators can cover multiple stations (Monden, 2011). L- and S-shaped configurations are typically adopted to adapt the production line to physical constraints on the factory floor, such as support columns or building boundaries, while still maintaining a continuous flow of material.

A key characteristic of line-based layouts is their sensitivity to disruptions (Slack et al., 2022). Since they typically operate with limited buffer inventory between stations, often only the material present on the conveyor, any stoppage at one workstation can quickly affect the entire line. This makes them generally more vulnerable to production interruptions compared to cell layouts, which typically maintain more buffer inventory between cells and often use different material handling systems than conveyor-based flow.

To manage this sensitivity, several strategies can be implemented, such as introducing buffer stocks at critical points, balancing the line to avoid bottlenecks, implementing preventive maintenance, and increasing workforce flexibility so that operators can assist at multiple stations when disruptions occur (Slack et al., 2022). In line systems, these buffers are typically small and controlled rather than large inventories, and can take forms such as inter-station buffers, accumulation conveyors that allow products to queue without stopping the entire line, or supermarket solutions positioned close to the line. Buffers are often strategically placed before bottleneck stations to ensure their continuous utilisation.

4.3.3 Channel concepts

A fundamental challenge in manufacturing strategy concerns how production flows are organized to match the demands of different product types and order volumes (Slack et al., 2022). Slack describes the channel concept as a way of structuring production into distinct, dedicated pathways, where each channel is designed to handle a specific type of product or order with consistent volume and variety characteristics. Rather than routing all products through the same production system, the channel concept recognizes that different products place fundamentally different demands on manufacturing, and that efficiency is best achieved by separating these flows and tailoring each channel accordingly (2022). As such, the channel concept operates at the process layout level of decision-making, sitting above the detailed physical arrangement of equipment and workstations, and instead concerned with how production flows are strategically organized across the facility.

The choice of layout is therefore central to how each channel is physically realized, and the layouts described in the previous sections can each serve as the basis for a dedicated channel. A functional layout suits a channel handling low-volume, high-variety or customer-specific orders due to its inherent flexibility. A line layout is better suited to a channel focused on high-volume standardized products, where efficiency and throughput are prioritized over flexibility. Cell production occupies a middle ground, making it appropriate for a channel processing a family of similar products that require a balance between variety and efficiency. The channel concept thus does not prescribe a single layout; rather, it provides the strategic rationale for deliberately matching each product flow to the layout that best serves its competitive priorities, whether that is cost, speed, or flexibility (Slack et al., 2022).

4.4 Levels of Automation in Manufacturing

The definition of automation can be described according to The Oxford English Dictionary (2011):

> *"The action or process of introducing automatic equipment or devices into a manufacturing or other process or facility; (also) the fact of making something (as a system, device, etc.) automatic".*

Frohm (2008) suggested that levels of automation can be viewed in two ways: mechanisation and computerization. In mechanisation, automation is seen as a connection between tasks that can be done physically and cognitively. This means that there are tasks that are most suitable to be done with physical labor, or mechanically where human competence shifts to supporting the automated system cognitively, e.g. monitoring the physical task. In computerized automation, the LoA shifts from manual data collection, information processing, and human decision making, to being fully computerized without any human involvement. The different levels of automation within these categories can then be classified into an amount of categories based on the model used. The table below shows which tasks humans surpass machines, and vice versa.

Table 3: Fitts' List, in (Hoffman et al. 2002)

Humans surpass machines in the:	**Machines surpass humans in the:**
● Ability to detecting small amounts of	● Ability to respond quickly to control

visual or acoustic energy ● Ability to perceiving patterns of light or sound ● Ability to improvise and use flexible procedures ● Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time ● Ability to reason inductively ● Ability to exercise judgement	signals, and to apply great force smoothly and precisely ● Ability to perform repetitive, routine tasks ● Ability to store information briefly and then to erase it completely ● Ability to reason deductively, including computational ability ● Ability to handle highly complex operations, i.e. to do many different things at once

In Frohm’s (2008) review, automation is seen as a continuum between fully manual performance to full automation without any human involvement. The table below shows Frohm’s (2008) interpretation of mechanisation and computerisation in relation to the level of automation.

Table 4: LoA-scales for computerized and mechanized tasks within manufacturing (Frohm, 2008).

LoA	**Mechanical and Equipment**	**Information and Control**
1	**Totally manual** - *Totally manual work, no tools are used, only the users own muscle power. E.g. The users own muscle power*	**Totally manual** - *The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge. E.g. The users earlier experience and knowledge*
2	**Static hand tool** - Manual work with support of static tool. E.g. Screwdriver	**Decision giving -** The user gets information on what to do, or proposal on how the task can be achieved. E.g. Work order
3	**Flexible hand tool** - Manual work with support of flexible tool. E.g. Adjustable spanner	**Teaching -** The user gets instruction on how the task can be achieved. E.g. Checklists, manuals
4	**Automated hand tool** - Manual work with support of automated tool. E.g. Hydraulic bolt driver	**Questioning -** The technology question the execution, if the execution deviate from what the technology consider being suitable. E.g. Verification before action
5	**Static machine/workstation -** Automatic work by machine that is designed for a specific task. E.g. Lathe	**Supervision -** The technology calls for the users’ attention, and direct it to the present task. E.g. Alarms
6	**Flexible machine/workstation -** Automatic work by machine that can be reconfigured for different tasks. E.g. CNC-machine	**Intervene -** The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable. E.g. Thermostat
7	**Totally automatic -** Totally automatic work, the machine solve all deviations or	**Totally automatic -** All information and control is handled by the technology. The

	problems that occur by it self. E.g. Autonomous systems	user is never involved. E.g. Autonomous systems

4.4.1 Physical and Cognitive Task Allocation

Physical and cognitive task allocation refers to the human involvement in the process, which is the foundation of the table shown above (Frohm et al., 2008). The following table shows the distinction between the tasks done by physically operating the process, and controlling and monitoring the physical task. The shift lies in the mental workload on the operator, meaning that a high level of automation can imply varying human involvement.

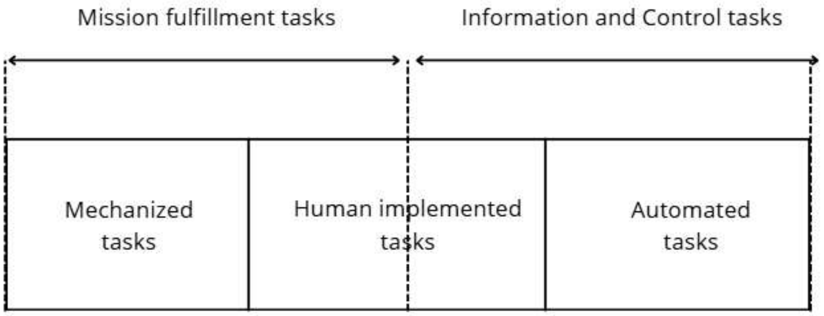

Figure 8: *Human implemented tasks may be classified either as mission fulfillment task or as information and control task, based on the PURDUE Architecture for manufacturing Systems (PERA). (Williams, 1999)*

An example in Frohm's (2008) study is the task of application of plinth on the base of the office cabinet, which requires a LoA=4-5, according to the reference scale.

The physical task done by the human is to physically assemble or adjust if the plinth has not been assembled correctly. The cognitive task done by the human is to monitor or inspect the industrial robot so that the assembly is done correctly.

In automation, the industrial robot replaces the human labor in positioning the cabinet before conducting the automated task, picking the plinth from the plinth stock, and assembling the plinth on the bottom of the cabinet. The automatic cognitive task is deciding which plinth that is going to be picked for assembly, and deciding where to apply the plinth on the cabinet based on the control program.

4.4.2 Level of Automation: Manual (1-4)

Low automation, which often refers to manual in Frohm's (2008) scale in manufacturing, relies on human intelligence and labor to feed the machine with input, as well as control, adjust or reconfigure operations in the production system (Frohm, 2008). The decision making includes starting, stopping and executing the task to run smoothly. The operator also manually inspects each product rather than relying on automatic systems for quality control.

Manual production is best suitable when used in smaller industries that use light-weight equipment with simple operations or products that have a short production cycle, as complex operations would require multiple processes that would be more efficient as fully automated (Afolabi, 2023). Advantages include the flexibility to reconfigure the process layout due to its light weight, as well as reprogramming the system since it requires less advanced coding to execute the process. Additionally, manual production equipment requires a lower initial cost due to its simple design and does not need intricate software development or robotics to operate. Thus, the maintenance cost is also lower since expenses such as technical support and service are seldom needed for simple tools. The disadvantage to manual production is the increased production time due to human errors, setup time, material handling between stations, and reacting to mistakes in the process control due to the lack of sensors to predict errors in the process. Since simple processes are usually monotone, the risk of stress or fatigue can affect the quality of the work rather than fully automated processes. These tasks can increase the risks of “slips” and “lapses” where the operator accidentally makes a mistake or forgets how to execute the task correctly in that specific moment (Bergman & Klefsjö, 2020).

4.4.3 Level of Automation: Semi-automatic (4-6)

Semi-automation in manufacturing refers to a combination between mechanization and computisation (Frohm, 2008). Semi-automated operations enable flexibility between manual and automated tasks, which means that the operator has a set of controls that the machine conducts. The difference between manual and semi-automation is that the physical and mental load on operators is reduced (Afolabi, 2023).

The standard procedure of semi-automated operations in mechanization is that the operator feeds the equipment with input that the semi-automatic equipment or machine analyses and does the work (Afolabi, 2023). In computisation, the technology requires human verification before action, but also supervises and intervenes in faulty processes. The operation is fully executed and quality controlled by the machine, although the operator must still be present for monitoring that the operation was successful.

Advantages include higher efficiency than manual since repetitive tasks are done automatically (Afolabi, 2023). This reduces the percentage of faulty products or longer production times due to fatigue or stress from the operators. This factor makes it optimal for medium-scale industries that cannot afford fully automated procedures. As semi-automation is more flexible than full automation and more efficient than manual automation, this setup is most optimal for industries with products that require constant reconfiguration or want to introduce new items to their product range. Disadvantages include that human errors remain present, and that operators must develop the necessary skills to run the equipment, meaning the overall performance still depends heavily on their competence. In the worst case, semi-automation can even be less efficient than both manual and fully automated operations.

4.4.4 Level of Automation: Fully Automatic (7)

Fully automatic processes require computer algorithms and/or artificial intelligence to manage the entire workflow in an operation (Frohm et al., 2008). This includes feeding the input into the machines, analyzing the data, and finally executing the operation. The input is automatically handled, monitored, and tracked as the system continuously evaluates performance to maintain consistent quality and high efficiency.

Fully automatic equipment has the highest cost of all automation levels, both in terms of initial investment and continuous maintenance, and programming (Afolabi, 2023). As a result, full automation is typically most suitable for well-established industries where high precision and short production times justify the high costs.

Continuous and mass production environments are common examples where full automation is needed, as they require high output volumes and minimal flexibility (Afolabi, 2023). In such cases, both manual and semi-automatic solutions would be more costly and less efficient.

The main disadvantage is the limited flexibility for newly introduced items to the product range, or any design changes (Afolabi, 2023). Complex reprogramming would be required, which can be time-consuming and dependent on technical specialists. Another drawback is the risk of programming errors which may lead to increased costs in defective products and unplanned production downtime.

4.5 Manufacturing planning and control systems

The following section presents the theoretical framework for the digital business systems used within the studied production environment. An understanding of these systems and their respective functions is necessary to contextualise the findings of this study, as the systems collectively govern the flow of information, materials and operational instructions throughout the production facility.

4.5.1 Enterprise Resource Planning Systems

An Enterprise Resource Planning (ERP) system is an integrated software platform used by organisations to manage and coordinate core business processes across multiple functions (Klaus et al., 2000). ERP systems consolidate data and workflows from functional areas such as procurement, material management, production planning, finance, and logistics into a single, unified information architecture (Klaus et al., 2000). By centralising information through an integrated database, ERP systems allow for enterprise-wide management of resources, which supports more informed decision-making and provides a holistic view of the business (Klaus et al., 2000). In manufacturing contexts, ERP systems typically support the entire production planning and control cycle, communicating production orders downstream to the production process as materials and capacity become available (Klaus et al., 2000)

4.5.2 Production Logistics Systems

A Production Logistics System (PLS) functions as an intermediary layer between enterprise-level planning systems and the physical production environment, coordinating material flows and production activities across the shop floor. Similar to Manufacturing Execution Systems (MES), the PLS receives production orders from ERP systems and translates them into operational instructions for machines, automated vehicles, and other production equipment, thereby enabling communication between higher-level planning systems and cyber-physical production systems (Kagermann, Wahlster & Helbig, 2013). Because communication and coordination between production resources are centralized through the PLS, the reliability and availability of the system are critical for maintaining uninterrupted production operations. Failures or disruptions within the PLS can rapidly propagate across interconnected production systems and result in production stoppages throughout the facility.

4.5.3 Programmable Logic Controllers

A Programmable Logic Controller (PLC) is a ruggedised industrial computer designed to control and automate specific machinery or processes on the shop floor (Boyer, 2004). PLCs operate by continuously monitoring inputs from sensors and other devices and executing pre-programmed logic to control outputs such as motors, valves and actuators . In highly automated production environments, individual machines are typically governed by their own dedicated PLC, which manages the specific operational sequences required for that machine's function (Groover, 2015). While PLCs are highly reliable in executing their designated tasks in isolation, integrating multiple PLCs from different manufacturers or development teams into a unified system can introduce challenges related to communication protocols and data structure compatibility (Respondent 7, personal communication, Apr 23).

4.5.4 Manufacturing Intelligence Systems

A manufacturing intelligence system is a data collection and analysis platform designed to capture, structure and visualise operational data generated on the shop floor (Zhong, Xu, Klotz & Newman, 2017). These systems can receive data inputs both automatically, through integration with machines and sensors, and manually, through operator reporting (Respondent 1, personal communication, Apr 8). The collected data is used to calculate and monitor key performance indicators such as Overall Equipment Effectiveness (OEE), enabling organisations to identify production bottlenecks, track downtime and support continuous improvement initiatives (Respondent 3, personal communication, Apr 8). The Manufacturing intelligence systems function as read-only data receivers within the broader system architecture, meaning they consolidate and present production data but do not actively send instructions or communicate bidirectionally with other operational systems such as PLS or PLC systems (Respondent 7, personal communication, Apr 23).

4.6 Production planning approaches

With the choice of layout and production flow established, a further set of decisions concerns how production is planned and controlled on an operational level, specifically how orders, inventory and materials are managed over time. Two central dimensions of this are the choice between push and pull systems, which determines how production activity is triggered, and the choice between make-to-order and make-to-stock, which determines whether production is directed toward a specific customer order or toward replenishing inventory.

4.6.1 Push and pull systems

Push and pull systems are central concepts within production planning and control (Holweg et al., 2018; Liker, 2004). The choice between the two is largely determined by the predictability of demand: a firm facing stable and forecastable demand may benefit from a push system, whereas a firm operating in an environment of variable or customer-specific demand will typically favour a pull system in order to avoid overproduction and waste.

In a push-based production system, manufacturing is driven by a central schedule based on forecasts rather than actual customer demand (Holweg et al., 2018). Production orders are initiated based on projected demand and materials are pushed forward through each stage of the production process regardless of whether downstream operations are ready to receive them. This approach relies on so-called time-phased requirements, where all processes and suppliers receive orders from a central planning function, and without such orders, material is neither worked on nor shipped to the next stage (Holweg et al., 2018). While push systems can achieve high capacity utilisation, they risk generating excessive inventory when forecasts deviate from actual demand, and errors in planning tend to propagate throughout the entire production chain.

In a pull-based production system, production is instead driven by actual demand, where each stage only initiates work in response to a signal from the downstream process or end customer (Holweg et al., 2018). Rather than producing according to a central schedule, work is only started at the moment it is needed, a principle closely associated with lean manufacturing and Just-In-Time production. This is reflected in Liker's (2004) Principle 3 of the Toyota Way: to use pull systems to avoid overproduction by delivering to internal and external customers what they want, when they want it, and in the amount they want. Small inventory buffers, referred to as kanban supermarkets, are maintained between process steps to enable replenishment, but the overall logic is that no production is triggered without a real demand signal (Holweg et al., 2018; Liker, 2004). Pull systems aim to reduce inventory levels, minimise waste and improve responsiveness to real demand. However, their effectiveness depends on a relatively stable and visible demand signal. In environments where demand is highly irregular or difficult to anticipate, pull systems may struggle to maintain a smooth production flow.

While the fundamental distinction between push and pull is consistent, the concepts operate at different system levels and carry different practical implications in manufacturing and supply chain management respectively.

In supply chain management, push and pull primarily describe how inventory, replenishment and distribution decisions are coordinated across the broader network of suppliers, manufacturers and customers (Simchi-Levi et al., 2008). Here, the central challenge is determining how far back into the supply network a customer order should travel which is what Holweg et al. (2018) refer to as the order penetration point. In a push-oriented supply chain, upstream tiers produce and stock inventory based on demand forecasts, with finished goods positioned downstream in anticipation of future orders. In a pull-oriented supply chain, replenishment signals flow upstream in response to actual consumption, reducing the need for speculative inventory across echelons. In practice, most supply chains operate a hybrid, whereby customer-pull is used for final assembly or distribution while forecast-push governs upstream procurement and production, particularly where supplier lead times exceed the customer's willingness to wait (Holweg et al., 2018).

In manufacturing, the push-pull distinction operates closer to the shop floor, where it governs the real-time sequencing and flow of materials between machines and workstations (Ohno, 1988). In this context, pull production typically involves constrained work-in-process (WIP) inventory, sequential material flows, and FIFO (First-In-First-Out) logic to maintain stable and predictable throughput across interconnected production stages (Hopp & Spearman, 2011). FIFO structures ensure that products move through the system in the same sequence in which they entered, reducing waiting times, limiting inventory accumulation and increasing process transparency. Because downstream demand directly controls upstream production activity, pull systems generally provide less flexibility for dynamic resequencing or urgent reprioritisation compared to push-based systems, where a central planner can intervene and reallocate capacity. Changes in production sequence in a pull environment may disrupt synchronised flows, create material shortages or generate bottlenecks that propagate throughout the production system (Hopp & Spearman, 2011). The kanban system, as developed by Ohno (1988) at Toyota, operationalises this logic at the shop-floor level by using visual signals to authorise production only when a downstream stage has consumed material - ensuring that WIP levels remain controlled and that overproduction is structurally prevented.

4.6.2 Make-to-Order and Make-to-Stock

A central dimension of production planning concerns the type of order against which production is directed. Hill (1993) distinguishes between make-to-order (MTO) and make-to-stock (MTS) as two fundamentally different production logics. Under MTO, production is initiated only upon receipt of a customer-specific order. Nothing is produced speculatively, and lead time is therefore determined by the production cycle itself. MTS, by contrast, involves producing to inventory, enabling immediate delivery but requiring effective inventory management and a high degree of product standardization (Hill, 1993).

While MTO aligns naturally with pull logic - since production is triggered directly by real customer demand - the relationship between MTS and push or pull is less straightforward. MTS is commonly associated with push systems, where production is driven by forecasts and finished goods are held in anticipation of future demand. However, MTS can also operate according to pull principles, where depletion of finished goods inventory triggers a new production order rather than a forecast. In this case, the inventory itself acts as a buffer, and replenishment is demand-driven rather than schedule-driven. The distinction between MTO and MTS therefore does not map directly onto push and pull, but rather concerns *when* in the process customer demand is linked to production activity, which is a decision that must be aligned with the firm's competitive priorities regarding delivery speed, flexibility and inventory cost (Hill, 1993).

4.7 Industry 3.0 and 4.0

Industry 3.0 and Industry 4.0 are concepts used to describe the degree of digitalization and integration in manufacturing systems (Lasi et al., 2014). Industry 3.0 is characterized by the use of electronics, information technology, and computer-based automation, where individual machines and processes are automated but typically operate as separate systems with limited interaction. In contrast, Industry 4.0 refers to manufacturing systems where machines, products, and IT systems are interconnected through technologies such as the Internet of Things (IoT) and cyber-physical systems, enabling real-time data exchange and more autonomous and flexible production. The concept is structured not only around individual technologies, but also around their connections and combinations, with IoT consistently identified as one of the most central enabling technologies across the Industry 4.0 literature (Culot et al., 2020). Furthermore, Hermann et al. (2016) identify a set of core design principles underlying Industry 4.0 implementations, namely interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity. Taken together, these principles form the basis of what is commonly referred to as the smart factory - a production environment in which processes and operations are coordinated through interconnected cyber-physical systems and digital technologies, designed to support flexible and customized manufacturing (Hermann et al., 2016). In this sense, Industry 3.0 focuses on automating individual tasks, whereas Industry 4.0 focuses on connecting and coordinating entire production systems to improve adaptability and responsiveness (Lasi et al., 2014).

4.8 Key Performance Indicator

A Key Performance Indicator (KPI) is a quantifying measurement for organisations to be able to assess the performance of production processes (Almström et al., 2017).

The foundation of KPIs are elements, and function as supporting or diagnostic metrics that provide isolated information about machine behavior or facility conditions (Almström et al., 2017). Examples include actual production time, produced quantity, and changeover time. While useful, these indicators do not provide a holistic perspective on system performance. Instead, they describe local phenomena and therefore cannot fully capture how different parts of the production system interact or how changes in one area influence overall flow, stability, or capacity.

The elements that build the KPIs are called basic KPIs. These give a better evaluation of performance rather than basic elements, and capture improvement opportunities (Almström et al., 2017).

Through the usage of mathematical formulas and the results from basic KPIs, comprehensive KPIs can be created. Comprehensive KPIs are designed to evaluate the performance of the business as a whole (Almström et al., 2017). They focus on financial outcomes, customer delivery, workforce productivity, and cost efficiency (Slack et al., 2022). These indicators are typically aggregated across departments and time periods, meaning they provide a high-level view of how well the organisation is performing against strategic goals.

When evaluating performance, it is generally unrealistic to achieve outstanding performance across all KPIs simultaneously (Slack et al., 2022). In most situations, there will be a trade-off between them, where improving one metric requires compromising another. To interpret the concept of trade-offs, prioritizing specific KPIs may lead to overall success rather than investing equal weight across all indicators. Organisations may also focus on improving operational effectiveness to overcome trade-offs, without reducing the performance of other KPIs. The trade-off is instead shifted toward other dimensions, such as the time and effort required to develop alternative strategies for effectiveness.

A common pitfall in practice is that organisations accumulate KPIs over time without removing outdated or redundant ones, leading to unclear priorities and diffuse attention (Almström et al., 2017). Another frequently observed issue is that KPIs are defined in ways that allow different interpretations across departments or organisational levels, which undermines comparability and erodes trust in the measurement system.

4.8.1 Overall Equipment Effectiveness

The overall equipment effectiveness (OEE) is a measurement of how efficiently an equipment is utilized and is calculated by multiplying three basic KPIs, time availability, performance, and quality together (Bergman & Klefsjö, 2020).

Availability measures how much of the available time the equipment is in operation (Bergman & Klefsjö, 2020). Both planned downtime and unplanned downtime are taken into account to accurately measure the actual productive time.

Performance evaluates how efficiently the equipment produces during the operation (Bergman & Klefsjö, 2020). It compares the actual production speed to the optimal or designed cycle time. Stoppages, reduced speed, and inefficient utilization are factors to be taken into account since they directly impact the performance.

Quality measures the quantity of the units produced without defects (Bergman & Klefsjö, 2020).

To improve the OEE, it is important to identify the causes of stops and losses (Bergman & Klefsjö, 2020). The causes of stops can include electrical faults, mechanical faults, oil changes, program changes, tool changes and daily stops for inspection and cleaning. Analyzing data on downtime and causes makes improvement actions easier to prioritize.

$$\boxed{OEE = Availability * Performance * Quality}$$

Equation 1: Formula of OEE (Bergman & Klefsjö, 2020).

4.8.2 Throughput rate

Throughput Rate (TR) measures how much good product is produced per unit of time (Bergman & Klefsjö, 2020). It represents the actual productive output of the system and is closely tied to bottleneck performance. Throughput is influenced by cycle times, machine availability, and quality losses, making it a powerful indicator of overall flow efficiency. In practice, TR is often used to evaluate whether a production line can meet demand, identify constraints, and assess the impact of improvement initiatives. Because throughput connects operational performance to financial outcomes, it is one of the most strategically important KPIs.

4.9 Tacit and Explicit Knowledge

Tacit and explicit knowledge describes two distinct forms of knowledge (Jacobsen & Thorsvik, 2021). Tacit knowledge consists of the experience-based competence that individuals develop over time. It is knowledge that works in practice but is difficult to verbalise or formalise, and which the holder is often neither aware of nor reflects upon. Explicit knowledge, by contrast, is articulated and communicable. It can be documented in routines, procedures and governing documents, and typically forms the basis of organisational discussions around tasks and problem-solving (Jacobsen & Thorsvik, 2021).

The distinction is central when analyzing organisations' vulnerability to knowledge loss. Explicit knowledge is in principle preservable and can be systematically transferred to new employees. Tacit knowledge, however, represents a more critical vulnerability. Since it is difficult to articulate and often unconscious, it risks being lost when experienced employees leave the organisation, whether through retirement, voluntary turnover, or reorganization.

Jacobsen and Thorsvik (2021) emphasises that a prerequisite for learning organizations is the ability to externalise tacit knowledge to articulate and make it available to others. Tacit knowledge is most readily transferred through socialisation, where employees learn from one another through direct collaboration, which is a process that requires physical proximity and continuity over time.

To counteract knowledge loss, systematic structures are needed that support externalisation, for example through mentorship and documentation of professional knowledge so that tacit knowledge is articulated and explicit knowledge is internalized into daily practice (Jacobsen & Thorsvik, 2021).

4.10 Introduction to Computers and Systems

A computer is defined as a machine that accepts data as input, processes data without human intervention by using stored instructions, and outputs information (Bidgoli, 2024). In other words, a computer always follows the same fundamental flow: input – transformation – output. Input refers to raw data being entered into the system. Transformation refers to the processing that occurs inside the computer, where data is converted into meaningful information. Output is the result of this processing, such as a report, a chart, or a decision presented to the user.

Computers perform three basic types of operations: arithmetic operations (addition, subtraction, multiplication, and division), logical operations (comparisons such as determining whether a value is greater than, less than, or equal to another), and storage and retrieval operations (saving and recalling data from memory) (Bidgoli, 2024). All more complex tasks are fundamentally combinations of these three operations.

The power of a computer as a tool is grounded in three properties that far exceed human capacity (Bidgoli, 2024). First, computers operate at tremendous speed, where modern computers can execute billions of instructions per second, enabling users to solve problems and make decisions in a fraction of the time it would otherwise require. Second, computers offer exceptional accuracy, unlike humans, computers do not make calculation errors. Third, computers enable efficient storage and retrieval of information, vast amounts of data can be saved and quickly retrieved, making knowledge workers significantly more productive.

Even though computers can perform operations with high speed accuracy and great capacity for storage and retrieval its necessary to understand the importance of data quality. Since computers operate following the flow: input - transformation - output, its output can never be better then its input. This principle, often described as GIGO, which stands for Garbage In, Garbage Out (Bidgoli, 2024), stands as an important reminder for system design. Since most systems cant correct or question erroneous input; if incorrect data is entered, the output will be equally flawed. GIGO highlights the importance of data quality and demonstrates that a computer's accuracy is entirely dependent on receiving correct information in the first place.

Finally, computer technology today is in a phase where artificial intelligence (AI) plays an increasingly important role. AI is defined as a set of related technologies that attempt to simulate and reproduce human thought and behaviour, including reasoning, speaking, feeling, and understanding (Bidgoli, 2024). AI technologies are applied to areas requiring knowledge, perception, and cognitive abilities, and are used across fields ranging from healthcare and manufacturing to banking. Through machine learning, computers can furthermore learn from experience without being explicitly programmed, opening up possibilities that were never achievable with traditional computing.

5. Current state analysis

The following chapter presents the results collected throughout this study. The data presented below has been collected from interview studies and observations of the production process. Finally, these insights will be used as the foundation for the analysis that will be presented in the next chapter.

5.1 SKF’s Current Situation on an Operational Level

This segment describes SKF’s current operational situation with regard to SKF’s current operational situation.

5.1.1 Business Systems and System Integration

A recurring theme across the conducted interviews is the effects and disruptions that all employees experience in relation to SKF's various business systems. These systems are central to all aspects of the organisation, including production, planning, logistics, administration and follow-up. The systems are used by many people across the organisation, but for different purposes and with different levels of access.

The ERP system sends orders to the PLS system. Once all required materials are available, production of an order is initiated, after which the PLS system communicates with the local PLC systems and assigns tasks to the AGVs used for material transport in production. All communication between the PLC systems and the AGVs is routed through the PLS system, meaning that a large number of messages are continuously transmitted throughout production, even for simple and routine tasks. The organisation also makes use of a manufacturing intelligence system for fault reporting and data collection in production. Data from the manufacturing intelligence system is used to analyse various KPIs, such as OEE, availability and quality, as well as the identification of production bottlenecks. The manufacturing intelligence system is fully separate from the PLS system and can only receive data. Any data and KPIs that are to be reported back to the ERP system must be transferred manually.

5.1.2 Disruptions and Limitations

The systems used by SKF are largely built on the traditional model of computer systems, in which specific inputs are required, either from upstream systems or through manual entry, in order to execute a pre-programmed task and produce an output. The systems do not make use of deep learning or probabilistic estimation. This type of system is susceptible to the well-known GIGO problem. As a consequence, the accuracy of KPI calculations is directly weakened by deficiencies in data input, making it difficult to rely on these metrics for data-driven troubleshooting and decision-making.

Messages between systems are at times lost or significantly delayed, which can cause production stoppages as machines and AGVs are unable to communicate with one another without the PLS system. According to the automation specialist, these stoppages can vary in duration depending on where the fault originates. Since production data and IT infrastructure are shared with the PLS system vendor, some issues can be resolved locally, while others require troubleshooting and correction by the vendor. Identifying the root cause of lost or delayed messages has proven difficult due to the shared IT infrastructure, as responsibility can be deflected between the vendor and the organisation.

Some faults and disruptions in the manufacturing intelligence system are reported automatically, while others must be entered manually by operators. Respondent 1 and respondent 2, both working in the assembly cell, describe this as a recurring issue. Problems arise partly in line with the GIGO scenario, where input data has been incorrect but not detected by the systems, with many errors only becoming apparent late in the process, in this case at the assembly stage. Due to the interconnected nature of the production cells, an operator error or technical disturbance in one cell can cause stoppages that propagate to other cells, often requiring manual adjustments to restore normal operations. Recurring production stoppages also occur as a result of deficiencies in information transfer and digital communication. Respondent 1 describes system development as lagging behind the development of the physical machinery, and notes that since the two are interdependent, shop floor operations do not perform as well as they should. The automation of the systems still requires considerable manual handling, adjustment and data entry.

Some of the disruptions that arise in production are within the operators' own competence to resolve, such as many of the process adjustments required during changeovers. However, this competence tends to be unevenly distributed and is largely based on individual initiative rather than standardised training. Even faults that operators are able to address themselves result in lost time, an interruption to workflow and additional administrative work, as operators are also responsible for subsequently logging the faults and corrective actions in the manufacturing intelligence system. Disruptions that operators cannot resolve on their own are handled by submitting a request through the manufacturing intelligence system, which is then to be addressed by IT. These requests are not always prioritised, which can result in unnecessarily prolonged and costly stoppages. Both operators and the production manager describe this as a significant shortcoming: while the level of automation enables faults to be identified and reported quickly, the organisation is not equipped to respond to them in a timely manner.

5.1.3 KPIs and Their Relationship to Automation and Layout

The primary KPIs used in the assembly area include cycle time, units produced per hour, availability and planned capacity utilization. Operators work towards a planned production rate based on expected cycle times and losses. The target is 35 units per hour as the system’s maximum output is 60 units per hour, meaning the planned efficiency is typically set at around 40-60% of full capacity.

The main reasons KPI targets are not met include system stops, variation in incoming materials, adjustments required after changeovers, and poor integration between digital systems.

One of the main reasons for differences in KPI performance is material variation. For example, ground rings can be purchased by various suppliers, and thus can have differences in their exterior that require manual adjustments or overrides to correct. Even small geometric variations can lead to stops, manual corrections, misalignment during assembly, or in fewer cases, scrap. This affects how smoothly the flow in the production runs, and KPIs.

Sensitivity in automation means that KPI outcomes often reflect system limitations rather than operator performance. This reflects the difficulty in today’s production where automation, which is supposed to facilitate operations, instead causes repetition of work. This underscores the gap between theoretical and actual performance in a highly automated environment.

A similar sensitivity applies to load carriers and material flow. The AGV system, central to the automated layout, often fails when faced with dimensional inconsistencies in pallets. This shows that automated layouts lack the flexibility to handle equipment that is not fully standardised. For automation to succeed without a system-wide disruption, it requires absolute uniformity across the entire supply chain. While modern advancements in flexible automation are beginning to reduce this need, they often face challenges related to cost and technical complexity. As a result, it has historically been simpler to revert to manual handling of these deviations.

5.1.4 The Impact of Automation on Operational Activities and Process Complexity

A high degree of automation fundamentally reshapes the demands placed on operators and the conditions under which daily operations are carried out. Tasks that were previously manual and physically demanding have shifted toward monitoring, troubleshooting and managing complex system behaviour, meaning that the workload has transitioned from primarily physical to primarily cognitive as the level of automation has increased. Operators describe how a high level of automation places considerably greater technical demands on them, as they are expected not only to manage the process steps within their own cell but also to operate multiple advanced systems and handle disruptions in the automation. Furthermore, automation reduces the total number of operators on the shop floor, meaning that each individual operator carries responsibility for a larger share of the production process than before.

Operating at this level of automation also makes it more difficult to clearly define and concretise job tasks, as the work environment becomes inherently more complex. Onboarding and training in the handling of technical systems and disruptions occurs primarily through social learning, where new employees acquire knowledge informally by shadowing experienced colleagues or by asking questions, rather than through structured and standardised training programmes. This places considerable personal responsibility on individual operators regarding how actively they engage with learning. As a result, knowledge tends to become asymmetrically distributed across the workforce. A small number of senior employees hold a substantial amount of knowledge acquired through personal experience, and this knowledge is not widely documented in a structured or accessible way. Operators who have developed the deepest understanding of how disruptions can be resolved tend to be the same individuals who are consistently called upon when problems arise. When experienced employees retire or resign, this valuable knowledge is lost, and remaining employees must iterate to find their own solutions. Even senior employees may lose access to seldom-used knowledge after an absence, which further underlines the need for systematic documentation and standardisation. The more complex problems, which occur infrequently, require professional judgement, experience and a holistic understanding of the system, and these are precisely the areas where structured documentation is most lacking.

Respondent 1 also describes how attitudes toward working in a complex and digitalised production environment vary considerably between different teams, and that a culture of resistance to change can affect the smoothness of operations and the adoption of new ways of working. This cultural dimension represents an organisational challenge that extends beyond technical implementation and requires active management attention.

Despite these challenges, both operators highlight that the increased level of automation has brought significant improvements to the working environment. In SKF's D-factory in Gothenburg, automation has contributed to a substantial reduction in noise and sound levels, improved ergonomics and a reduction in work-related injuries, all of which have made the physical work environment considerably less demanding. These improvements represent an important dimension of the organisation's systematic work environment efforts, as a well-functioning automated production environment can simultaneously enhance operational performance and safeguard employee health and wellbeing over the long term.

5.1.5 The Practical Functioning of the Production Layout

The assembly work is organized into production cells, which are meant to support flexibility, shorter flow paths and large operator oversight over the production. However, the interviews suggest that automation can limit these benefits in practice. The system depends heavily on everything working exactly as planned, and thus reduces flexibility as problems occur.

Bottlenecks appear in different parts of the process depending on the product and production channel. In some cases, the assembly cell is slower than the grinding cell and vice versa. This creates an uneven flow and requires the use of buffers though SKF aims to reduce inventory between steps.

5.2 Production Layout Transformation and Automation Strategy

5.2.1 Transformation of the Production Layout from Line to Cell

The production layout has undergone a major transformation from a traditional "line-based" approach, where machines were physically connected, to today's autonomous robotic cells and channel concepts. In the earlier setup, chutes and mechanical lifts were used to transport rings between machines, creating a rigid flow in which a failure in one machine would stop the entire line.The cell-based production system with the channel concept makes SKF's production more robust, as the entire production flow does not stop when disturbances occur in a single machine, while intermediate inventories act as buffers. This enables SKF to operate with less total downtime, which can reduce lead times and improve delivery precision.

This transition is viewed not only as a means of improving efficiency but as a prerequisite for maintaining production in Sweden in terms of competitiveness on a global market.

The transition to cell-based production with two-way lanes for Automated Guided Vehicles (AGVs) has introduced larger flexibility, as it enables the possibility to handle a broader product mix within the same physical area. However, layout redesigns are often constrained by the building's structural features, such as columns and existing tanks. Consequently, new flows must frequently be adapted around these obstacles rather than optimized from a clean state.

Another key development from the previous setup is that the material transport between cells is now handled by AGVs. Historical data indicates that the layout must be carefully engineered to avoid the AGV system becoming a bottleneck, particularly in narrow corridors between grinding and assembly.

Increased automation in general has significantly reduced staffing requirements. As earlier production lines required approximately ten operators per shift, modern cells can be managed by one to two operators. Overall, staffing per flow has decreased from roughly fifty people to much fewer in the most automated areas.

Lastly, extensive simulation models were developed to guide decisions related to automation investments and layout changes. These models allow the evaluation of variables such as setup times, product mix frequency, and cycle times before any physical modifications are made.

5.2.2 Changeovers and Flexibility in Production Setups

Changeovers are an important part of the production system design and affects how flexible the system is. Operators typically perform one or two changeovers a day based on the market conditions and production scheduling. As a machine’s downtime is only about ten minutes, the additional adjustments such as aligning rings, changing machine settings, calibrating sensors and performing trial runs until stable production is achieved can take up to one hour. The practical flexibility of the layout is limited by the fine-tuning required after each changeover.

Production managers state that changeover frequency has increased in more recent years due to the reduction of batch sizes in response to lower inventory level, to in turn be able to meet customer requirements. Global market fluctuations due to geopolitical instability, trade disruptions, among others, increases the operational importance of minimizing changeover time for operational survival.

5.2.3 Data-driven Decision making and Its Limitations

SKF aims to make data-driven decisions regarding automation and layout, and the available digital infrastructure provides access to a notable amount of operational data. However, the ability to evaluate performance based on the reported KPIs is limited.

The major problem is that not all stops are reported in the system since they are quickly resolved through manual operation intervention. A risk with this is that the same problem may reoccur without corrective adjustments. This creates a paradox where decisions are expected to be data-driven, but the data is incomplete or incorrect. This in turn results in that experience and intuition remain essential for employees. Thus, strategic decisions about automation and layout rely on a mix between quantitative data and personal assessments, without a structured framework for balancing the two.

Automation has therefore reduced the need for manual operators, though it has also increased the need for technical expertise for decision making. Competence supply is a strategic bottleneck today.

5.2.4 Strategic Adjustments and External Factors

Operations are strongly influenced by global strategies such as “Regional for Region” where high-volume products for Asia are produced locally in that region, as Gothenburg focuses on more complex and specialized variants.

The upcoming division of SKF into Automotive and Industrial units might introduce new layout requirements. Legal and operational requirements might need separation between previously shared flows, such as by installing walls. This may lead to short-term layout modifications that are not necessarily the most optimal solution.

5.3 Automation and Simulation Standards in Global Manufacturing

5.3.1 Production Strategy as the Foundation for Automation Decisions

The choice of which LoA deems most suitable for each process is determined by the broader production strategy. Key factors include understanding what is being produced at a given unit and the manufacturing cost. Economic decisions are typically made based on strict payback requirements. Historically, the expected payback period has been around three years, although certain projects have allowed up to five years depending on their strategic performance.

When these key factors are identified, it facilitates the decision regarding which production is required, for example, make-to-order, engineer-to-order, or make-to-stock. To be able to validate whether the supply strategy is effective, specific KPIs each related to the strategy are measured. If the results are not met, a root cause analysis is made to identify the causes of varying data. Afterward, adjustments and decisions will be made whether to reassess the choice of supply strategy completely, or to alter segments of the given strategy to improve the KPIs. An example could be the process design.

A common organisational challenge in the decision-making process is knowing which production strategy applies to a given unit and why. This leads to setups where, for example, make-to-stock is applied to a product mix with a high variety. This results in unnecessary complexity and capital tie-up, especially with varying demand.

5.3.2 Automation in Relation to Flexibility

A common misconception stated is that high automation conflicts with flexibility, according to respondent 6. The assumption is that a high LoA reduces the production system’s ability to handle product variety. The reality is that factors such as shorter changeovers can increase flexibility by enabling faster transitions between products than lower levels of automation. However, the trade-off lies in higher initial investment costs, the sensitivity to disruptions, and maintenance costs due to machine complexity, which in turn affects the downtime.

Another aspect to take into consideration is that automation setups may be less suitable as product mix and volumes evolve. For example, a setup made ten years ago may no longer be suitable today. This highlights the importance of continuous re-evaluation, regarding the trade-offs between initial investment decisions and if higher flexibility is required for the given time.

5.3.3 Trade-offs in Production System Design

The tradeoffs in production system design is inevitable, but they can be managed efficiently by optimizing choices within supply strategy, as each strategy carries its own set of trade-offs between cost, flexibility, and robustness.

Historically, SKF Gothenburg has battled with adjusting its strategy as the product portfolio increased since the D-factory was originally designed for a simpler, high-volume production. Today, the organization opts to increase its flexibility by smaller batch-processes, which requires a different production configuration. One measure is described by breaking up flows into more differentiated configurations where different parts of the assortment are made uniquely rather than to a repetitive flow. Thus, the correct approach varies based on the product type, volume, and customer requirements.

5.3.4 Standardisation and the Framework for Production Setups

SKF is, in general, in the forefront of developing global standards for automation and production setup, and that the process of creating a framework had only been established recently. The demand for standardisation has increased heavily, as the need for flexibility has increased for organisational survival. Standardization ensures that certain configurations are consistent throughout factories, and can be used as guidelines in future projects in automation and production setups. While it is unrealistic to apply standardisation across all factories globally, it is considered possible and necessary to implement a guideline for common process flows or certain LoAs for specific product ranges, to name some examples. The key takeaway is that some elements must be globally standardised, though local variations, such as supplier choice or other operations that do not create value do not have the same need.

6. Analysis

This chapter represents the analysis of the study, where the empirical findings from SKF are interpreted and how they correlate with theoretical models within strategic parameters, and Industry 4.0 principles. The analysis serves as a foundation to the conclusions and recommendations to SKF.

6.1 Strategic Considerations in Automation Decision-Making

A high degree of automation significantly reduces the need for manual labour, both in terms of physical and cognitive tasks, and consequently lowers the number of personnel required to operate a production system. Automated systems are particularly effective at tasks that require high precision, rapid execution, or the processing of large volumes of data, capabilities that represent key strengths of computer-based technologies. By leveraging these strengths, organisations can monitor operations more comprehensively, gain deeper insight into production performance, and make decisions based on larger and more objective datasets than would be feasible through human analysis alone. This enables faster responses to deviations, more accurate performance evaluations, and decision-making that is less influenced by individual judgement or cognitive bias.

Furthermore, automation increases organisational visibility by providing real-time information about activities on the shop floor, allowing managers and engineers to identify problems, understand operational needs, and evaluate performance more quickly and accurately. High levels of automation can also play an important role in improving workplace health and safety. By taking over tasks that involve exposure to hazardous substances, extreme temperatures, heavy physical strain, or repetitive motions, automation reduces operator risk and can significantly lower the incidence of work-related injuries.

However, high automation also carries significant limitations. High levels of mechanization are best suited to organisations producing relatively high volumes with limited product variety. Since automated systems can only perform the tasks they are programmed for, they are inherently constrained in what they can execute. A high degree of automation therefore involves a trade-off in flexibility, particularly in the ability to handle unique product variants or special customer adaptations, which may need to be managed outside the standard production channel. Beyond product variety, automation is also bounded by the capabilities of the hardware and software it relies on, meaning its performance is limited by how systems are programmed, how well they are integrated, and the quality of the input data they receive. At an operational level, high automation also brings significant changes for the workforce. While it relieves employees of physically demanding and repetitive tasks, it simultaneously raises competency requirements. As automated systems take over production and support functions, fewer workers are needed, but those who remain are often expected to cover a broader range of responsibilities and must be proficient in managing various systems, sometimes including technical knowledge of both hardware and software.

Given these advantages and limitations, the strategic decision regarding the appropriate level of automation should, following Hill’s (2000) framework, primarily be evaluated against whether it supports the firm's chosen market and manufacturing strategy, and whether it would improve performance across the five performance objectives most relevant to the target market segment. The first question a firm should ask is whether the level of automation can be estimated to generate a return, either through increased revenue or reduced costs over time. This should be followed by an assessment of whether the automation supports the firm's broader strategy and what it would contribute across the five performance objectives. From a bottom-up perspective, the firm should also examine what demands the automation would place on the organisation, and whether there are limiting factors such as spatial constraints or integration challenges with existing systems. Finally, it is important to consider whether other strategic decisions, such as those concerning workforce training, would need to be revised in response to a change in automation level. When implementing a high level of mechanization, it is also important to ensure that administrative and information systems are adapted to send and receive the data that machines generate and require as input and output. A decision regarding the right degree of automation should therefore be understood from a systems perspective, where the chosen level must fit the organisation holistically, aligned with its goals, market strategy, manufacturing strategy, workforce, local conditions, existing constraints, and current systems.

6.2 Integration between systems

The interview material and current-state analysis indicate that a significant challenge associated with automation is not necessarily the performance of individual technologies, but rather their integration within a larger organisational context. When systems are developed and tested in isolation during pilot phases, they may perform well under controlled conditions. However, when implemented in large and complex organisations operating multiple interconnected business systems, unexpected problems frequently emerge. The findings of this case study illustrate this challenge clearly, as the various systems governing production at SKF operate with differing IT infrastructures and data structures, creating friction at the points where information must pass between them. As a result, a notable imbalance has emerged: while the level of automation in mechanised shop-floor tasks is high, the computerisation intended to support, coordinate, and integrate these activities remains at a considerably lower level of maturity. Closing this gap is therefore not merely a technical ambition but a strategic necessity for realising the full benefits of automation.

The tendency for messages to be lost or delayed between systems points to a potential digital routing problem that warrants further investigation. In a system architecture where communication between PLC systems and AGVs is routed through the PLS system, a high and continuous volume of messages is transmitted throughout production at all times. Under conditions of high network load, communication routes may become congested, as only a limited amount of data can be transferred per unit of time. An overloaded network, or one in which certain types of communication are prioritised over others, can cause messages to arrive later than intended or to be lost entirely, disrupting mechanised production activities. Other contributing factors may include ageing server hardware with insufficient processing capacity, incompatible communication protocols between systems developed by different vendors, and inadequate error-handling logic that fails to automatically resend lost messages. The shared IT infrastructure between SKF and the PLS system vendor further complicates fault identification, as responsibility for resolving issues may become unclear. A structured technical investigation that enables individual messages to be logged and traced throughout the entire system chain would therefore be an important first step toward identifying where and why communication failures occur.

A related challenge concerns the differing data structures across systems, particularly among PLC systems developed by different vendors without common standards. Inconsistent data structures require translation layers between systems, introducing additional points of failure and processing delays. More importantly, fragmented data structures limit the organisation's ability to further develop computerisation beyond its current level. Standardised data structures constitute a prerequisite for more advanced forms of digital coordination, including the future deployment of AI-based decision support and autonomous agents across production systems. Such technologies could support activities that currently rely heavily on human judgement, including production planning, scheduling, and predictive maintenance. However, developing separate AI solutions for each isolated system would be both technically complex and economically inefficient. Standardisation therefore represents not only a solution to current integration challenges but also an enabling condition for future automation initiatives.

Finally, the gap between the organisation's ability to detect faults and its capacity to respond to them in a timely manner reflects an organisational challenge that cannot be resolved through technical integration alone. The high level of automation enables rapid fault identification and reporting, but if the IT support function lacks the resources or prioritisation mechanisms required to act on these reports, the potential benefits of automation are partially negated. Addressing this gap therefore requires organisational measures alongside technical ones, including clearer escalation procedures and dedicated response capacity for production-critical IT issues.

Taken together, the integration challenges identified in this section point to a common underlying need: to align the level of computerisation and systems-level automation with the mechanised automation already present on the factory floor. Without such alignment, the benefits of automation remain constrained by the organisation's ability to coordinate information across its system landscape.

6.3 KPIs as an Operational Decision Support

Since production KPIs are derived from data originating across multiple interconnected systems, shortcomings in system integration directly influence the reliability of the performance measures used to support operational and strategic decision-making.

A central ambition within SKF's manufacturing strategy is to make data-driven decisions regarding automation levels, production layouts, and operational improvements. Within Hill's (2000) framework, the ability to measure and evaluate performance against strategic objectives is a prerequisite for aligning infrastructure with process choice and market requirements. KPIs serve as the primary instrument through which this alignment is monitored and maintained. However, the findings of this study reveal a significant gap between the intended role of KPIs as decision support tools and their practical reliability in SKF's current operational environment.

The assembly cell monitors several basic KPIs including cycle time, units produced per hour, availability, and planned capacity utilization. These are relevant metrics that provide the information needed to evaluate production system behavior and support engineering-level decisions about automation and layout.

Despite their relevance, the practical value of these KPIs is substantially undermined by the quality of the data on which they depend. As described in the current state analysis, the various systems used in production operate with differing data structures and limited end-to-end integration. Data and KPI values cannot flow automatically between these systems without disruptions, and must in several cases be transferred manually. This creates conditions consistent with the GIGO problem. When input data is incomplete, incorrectly entered, or lost in transit between systems, the resulting KPI calculations are unreliable. A system that produces inaccurate performance metrics fails to support data-driven decisions, and also risks actively misleading them.

A particularly consequential example is the underreporting of production stoppages. Many disruptions are resolved quickly through manual operator intervention and are never formally logged in the manufacturing intelligence system. From a KPI perspective, these events are invisible. The measured availability and cycle time figures therefore reflect an incomplete picture of actual system performance, and the gap between reported and real performance can be substantial. As previously noted, the organisation expects decisions to be data-driven, but the data is systematically incomplete. As a result, experience and individual judgement remain indispensable inputs to decision-making, even in areas where structured data should, in principle, be sufficient.

This dynamic has direct implications for manufacturing strategy. Within Hill's (2000) framework, the choice of automation level and process configuration must be grounded in a realistic understanding of operational performance. When the KPIs used to evaluate that performance are distorted by data quality issues, the strategic decisions that follow rest on an unreliable foundation. The consequence is that capital-intensive automation investments may be justified on the basis of performance figures that do not accurately represent system behaviour under real operating conditions.

Addressing this requires that the technical preconditions for reliable KPI generation must be strengthened, including improved system integration, standardised data structures across PLC systems, and automated data transfer between the manufacturing intelligence system and the ERP system. The organisation must also establish clearer routines for consistent fault reporting, so that stoppages and deviations are systematically captured regardless of whether they are resolved manually or through the system. Only when the input data is trustworthy can the KPIs fulfil their intended role as an operational decision support tool. As a result, SKF's ambition of data-driven manufacturing strategy can be realised in practice.

6.4 Aligning Theoretical Models of Production Layout in Practice

The theoretical channel concept, as described by Slack et al. (2022), provides a strategic rationale for organising production into dedicated flows, each matched to a specific product type and its competitive requirements. At SKF, the concept has been central to how production is organised and communicated internally for decades. However, the way the term is used in practice diverges from its theoretical definition in an important way: at SKF, "channel" is used both to describe the physical grouping of cells on the factory floor and the material flow passing through them. As discussed in section 3.3, these do not always coincide. Components can cross physical channel boundaries during processing, particularly at the flat grinding cell which serves multiple product families. This confusion has contributed to misalignment between departments and complicated strategic decision-making, and reflects a case where a well-established concept has accumulated conflicting interpretations over time.

When evaluated against the layout typologies in section 4.3.2, SKF's production is most accurately described as a cellular layout. Machines are grouped into self-contained cells responsible for defined process steps, with AGVs handling material transfer between them, consistent with external cell formation as described in the theory. The inter-cell layout has evolved incrementally, constrained by structural features such as columns and existing floor plans.

At the intra-cell layout level, most cells resemble a robot-centered layout, where the centered robot performs core operations while peripheral equipment handles supporting tasks around it. The assembly cell represents a hybrid: it begins with a centrally positioned robot before transitioning to a conveyor-based linear sequence of downstream operations. As noted in section 4.3.2.3, such combined structures remain valid as a single production cell as long as material flow is continuous and uninterrupted by significant buffers which is a condition that is met within SKF's assembly cell.

In summary, SKF's production layout is best understood as a cellular system with hybrid intra-cell formations and loosely connected inter-cell arrangements, organised around channels that define material flows rather than physical boundaries. The channel concept remains theoretically sound as a strategic tool, but its practical application at SKF has introduced terminology ambiguity that partially undermines the strategic clarity it is intended to provide.

6.4 Knowledge Transfer and Competence Retention in a Highly Automated Environment

The current-state analysis demonstrated how the high degree of automation has had significant implications for the daily work carried out by operators. As operational tasks become increasingly centred on managing automated systems rather than performing manual activities, the competence requirements placed on operators change accordingly. This has implications for workforce recruitment and selection, as SKF must place greater emphasis on technical understanding while also seeking individuals who are motivated by and capable of working in a more cognitively demanding environment.

The high degree of automation has also affected how operational knowledge is acquired, documented, and transferred within the organisation. SKF's current reliance on social learning as the primary mode of knowledge transfer represents a structural vulnerability. Informal knowledge sharing through shadowing and peer interaction is well-supported by social learning theory as an effective mechanism for knowledge transfer, particularly for tacit, practice-based knowledge that is difficult to document. However, while socially embedded learning facilitates the transmission of nuanced operational know-how, it is also inherently fragile. Knowledge transferred primarily through individuals is at risk of being lost when those individuals leave. As a foundation for preserving the operational knowledge that a complex, highly automated environment requires, it is therefore insufficient on its own.

SKF does provide internal training programmes accessible to employees, though these appear to operate primarily at a foundational level. While such programmes establish a baseline of technical competence, they do not fully address the depth of knowledge required to manage complex fault scenarios, advanced system integrations, and other infrequent operational challenges. Structured onboarding programmes, standardised training materials, and systematic documentation of advanced practices would therefore complement existing social learning mechanisms by reducing dependence on individual knowledge carriers and ensuring that critical know-how is retained within the organisation regardless of personnel changes. This is particularly important in highly automated environments, where specialised knowledge is often concentrated among a limited number of experienced individuals.

The interviews with operators further revealed that operational knowledge is distributed asymmetrically across the workforce, with certain individuals possessing significantly more experience and system-specific expertise than others. This asymmetric distribution of knowledge creates an operational imbalance, where the same individuals are repeatedly relied upon when disruptions arise. From an operational perspective, this is understandable, as involving the employee who already possesses the relevant knowledge is often the fastest and most efficient way to restore production. However, this practice also reinforces the existing asymmetry, as opportunities for less experienced operators to develop similar expertise become limited. As a result, critical knowledge remains concentrated among a small number of individuals, increasing the organisation's vulnerability to employee absence or turnover.

To reduce this dependency, SKF could benefit from more systematic cross-training between operators and the formalisation of currently undocumented practices. Such measures would not only distribute competence more evenly across the workforce but also reduce the risk of critical knowledge becoming tied to specific individuals and subsequently being lost. This becomes particularly important in highly automated environments, where the knowledge required to diagnose and resolve complex system disturbances often takes considerable time to acquire. As a result, initiatives aimed at improving employee wellbeing, job satisfaction, and professional development become increasingly important, as retaining experienced employees is not only a workforce issue but also a means of preserving critical organisational knowledge and maintaining operational stability.

6.6 Practical Implementations of SKF’s Corporate Objectives

This section examines the requirements for meeting SKFs future strategic ambitions by analysing the alignment between corporate objectives, market requirements and manufacturing strategy. A discussion around the operational reality based on that will be further conducted, combining theoretical models of strategy within manufacturing with empirical findings from SKF.

6.6.1 Standardisation as a Strategic Prerequisite

Standardisation is deemed as one of the most fundamental requirements for SKF to pursue its 2030 strategy, and also the most difficult to achieve in practice. SKF's third strategic pillar, business-driven value chains, identifies standardised manufacturing setups as a condition for simplifying operations and responding faster to market demand. Without a common foundation in process descriptions, data formats, and automation frameworks, manufacturing solutions cannot be transferred across sites. Each facility instead operates as separate units, which directly contradicts this strategic intent of building a globally coherent manufacturing organisation.

A significant obstacle to achieving this is the age and diversity of SKF's system base. Many facilities operate systems that are decades old. Some can be partially connected to modern systems, but their compatibility is limited by their original design, and full replacement raises investment costs and risks long production stoppages. Complete standardisation across the system base is therefore not achievable in the near term. The practical question is which parts of the operation to prioritise and at what pace. This is a decision that involves financial and operational trade-offs that must be weighed against the long-term strategic gains.

Standardisation does not mean that everything must be uniform across all sites. SKF's strategy includes regionalisation, where high-volume production is managed at a regional level to shorten lead times and reduce supply chain disruptions. The distinction that matters is between what must be consistent globally and what can vary locally. Process standards, data formats, and automation frameworks need global alignment. Decisions such as supplier choices, minor layout differences, or locally adapted mechanical configurations do not carry the same requirement. As respondent 6, global manufacturing manager, notes, the goal is to define what appropriate automation looks like for a given product segment and apply that consistently, while permitting local variation where it does not affect the core logic.

Based on Hill’s (2000) manufacturing strategy framework, infrastructure, that is planning systems, quality control, work structures, and organisational design, must be aligned with the chosen process and the market it serves. Thus, standardisation must be established as a foundation to ensure that shared concepts, data structures and process descriptions can be enabled across facilities. This is the precondition for meaningful digitalisation, AI implementation, and the kind of global agility that SKF's corporate strategy wants to achieve.

6.6.2 The Channel Concept and Its Limitations

SKF's channel concept was originally implemented to organise production flows more efficiently. The production environment resembled mass production more, as volumes were high, product variety was limited, and demand was relatively stable. Under those circumstances, the approach worked well. However, as time passed, new machines, load carriers, buffers and technologies were installed into the existing structure to adapt to global changes and development.

As SKF's product portfolio expanded and customer demand varied, the limitations of this setup became clear. Introducing more product variants into a channel-based system creates larger changeovers, as machines must be consistently reconfigured between runs. This reduces flexibility and instead increases changeover times and batch sizes, which in turn lengthens lead times and increases the risk of overproduction. The buffer logic that once provided robustness now becomes a constraint, as larger buffers require more floor space, capital tie-up, and changes in customer demand become less visible in production. By the time a drop or increase in demand becomes apparent, the system has already over- or underproduced. As noted in interviews, floor space at the D-factory in SKF Gothenburg is already a limiting factor, which leaves little room to expand buffer capacity without compromising other operations.

The transition from line-based to cell-based production, or as employees call it, “breaking up the channel concept” which SKF is currently pursuing, addresses some of these structural issues. Production cells enable flexibility in product variants, smaller batch sizes, several buffers, and creates a more pull-oriented flow. Reducing batch sizes and moving toward single-piece flow shortens lead times and improves service levels, which strengthens SKF's speed and dependability performance objectives. On the other hand, the transition leads to higher investment costs and instability. The reconfiguration of physical flows, load carriers, and planning must be coordinated simultaneously. For the risk of production stoppages increases, and so the trade-off between short-term disruption and long-term robustness is a strategic decision that must be taken into account.

The channel concept also created a terminology problem. As respondent 6 describes, the word “channel” came to mean different things to the manufacturing and supply chain department, whereas one refers to a physical production setup, and the other to supply flow. This misunderstanding led to planning inconsistencies and weak strategic decisions. The importance of standardisation of concepts becomes evident, even when well-planned strategies are made. Therefore, the priority shifts to optimising existing setups rather than increasing automation or digitalisation for the sake of development.

6.6.3 Connecting Production Strategy to Market Requirements

The challenges surrounding the channel concept are a part of a larger issue, which is the need to connect production strategy choices to market requirements. Hill’s framework emphasises that the choice of process and its infrastructure must be derived from a clear understanding of order-winning and order-qualifying criteria. At SKF, this link has not always been apparent. Different product segments, high-volume standard bearings, customised variants, and engineer-to-order specialties, have different market requirements and have yet occasionally been treated by the same production logic.

For high-volume standard products, a make-to-stock strategy remains appropriate. The reason for this is that it increases availability and a better service level. SKF’s strategic focus is on optimizing stock levels, minimising changeover times and reducing batch sizes to improve responsiveness without trading off efficiency. So it is contradictory that today's production planning approach uses MRP-based planning, where decisions are made as late as possible, to be able to handle forecast uncertainty. The challenge is that demand volumes are driven by macroeconomic conditions and are difficult to forecast. The practical response is to make well-informed estimates, continuously recalibrate, and accept that a degree of uncertainty is inevitable.

For lower-volume or more complex variants, customers are willing to accept longer lead times, making a make-to-order or assemble-to-order strategy more appropriate. In these circumstances, flexibility and the ability to respond to fluctuating demand are the driving performance objectives rather than dependability or cost. Mixing these within a single production system forces trade-offs that satisfy neither product families sufficiently.

The consequence of this is a misalignment between the manufacturing and supply chain department, with inventory levels as the primary conflict of interest. Supply chain seeks to minimise stock levels to reduce capital tie-up, while manufacturing requires buffer inventory to maintain stable utilisation and handle demand variation. The market requirements ultimately determine who holds the stronger argument in any case, and so this conflict requires ongoing reassessment as the market conditions change. Respondent 5, Standardisation and Automation Lead, states that reaching a decision takes time, but working through the disagreement is the process to make the right choices.

As both Hill's (2000) framework and SKF's own experience illustrate, the surrounding infrastructure, terminology, and decision-making must be coherent and communicate with each other to be able to create a holistic manufacturing strategy. Building this coherence across a large, historically fragmented and decentralised operation is undoubtedly the most demanding and riskful challenge that SKF faces in regard to its 2030 ambitions.

7. Conclusion

The following chapter presents the conclusions drawn from the case study conducted at SKF, with regard to the research questions and the theoretical framework in this thesis. Furthermore, a critical reflection on the sources of error of the study is presented.

7.1 Automation as a Strategic Manufacturing Decision

The LoA is based on the manufacturing decision within Hill's (2000) framework and must reflect the market strategy, as well as the corporate strategy. The manufacturing strategy must further account for local infrastructural constraints and be developed through both a top-down and bottom-up perspective, to align strategic decisions at different levels of the organisation. This ensures that the stakeholders affected by the decision can realistically adapt to the changes and give insights into whether the changes are possible or not.

Automation decisions must also consider supporting infrastructure and workforce competence. When the degree of mechanisation in production is elevated, the computerisation, manufacturing planning and control systems, and organisational capabilities that support it must develop at a corresponding pace. Automation decisions often require substantial investments in both equipment and software, making them costly and difficult to reverse. Consequently, decisions regarding the degree of automation must not only support current operational requirements but also prepare the organisation for future technological development. Systems embedded within the existing infrastructure may otherwise become constraints on continued technological progress.

7.2 Manufacturing Strategy, Trade-Offs and Future Competitiveness

Looking ahead, SKF's ambition to attract more demanding customer segments, including customers requiring make-to-order solutions, will require careful consideration of the trade-offs inherent in manufacturing strategy. As market requirements evolve, greater emphasis is likely to be placed on responsiveness, shorter lead times, and the ability to accommodate varying customer requirements. However, improvements in these areas are unlikely to be achieved without affecting other performance objectives, making the management of strategic trade-offs increasingly important.

This tension is particularly evident in SKF's production system, which operates as a combination of pull- and push-based principles. In an ideal pull-based production environment, single-piece flow would increase customer availability by producing smaller batches more frequently, thereby reducing lead times, changeover times, and improving flexibility. However, more frequent inbound deliveries also increase the system's sensitivity to disruptions, reducing robustness and service levels. SKF therefore relies on fixed purchase quantities and strategically placed buffers to maintain stability and protect production from supply disturbances. Regardless of whether material is held in inventory or buffers, the associated cost remains largely the same. Consequently, there is a practical limitation to how lean SKF Industrial Gothenburg can become, even though increased flexibility remains one of its central strategic ambitions.

The implications of these trade-offs become particularly apparent in SKF's make-to-order segment. Long lead times for customer-specific products risk positioning the company as an order qualifier rather than an order winner within that market. In contrast, SKF maintains a stronger competitive position within its make-to-stock segment, where factors such as brand recognition contribute to its order-winner status. The strategic challenge therefore lies in determining which trade-offs generate the greatest commercial value. Increasing flexibility and speed may strengthen SKF's position in customer-specific markets, but these improvements may simultaneously reduce dependability if the production system becomes more vulnerable to disruptions.

SKF's corporate strategy reflects an ambition to reduce its product portfolio by 25% while targeting more demanding customer segments. To support this shift, the corresponding manufacturing strategy must adapt towards smaller batch sizes, shorter lead times, and greater responsiveness. Such changes would strengthen the company's speed and flexibility performance objectives and could improve its position as an order winner within the make-to-order segment. However, smaller batch sizes require more frequent inbound deliveries, increasing exposure to supply-chain disruptions. A delayed delivery therefore risks creating broader production delays, representing a trade-off between flexibility and dependability.

To minimise this risk while maintaining the ability to fulfil customer-specific orders, SKF should seek opportunities to postpone the customer order decoupling point where feasible. Delaying customer-specific commitment to later stages of production would allow a larger share of the process to be forecast-driven, reducing exposure to demand uncertainty while preserving flexibility and responsiveness. Such an approach would support the company's strategic ambition to serve more demanding customer segments without requiring a disproportionate increase in operational risk.

Ultimately, remaining competitive in a changing industrial environment requires the ability to adapt as market requirements evolve. Flexibility therefore emerges as a particularly important performance objective for SKF's future manufacturing strategy. The company's ability to position itself as an order winner across selected market segments will depend on its capacity to build and sustain flexibility not only within the production system itself, but also across the supporting infrastructure, supply chain, and strategic decision-making processes that enable it.

7.3 Sources of Error

There are several potential sources of error that must be taken into account when analysing the findings of this study, as they may have affected the reliability and generalisability of the conclusions drawn.

Firstly, there is a limitation in the data collected in the study, since it relies heavily on qualitative interview data. The risk is collecting subjective experiences and interpretations of individual respondents. Naturally, the goal was to include stakeholders across different roles and levels of the organisation to achieve a holistic view of the organisation, but the findings are inevitably shaped by the perspectives of the people interviewed. Different respondents may have interpreted the same questions differently and the authors’ own interpretation of the material is also subjective. Quantitative data, together with the theoretical framework would have strengthened the study further as a support to the interview studies.

Another source of error is that the studies include a current state analysis that risks becoming outdated in the near future. SKF is currently undergoing a major organisational restructuring, where operational conditions may shift significantly. This includes production layouts, system configurations, management structures and strategic priorities. From an organisational perspective, the responses from the interviews may also have been tainted, due to uncertainties about their own future role within the organisation. Employees may be more hesitant to express criticism during a period of instability. For that reason, the current state analysis is limited to a specific point in time, and may become less accurate or relevant as the restructuring progresses.

Finally, the study is limited to SKF's D-factory in Gothenburg, and a specific assembly cell within SKF's operation. Since SKF is leaning toward a decentralised structure currently, it is difficult to fully generalise the findings to other SKF factories or industries, and must be adjusted to local conditions. Consequently, the insights from the study must be interpreted contextually rather than universally.

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Appendices

Appendix A - Interview Guide: Production Managers

Background and Role

- How long have you worked at SKF?
- How has the factory changed during your time at SKF?
- How have your responsibilities evolved over time?
- What types of decisions are you responsible for?

Decision-Making and Decision Support

- How do you typically make decisions in your role?
- What tools or systems support your decision-making?
- What data do you rely on when making decisions?
- To what extent are decisions based on experience versus data?
- Which KPIs are most important in your role?
- How is alignment ensured between operational decisions and overall strategy?

Data Quality and Information Flow

- How do you perceive the quality of manually entered vs automatically collected data?
- What data or decision support is missing today?
- Is any collected data underused or redundant?

Industry 4.0 and Automation

- How does the Gothenburg factory align with Industry 4.0 principles?
- What is missing to reach full Industry 4.0 maturity?
- What future opportunities do you see in digitalization and automation?
- How does the Gothenburg factory differ from SKF factories in China?

Production Layout and Automation

- What types of layouts are used across SKF factories globally?

- How do automation levels differ between factories?
- Which factors determine layout and automation choices?

Production Optimization and Cost Structure

- What are the main optimization priorities today?
- How is production cost structured and analyzed?
- What drives inventory levels and capital tied up in stock?
- How is demand variability managed?

Challenges and Robustness

- What are the main challenges with current automation levels?
- How is flexibility maintained in production?
- How are production changeovers handled?
- How do layout and automation affect adaptability?

Appendix B - Interview Guide: Operators

Background and Work Tasks

- How long have you worked at SKF?
- What are your main tasks in the assembly cell?
- Which tasks are manual vs automated?
- How do you experience daily work in the cell?
- What parts of the process create inefficiencies?

Data Entry and Systems

- How is data reported in your work?
- What is entered manually vs automatically?
- Which systems do you use (e.g. SAP, Factbird, Prevas)?
- How well do these systems support your work?
- What creates unnecessary administrative work?

Work Experience and Improvements

- What works well today?
- What would you improve?
- How could technical systems better support your work?
- How flexible is production during changeovers?

Performance and KPIs

- How is performance measured?
- Which KPIs are followed in daily work?
- How clear are work instructions?

Competence and Training

- How was onboarding and training structured?
- Which competencies are most important?

Production and Changeovers

- What types of stops or errors are most common?
- How are changeovers handled?
- What are typical cycle times and throughput levels?
- What is the scrap rate?

Appendix C - Interview Guide: Manufacturing Reliability

Role and Responsibilities

- How has the factory evolved during your time at SKF?
- What are your main responsibilities today?
- What types of decisions do you make?

Decision-Making and Support Systems

- How do you make decisions related to reliability?
- What systems or tools support your work?
- What data sources do you rely on?
- How do you balance data-driven vs experience-based decisions?
- Which KPIs are most important?

Data Quality and Analysis

- What data is missing for proactive reliability work?
- Is any data underused?
- How is historical failure and maintenance data used?
- Are investment effects measured (e.g. automation impact)?

Reliability and Downtime Analysis

- How would you describe current reliability levels?
- What are the most common failures or stops?
- How do you perform root cause analysis?
- Can you give examples of successful improvements?

Automation Challenges

- What are the main challenges with high automation?
- How does automation affect problem detection?
- Which parts of the system are most robust or sensitive?

Flexibility and Changeovers

- How is flexibility maintained during demand changes?
- How do changeovers affect stability?
- What limits flexibility most today?

Future Development

- What opportunities do you see in AI, sensors, and predictive maintenance?

Appendix D - Interview Guide: Global Manufacturing Manager

Role and Decision Scope

- Can you describe your role and responsibilities?
- What decisions do you make regarding automation and layout?

Automation Strategy

- What factors determine automation level decisions?
- How do cost, ergonomics, sustainability, and complexity influence choices?
- How do you balance flexibility and automation?

Flexibility and Standardization

- How is flexibility maintained in highly automated systems?
- What is the role of standardization?
- What trade-offs exist between efficiency and adaptability?

Industry 4.0 and Digitalization

- How is Industry 4.0 implemented in practice?
- What maturity level has been reached?
- What are the main barriers to full implementation?

Future Development

- What are the next steps in automation and digital transformation?
- What tools or methods are needed to reach this?

Appendix E - Interview Guide: Automation Specialist

System Integration

- How do SAP, Prevas, Factbird, and machine systems interact?
- What causes delays or missing information in the system flow?

System Challenges

- What are the main integration problems today?
- Where do failures typically occur (software, hardware, network)?
- Why is system integration complex?

Data and Standardization

- How can data flow be improved?
- What role does standardization of PLCs and machine data play?
- How could vendor standards improve system integration?

Automation and Programming

- How can short machine stops be captured automatically?
- How can programming reduce setup and calibration time?
- How can systems become more adaptive?

Future Digital Factory

- What are the biggest opportunities for a fully connected factory?
- What are the limits of current software architecture?
- What is needed for self-optimizing systems?

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