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Enhancing Information Circularity in Generic Discrete Event Simulation Development

Creating a Simulation Model that Utilizes a Developed User-Friendly Interface for Evaluating Production Lines

Master's thesis in Production Engineering

SVANTE ANDERSSON, EMMA LÖFGREN

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

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Supervisor: Ebru Turanoglu Bekar, Department of Industrial and Materials Science
Industrial Supervisors: Carin Lindström and Marcus Wagner, Manufacturing Development SKF
Examiner: Anders Skoogh, Department of Industrial and Materials Science

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Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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Abstract

In global manufacturing organizations, effectively sharing operational knowledge across geographically dispersed sites remains a significant challenge. This master's thesis, conducted in collaboration with SKF's Manufacturing Development department, addresses this issue by developing a generic discrete event simulation (DES) model integrated with a user-friendly interface. This thesis aims to support knowledge sharing and benchmarking across SKF's production lines while simplifying simulation adoption, especially for users without prior expertise in simulation. The developed solution integrates Siemens Tecnomatix Plant Simulation with Microsoft's Power Platform tools such as Power Apps, Power Automate, and SharePoint to enable structured data input and automated model generation through a user-friendly interface by emphasizing customizability and reusability. This allows users to configure machine setups, process parameters, and layout alternatives without the need for advanced programming background. Focusing on the context of bearing manufacturing, the solution illustrates how standardization and simplified user interaction can enhance information circularity within a global industrial enterprise.

The research methodology combines a literature review with qualitative interviews and quantitative analysis of SKF's production systems to identify critical simulation parameters, user interface requirements, and overarching organizational goals. The resulting concept supports efficient, accessible, and simulation-driven decision-making and internal benchmarking. It enables manufacturing sites to visualize and assess production scenarios with minimal manual effort.

This work contributes to both academic research and industrial practice by enhancing the usability of DES and promoting scalable knowledge transfer through the application of digital technologies.

Keywords: Discrete Event Simulation, Information Circularity, Simulation Usability, Microsoft Power Platform, Tecnomatix Plant Simulation, Global Manufacturing, Knowledge Sharing

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Svante Andersson, Emma Löfgren, Gothenburg, June 2025

List of Acronyms

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

AI	Artificial Intelligence
AR	Augmented Reality
DES	Discrete Event Simulation
DT	Digital Twin
GUI	Grapical User Interfaces
HMI	Human Machine Interface
IoT	Internet of Things
KPI	Key Performance Indicators
MTTR	Mean Time To Repair
NDT	Non-Destructive Testing
OEE	Overall Equipment Efficiency
UI	User Interfaces
VR	Virtual Reality

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1
Introduction

This chapter provides an overview of the research topic and the background to the project. It outlines the study's main objectives and research questions while defining its scope and limitations. The chapter concludes by clarifying the project's boundaries by discussing its delimitation.

1.1 Background

AB SKF, founded in Gothenburg Sweden in 1907, is a leading global manufacturer specializing in bearings, seals, lubrication systems, and related services. The company operates in 129 countries and maintains over 42,000 employees worldwide [19].

This master's thesis is conducted in collaboration with Manufacturing Development department at SKF. The focus of the thesis is to develop a generic simulation model that generates a discrete event simulation (DES) based on user-specified input values such as machine and process parameters. The simulation model utilizes a user-friendly interface for unambiguous parameter input, which is also developed as part of the thesis project. The thesis aligns with SKF's vision to strengthen its simulation strategy within the company and facilitate knowledge sharing between factories and production lines. The findings will help SKF to improve production line performance and productivity, accelerate the design and testing phase, and enhance accuracy for new investments.

This project is part of SKF's broader goal to enhance manufacturing productivity and increase the implementation of simulation across their factories. One key strategy to accomplish this is to consolidate their factories, enabling a more streamlined and efficient manufacturing setup (internal document). To enhance productivity, SKF must optimize output while minimizing losses. As a global company, SKF faces variations in performance, productivity, and improvements across its factories. A key challenge is the localization of knowledge within the organization, which makes it difficult to access and share insights effectively.

SKF is in various stages of implementing simulation tools and has deployed Tecnomatix Plant Simulation in some factories (internal documents). Acquiring the expertise to perform simulations requires significant time and resources, which factory employees often lack. To address this, standardized solutions that are easy to integrate at the local level are needed.

SKF uses internal production line benchmarking to enhance manufacturing efficiency and knowledge sharing. This process involves evaluating and comparing key performance indicators (KPIs) and technological capabilities across production lines to identify best practices and drive continuous improvement.

To effectively compare and evaluate internal production lines, it is important to provide insights into why certain lines perform well and what improvements have been made to reach it. When global manufacturers perform internal benchmarking they often face challenges in sharing operations-related information and knowledge. Although meetings are commonly arranged to address communication issues, automated workflows are usually lacking to facilitate effective information sharing. This is particularly critical in processes such as developing Discrete Event Simulation (DES), where the precision of input data is crucial. To encourage broader participation, the simulation process should be easy to set up, require minimal resources, and deliver clear benefits—such as identifying potential improvements or testing different scenarios.

1.2 Aim

This thesis aims to develop a generic simulation model that imports various input data through an intuitive and interactive user interface. The model is designed to be accessible to users without prior simulation knowledge, allowing them to easily adjust parameters and test different scenarios. By enabling the reusability of simulation models and incorporating efficient data storage methods, this thesis emphasizes continuous improvement while highlighting information circularity and internal benchmarking.

1.3 Research Questions

The following are the research questions for the thesis.

- **RQ1:** How can a Discrete Event Simulation support the knowledge and data sharing within a global manufacturer?
  - **Explanation:** This question explores the existing challenges in data sharing within a global manufacturer and the reasons behind these challenges. This will be answered by examining how the use of DES can influence the severity of these challenges, utilizing insights from interviews and literature reviews.
- **RQ2:** How can a DES be developed as a generic model when simulating any SKF bearing production line?

  - **Explanation:** This question investigates the key factors that enable the development of a generic DES model. It will be answered by analyzing recurring machine types, production flows, and layouts, as well as identifying standardized data inputs and key performance indicators (KPIs). Additionally, the study will explore how an interface can facilitate data and information sharing, circularity, and model standardization.

- **RQ3:** What could be the benefits of utilizing a generic simulation model with unambiguous input parameters?

  - **Explanation:** This question will be answered by evaluating the extent to which leveraging a generic simulation model with unambiguous input parameters enhances accessibility, reduces resource requirements, minimizes input errors, and enables fast and reliable simulations.

1.4 Problem Description

In recent years, there has been a growing ambition within SKF to expand the use of simulation as a tool for improving production efficiency and supporting investment planning. One of the main challenges in developing DES is that it requires specialized knowledge and skills, which are not yet widely available across all sites. In addition, well-defined and accurate data is essential for effective simulations. To address these challenges, SKF has conducted internal training sessions on DES development. As part of their commitment to continuous improvement, they are actively working to strengthen and expand the use of DES across the organization globally.

The company operates on a large scale with a highly complex production network consisting of numerous production lines. These lines share similar structures and functions but differ enough that each one requires its own tailored simulation model to enable meaningful internal benchmarking. This creates a significant challenge in scaling simulation practices across the organization.

Moreover, the company wants to continue to improve the centralized system for collecting and sharing internal production data between factories. Currently, the data collection for developing DES depends mainly on personal contacts and manual communication, which can be resource-intensive for both the factory in need of support and the one developing the DES model. Further improving the centralized system for collecting and sharing internal production data, would benefit the cross-factory collaboration and the effective use of simulation for internal benchmarking.

1.5 Delimitations

The DES model developed for this thesis will focus solely on the manufacturing of bearings, specifically the production of outer and inner rings. Since Tecnomatix

Plant Simulation is the only simulation tool currently utilized for production flow analysis at SKF, alternative methods or tools will not be evaluated. Therefore, DES using Tecnomatix Plant Simulation will be the exclusive simulation approach considered in this study.

The generic simulation model will not include specific machine or station designs, nor will it feature machine-specific graphics. Instead, the emphasis will be placed on data input, process performance, and output analysis. The model will be tailored to low-mix, high-volume production environments.

The study is limited to a 20-week period, during which no assessment of usability or user-friendliness will be conducted. Additionally, the model will not undergo industrial implementation or proof-of-concept validation. Testing will be restricted to fictitious cases without the inclusion of actual operation.

1.6 Thesis Outline

The first chapter introduces the thesis by providing context for the topic, explaining its significance, and outlining its objectives. It also presents the research questions and concludes with the study's scope and limitations.

The second chapter covers the thesis's theoretical foundation, including a review of relevant literature and the supporting background essential for the research.

The third chapter details the methodologies employed in the thesis, including the overall project workflow and the specific methods used for the literature review, qualitative and quantitative studies, and the development of the simulation model.

The fourth chapter presents the findings from both the literature review and the empirical studies. It also introduces the developed concept aimed at supporting internal information sharing and circularity, along with a comprehensive explanation of the interface created in Power Apps and the operation of the simulation model. Additionally, the chapter outlines the identified inputs from the qualitative study.

The fifth chapter discusses the results and contributions of the thesis, emphasizing the key findings and their implications. It also addresses the study's limitations and offers recommendations for future research and practical applications. The sixth and final chapter concludes the thesis by summarizing the main insights and reflecting on the study's objectives, findings, and potential impact.

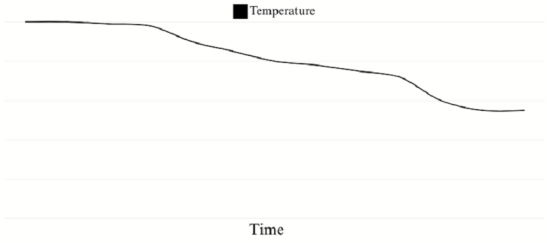
2
Theoretical Background

This chapter will examine relevant theories, models, and existing literature used to build a solid foundation for the study. It aims to provide an overview of key concepts and frameworks related to the stated research questions. The chapter aims to provide the theoretical foundation necessary to situate the thesis within the broader context of the field.

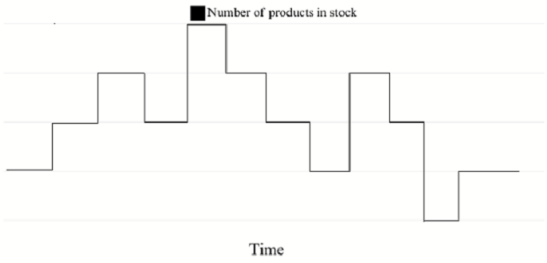
2.1 Discrete-Event Simulation

The concept of simulation has been used for many years, and has been defined as *"the process of designing a computerized model of a system (or process) and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of the system"*[4].

Building on this foundational idea, a discrete-event simulation (DES) models real-world dynamics by simulating events one at a time, generating detailed performance reports of the process [3]. It creates sample paths that describe the behavior of the system [1] and serves as an effective method to simulate and examine complex systems that change over time in response to specific events [12, 1]. In contrast, traditional time-continuous simulation continuously simulates events over a certain period, such as how temperature changes over time [10]. Discrete systems are composed of distinct or separate parts, whereas continuous systems are uninterrupted and unbroken [4]. The difference is visualized in Figure 2.1.



(a) Continous-Simulation State Variable



(b) Discrete-Simulation State Variable

Figure 2.1: Visualization of Time-continuous and Discrete-Event Models, freely adapted.

Simulating a dynamic system over time makes it possible to evaluate different scenarios, and identify bottlenecks, or improvement areas [12]. One of the main benefits of DES is its ability to replicate the randomness of the real world, making it possible to simulate systems such as queues, operations, and networks. The occurrence of events is represented using probability distributions to capture the involved randomness [13]. Consequently, it is essential to run these simulations multiple times, using the probability distributions of the parameters.

The simulation uses a time-stepping algorithm, advancing in small time intervals and updating the system's state based on the occurring events [12]. No changes are assumed between these states. To model the system, all possible event need to be

identified when they might happen, and how they affect the system [1]. In contrast to standard programming, where code runs sequentially, DES allows the execution flow to jump between different code segments [13]. This is controlled by an event scheduler, which decides the next event to execute and its timing.

When creating a simulation model, simplifications are often necessary. The process involves two key activities: analysis and abstraction. Analysis dissects the system into manageable components to align with the study's objectives. Abstraction reduces the complexity of the system by focusing on essential attributes and omitting irrelevant details through reduction or generalization [47].

2.1.1 DES Applications in Manufacturing

Traditionally, DES has been applied in industrial settings. In the 1980s and 1990s, manufacturing technology advanced rapidly in industrialized countries, with innovations like Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and Automated Guided Vehicles (AGV) emerging. These technological advancements played a crucial role in the shift towards more flexible and efficient production systems [3].

Building on this foundation, recent years have seen a significant rise in the demand for customized products in the manufacturing sector. This increase is driven by factors such as market saturation, evolving customer expectations, and the need for products tailored to specific individual preferences. As a result, industries such as fashion, automotive, and consumer goods have transitioned from mass production to mass customization and personalized products [5]. This shift further highlights the growing need for advanced manufacturing technologies and decision-making tools to support companies in navigating these dynamic market demands and increase flexibility.

As a result, companies face increasing pressure to shorten their time to market and be more flexible to adapt to dynamic requirements related to lot sizes, lead times, and cost [5]. Many organizations have invested in advanced technologies to address these challenges to improve operational flexibility while maintaining productivity [3]. In this context, DES has become a vital tool for supporting managers in making well-informed decisions at operational, technical, and strategic levels [3, 6]. It allows manufacturers to rapidly test and compare different scenarios, providing valuable insights on possible optimizations, an essential capability in today's competitive manufacturing landscape [6].

Beyond decision-making, DES is widely used in designing and evaluating new manufacturing processes [3]. It plays a crucial role in optimizing facility layouts and fine-tuning process parameters by identifying labor utilization and production capacity inefficiencies. Additionally, DES allows companies to test new scheduling practices, justify capital expenditures, and optimize production rates, ultimately improving overall business performance [6]. Evaluations can be conducted in a con-

trolled experimental environment, thereby avoiding disruptions to the real system and allowing for a more time-compressed analysis [4].

A 2014 study indicates a shift in research focus from manufacturing system design to manufacturing system operation [8]. The study also highlights that manufacturing operations planning and scheduling have become the most common applications of DES. Furthermore, the use of simulation in manufacturing system operations has expanded to encompass a new area: maintenance operations planning and scheduling [8]. Beyond these applications, simulation modeling has proven to be a powerful tool for optimizing various aspects of manufacturing systems operations. It enables businesses to determine plant capacity, balance manufacturing lines, manage bottlenecks, and address inventory and work-in-process challenges [4].

The use of simulation in manufacturing system design and operation is expected to expand as the industry remains a key driver of the global economy and faces increasing competition. To manage the growing complexity of manufacturing processes, more efficient techniques will be essential [8].

2.1.2 Benefits of DES Application in Manufacturing

The application of DES in manufacturing has become increasingly significant due to its ability to model, analyze, and optimize complex production systems. One of its primary uses is to enhance the efficiency of production lines [33]. DES effectively models and analyzes the uncertainties and time-varying behavior of complex real-world systems [35]. Because DES models are dynamic, they can be executed multiple times to generate a distribution of outcomes for thorough analysis [31, 33]. This enables manufacturers to evaluate factors such as equipment utilization, waiting and queuing times, cost-reduction strategies, and the impact of machine breakdowns [31]. Furthermore, potential improvements can be tested in a simulated environment before implementation [35]. The ability to conduct "what-if" analyses allows decision-makers to simulate and evaluate various scenarios before applying changes in real-world operations [31].

Managers often seek to understand why certain phenomena occur within a real system. By reconstructing events through simulation and analyzing the system at a microscopic level, DES can provide valuable insights into the root causes of these phenomena [31] while also enhancing overall system understanding [33]. Additionally, DES allows for the identification of unforeseen issues without incurring significant costs or operational downtime [33]. New policies, alternative operating procedures, and innovative methods can be tested within the simulation model without disrupting real-world operations. Furthermore, DES serves as an effective training tool, enabling new staff to gain experience and develop decision-making skills in a simulated environment before working with the actual system [31].

Furthermore, larger companies tend to adopt DES more readily than smaller firms, likely due to the greater availability of resources, the complexity of the software, and

associated costs [33]. However, DES offers advantages to organizations of all sizes by enabling the analysis of future scenarios to improve process time and efficiency. Critical investment decisions, such as purchasing new infrastructure or equipment, can be made with greater certainty [31, 33, 34]. By providing a more accurate and faster assessment of different options, DES helps determine the key performance parameters that influence manufacturing costs and budgeting decisions [34]. As a result, DES is widely recognized as a powerful tool for strategic decision-making [34].

Studies show that simulation modeling is extensively used at all management levels in the 500 largest corporations in the United States. Companies that have incorporated DES into their decision-making processes have reported capital cost savings of 5–10% [3]. These findings highlight the substantial role DES plays in enhancing operational efficiency, optimizing resource allocation, and supporting data-driven decision-making in the manufacturing industry.

2.1.3 Siemens Tecnomatix Plant Simulation

Siemens Tecnomatix Plant Simulation is a DES software tool used for simulating and modeling of production systems and processes. The software allows the user to make virtual models of real world productions and processes to test different scenarios and analyze the impact of factors such as factory layout and equipment capacity [7].

Production and process simulation in Tecnomatix Plant Simulation has a wide variety of application areas where it has been deemed useful. Several articles present case studies demonstrating the effectiveness of Tecnomatix Plant Simulation in real-world scenarios. One of the studies discusses how the simulation tool can be used in warehouse settings, e.g. for lowering the number of forklifts in use, hence improving efficiency and using resources economically. Additionally, the tool is used to optimizes the material flow from warehouse to production by identifying physical blockages and enabling reorganization and then efficient material flows [9].

Another study presents the effectiveness of using Tecnomatix Plant Simulation in the optimization of a production process. The use of the simulation model resulted in an increase in efficiency by more than 25% and a decrease in downtime for three machines with an average of 17%. The author of the case study added extra notations to the variability of the simulation, making it suitable for regular application in the planning of production capacities and for the creation of production plans [11].

A third study discusses the results of designing a Tecnomatix Plant Simulation model based on a case study with challenges related to increasing product customization and rapid fluctuations in demand. The model created in the study is tested and changed based on a variability of desired outcomes, where the tested changes are, for instance, a lower or higher number of buffers or that the machines were able to handle more operations than what it initially could. The results from the study were that by introducing a flexible production system based on a digital

model, they could observe a 15% improvement in system performance compared with the initial case study which it was based on [14].

2.1.3.1 Programming in Tecnomatix Plant Simulation

To model the behavior of realistic systems, Tecnomatix Plant Simulation provides the programming language SimTalk. SimTalk enables users to modify object behavior using control structures and programming constructs, including loops, conditions, and other elements that control the material flow within the simulation [47]. SimTalk programs are written within an instance of the information flow object called a Method. This allows for the creation of custom behaviors and interactions, facilitating more accurate modeling of complex systems. To create the generic simulation model, the built-in Methods *Init*, *Reset*, and *EndSim* are necessary. *Init* executes code when the simulation starts, *Reset* runs when the simulation is reset, and *EndSim* is triggered when the simulation ends [47].

2.1.3.2 Excel Compatibility with Tecnomatix Plant Simulation

Excel is one of the many software programs that are compatible with Tecnomatix Plant Simulation. Tecnomatix Plant Simulation can be utilized both for manually exporting and accessing Excel files through the software ribbons or by using some of the SimTalk programming functions, e.g. *readExcelFile* and *writeExcelFile*. Functions like these enable the possibility of working with Excel files in Tecnomatix simulation models and running the models without the need to take explicit actions [29].

2.2 User Interfaces for DES

The user interface (UI) is a crucial part of any systems success. Studies have shown that interface design has a larger impact on the learning time, performance speed, error rates, and overall user satisfaction. Since it is generally easier to modify the characteristics of a computer system than those of its users, the user interface holds significant importance. This is particularly true for DES systems, where user interaction is necessary for defining models, running experiments, and analyzing results [32].

As discussed in previous sections, conducting DES for complex manufacturing systems is widely regarded as both challenging and time-consuming. A key difficulty is the complexity of simulation software interfaces, which demand experience and understanding to effectively develop models of complex systems [27]. UIs play a critical role in preventing interaction failures, as design flaws can increase user errors when operating software. For example, improper interface design may lead to misconfigurations of file permissions within an organization, causing users to misunderstand required actions and potentially exposing sensitive information. Implementing design methods that ensure that the interface presents all necessary information clearly and accurately can significantly reduce errors. According to [28], such improvements

have shown to decrease user errors by up to 94% compared to previous interface designs, highlighting the importance of user-friendly interface modeling.

In recent decades, there has been a significant focus on developing visualization and animations for DES. However, efforts to improve data input facilities have been lacking [32]. Many existing systems still require users to rely on text-based approaches for model definition, and few provide database integration or structured data validation. Most DES tools lack features such as seamless data input from spreadsheets and databases, which could significantly improve usability. Furthermore, the presentation of simulation results often lacks logical interconnectivity, making it difficult for users to analyze outcomes. Addressing these limitations by implementing intuitive input methods could increase DES usability. As the focus of DES development shifts more and more towards enhancing usability, integrating solutions such as plug-and-play interfaces and improved data management tools will be essential [16]. As [32] suggests, future user interfaces might move away from a standardized or uniform design approach and instead be more specifically designed to fit the unique needs of each task. This means that instead of forcing users to adapt to a fixed interface structure, next generation interfaces should be highly customized and optimized for different tasks, improving usability and efficiency.

While Human Machine Interfaces (HMIs), typically referring to dashboards or screens used to control machinery, differ somewhat from UIs for DES, their shared focus on user interaction and the high degree of usability in HMIs make them relevant to be considered. To make HMIs as robust as possible and ensure seamless integration with a designated system while minimizing input errors, the use of unambiguous input data is highly beneficial. A study evaluating the impact of clear and unambiguous HMIs versus unclear and ambiguous ones in automated driving systems used a subjective user survey to gain a human-centric perspective on HMI quality. The study focused on how providing feedback to users based on system actions influenced their experience. The results indicated that participants associated clear and unambiguous HMIs to add more positive than negative value [36].

2.2.1 Microsoft Tools

Microsoft 356 offers a range of tools, including Power Apps, Power Automate, and SharePoint. These smart cloud services are widely adopted across organizations globally, offering efficient integration and user-friendly interfaces that enhance productivity. The combination of Microsoft tools creates a collaborative workspace that is user-friendly, efficient, easy to understand, and helps reduce both workload and costs [48].

2.2.1.1 Power Apps

Modern app design has evolved from focusing solely on functionality to emphasizing user-centric experiences. These improvements enhance user engagement through intuitive and user-friendly interfaces, interactive elements, and personalization based on user input, ensuring that employees within organizations contribute to the organi-

zational knowledge sharing [46]. Microsoft Power Apps is part of the Microsoft Power Platform and provides a low-code application development environment designed to make app creation accessible to both professional developers and non-developers [37].

Power Apps supports the rapid development of applications that streamline and support business processes. Its low-code approach enables users with limited programming experience, such as those familiar with Excel formulas, to design functional apps. This standardization of development encourages cross-functional collaboration, reduces development time, and can lead to increased efficiency and cost savings across organizations [38].

There are three main types of apps within the Power Apps platform: Canvas Apps, Model-Driven Apps, and Portals. Canvas Apps allow users to design applications using a drag-and-drop interface, where elements such as buttons, menus, and icons are placed freely on a screen. Logic is defined using a formula language similar to that used in Excel, allowing for behavior customization without traditional programming. In contrast, Model-Driven Apps are data-centric and rely on the underlying data structure in Microsoft Dataverse to automatically generate user interfaces. Portals provide external-facing websites that can be accessed by users outside an organization, offering secure interaction with business data through customizable web pages [37].

A key strength of Power Apps lies in its integration capabilities. Canvas Apps in particular support a wide range of data sources, including Excel, SharePoint, Microsoft Teams, and SQL Server. This flexibility enables the creation of custom applications that combine multiple systems into a single interface, improving workflow consistency and minimizing manual errors [38].

Despite its strengths, Power Apps has certain limitations. Performance can be affected when handling very large datasets in Canvas Apps, and some advanced functionality may still require custom code or integration with other Microsoft services [40]. However, the platform's combination of usability, scalability, and integration makes it a compelling solution for organizations aiming to enhance productivity through digital transformation [39].

In the context of knowledge sharing, Power Apps offers significant potential for organizations aiming to streamline knowledge management. Its intuitive user interface, combined with seamless integration capabilities across Microsoft services and various data sources, enhances rapid accessibility to critical information. This facilitates the sharing of knowledge and supports the development of a culture focused on continuous learning and process improvement. By enabling the creation of customized applications for specific knowledge sharing needs, Power Apps empowers knowledge managers to adopt a more strategic role in leveraging organizational information as a key asset, and in the end contributing to innovation [46].

2.2.1.2 Power Automate

In addition to the Power Apps development application, the Power Platform offers the cloud-based workflow automation platform, Power Automate. Power Automate is best described as, if Power Apps is used to build the interface and logic of custom applications, Power Automate is used to automate the workflows and processes that support those apps. It allows users to connect Power Apps to other services, trigger actions based on events, and move data automatically, without programming [41].

Power Apps represents one of several ways to initiate and utilize flows within the Power Automate platform. More broadly, Power Automate supports integration with over 275 prebuilt connectors and offers thousands of ready-made templates [41]. These connectors serve as bridges between Power Automate and external services such as SharePoint, Excel, and Outlook. Each connector provides two types of components: triggers, which initiate a flow based on an event (e.g., *When an item is created in SharePoint*), and actions, which define the steps executed after a trigger occurs. For example, a commonly used action available through the SharePoint connector is *Create File*. This action requires four input parameters: the site address which specifies the SharePoint site location, the folder path indicating the directory for file creation, the file name, and the file content, which defines the format and type of the file to be generated. This is merely one example; in total, there are 63 available prebuilt connectors for automating operations with SharePoint within the platform, of which 13 are triggers [42].

Power Automate include some additional processes and business logic for it to run smoothly and effectively. Additionally to the Action and Trigger components, Power Automate uses *Flow*, *Branching*, *Conditions* and a few more. Flows are the logical grouping of connectors, triggers, conditions, and actions used to automate the actions. There are several categories for different type of flows and two examples of these are: Automated flows that happen based on triggers or events and Buttons, also known as Instant or Manual which occurs when initiated by a user. As for these flows, each flow has individual use cases and configuration capabilities. Branching and Conditions allow flows to take different paths based on logic. Using conditions, it is possible to evaluate whether specific criteria are met, and then execute different actions based on true or false outcomes. Branching occurs when a flow splits into multiple logical paths and may be invoked through the use of conditions. Shown in Figure 2.2 is an example of an Automate Flow, containing the flow that is based on a trigger called *When a new tweet is posted* which is a connector for the *Twitter* (now *X*) webpage. After this, the user gets to chose from the *Microsoft Teams* connector where the action *Post a message* is highlighted. In this particular example, neither branching logic nor conditions are present [43].

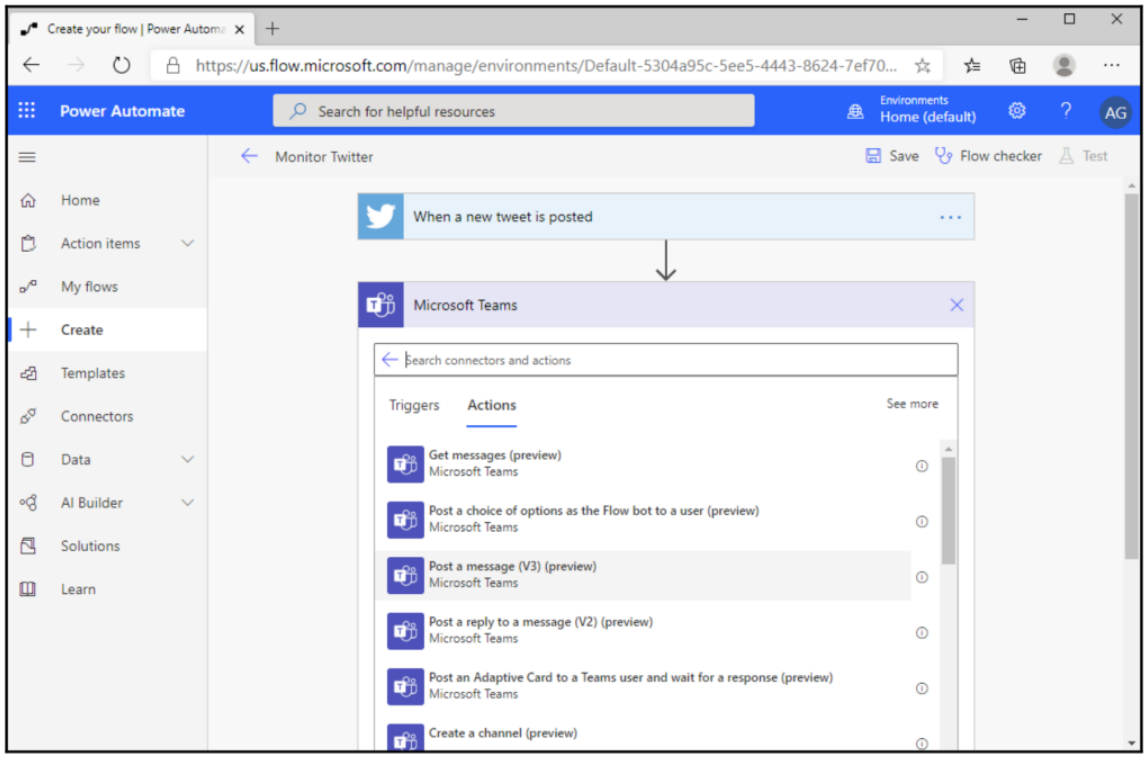


Figure 2.2: Power Automate Flow Example [43].

2.2.1.3 SharePoint

SharePoint is one of Microsoft's most widely adopted platforms for collaboration in the modern digital workplace. It serves as a centralized hub where employees within an organization can access, create, manage, and share content and knowledge. The platform supports a broad range of functionalities, including document management, content publishing, workflow automation, and integration with other Microsoft 365 services, thereby facilitating efficient and structured collaboration across teams and departments [45].

As part of SharePoint, specific Sites can be created for collaboration within organizations. A Site is a form of website, consisting of a home page, different items like lists and pages as well as a teams site and a communication site. A Teams Site connects team members to content and information, enabling the storage and collaboration on files or to create and manage lists of information. The Communication Site is more of a news center for sharing organizational news, reports, and other relevant information, often used by managers to share information with the employees [44].

Within a SharePoint site, different development tools and frameworks can be integrated and utilized to customize and add value to the site. Tools such as this could be the Microsoft platforms Power Apps and Power Automate. A Canvas App developed in Power Apps can be embedded directly into a SharePoint site page, allowing users to seamlessly interact with the application through the sites user

interface. Additionally, Power Automate flows can be implemented to automate routine operations within SharePoint. For example, a flow can be configured to automatically send an email notification to a designated recipient when a new file is added to a specified SharePoint folder, thus improving organizational responsiveness [44].

SharePoint lacks a standardized document format, which may be perceived as a limitation. However, this flexibility has been recognized as an advantage, as it allows organizations to define and implement document standards that are tailored to their specific operational requirements. This applies to the diversity of file types that SharePoint holds, moving away from the perception that knowledge should only be shared via documents, towards a more versatile file types utilized for specific use cases [46].

2.3 Information Circularity

Information circularity refers to the cyclical nature of information flow and its role in various systems, it involves continuous exchange and reuse of information to improve resource efficiency and sustainability [49].Circular Information Flow (CIF) is a key concept in discussions of the circular economy, referring to the creation, sharing, and storage of information throughout a product's life cycle to support the implementation of circular economy practices [50]. According to the extant literature, one of the primary barriers to adopting circular economy principles in manufacturing companies is ineffective information management, which complicates decision-making processes. This challenge is particularly pronounced in large, complex organizations, where hierarchical structures often lead to rigid and fragmented information flows—further emphasizing the need for efficient and integrated CIF [51].

3
Methodology

This chapter outlines the methodology applied in this thesis, starting with the overall project workflow, followed by the details of the literature review, qualitative and quantitative studies, and the development of the simulation model.

3.1 Overall Project Workflow

The project carried out alongside the thesis involved several steps designed to meet the objectives of the thesis. The different steps can be divided into three main sub-steps: project definition and goal specification, model development, and project implementation. During the model development phase, work on the simulation model and the interface was carried out in parallel. Each sub-step was continuously revised to verify inputs and outputs, ensuring satisfactory results. Validation was primarily conducted during the initial and final stages of the project, first to ensure that the work was aligned with the intended goals, and later to evaluate how well the project was received.

The different steps of the thesis project work are presented in Figure 3.1. The initial steps of the project involved gaining an overview of its background, purpose, and defining its goals and objectives. This process began with meetings with company stakeholders. Once the project team had developed a broader understanding of the project and its challenges, interviews were conducted as a second step to gather more detailed insights. After the key simulation model inputs were identified, the development of the Excel template for input parameters was initiated. A similar procedure was followed for the output parameters. Since the Excel template needed to be compatible with both the Power App and the simulation model, its design was developed iteratively to suit both purposes.

Before the model development began, a literature review was conducted during the pre-study phase to gain background knowledge on the relevant topics and to understand previous work in the area. The literature connected to the simulation model was reviewed to understand the limitations and challenges with DES, while literature related to the development of user interfaces was reviewed to identify best practices for designing intuitive, user-friendly systems that minimize input errors and enhance usability. The pre-study then continued with an exploration of the Tecnomatix Plant Simulation software and the Microsoft Power Platform.

To initiate the simulation model development, a conceptual model was created using a simple flowchart to visualize the overall data flow. The next step involved programming the model to generate the processes specified in the Excel data, followed by defining the material flow and configuring the process parameters based on the production plan schedule. For the interface development, the first step was to design the initial interface and configure all available options. Subsequently, Power Automate flows were developed to automatically generate the parameters based on the selected options. The development of the simulation model and the interface was carried out in parallel, with close coordination between the two.

The final project implementation phase began with the development of the SharePoint site page. The SharePoint site page was created within an existing SharePoint site that had been used for data sharing and communication throughout the project workflow. The page layout was designed with a focus on clarity rather than elaborate design. After adding the Power Apps interface to the SharePoint site, the functionality of the outputs generated by the interface was tested using the developed Plant Simulation model. To accurately replicate the end users experience, the SharePoint site page was operated as intended, following the guidelines, completing the steps within the application interface, downloading the latest files, and then running the simulation with the generated input files. The verification process to check whether the output data from the interface was compatible with the input file format of the simulation model was done for every production line combination. The last step was to introduce and present the concept to company stakeholders. The SharePoint, Power Apps, Power Automate flows, and Plant Simulation file ownership, were lastly handed over to company supervisors after presentation of the concept.

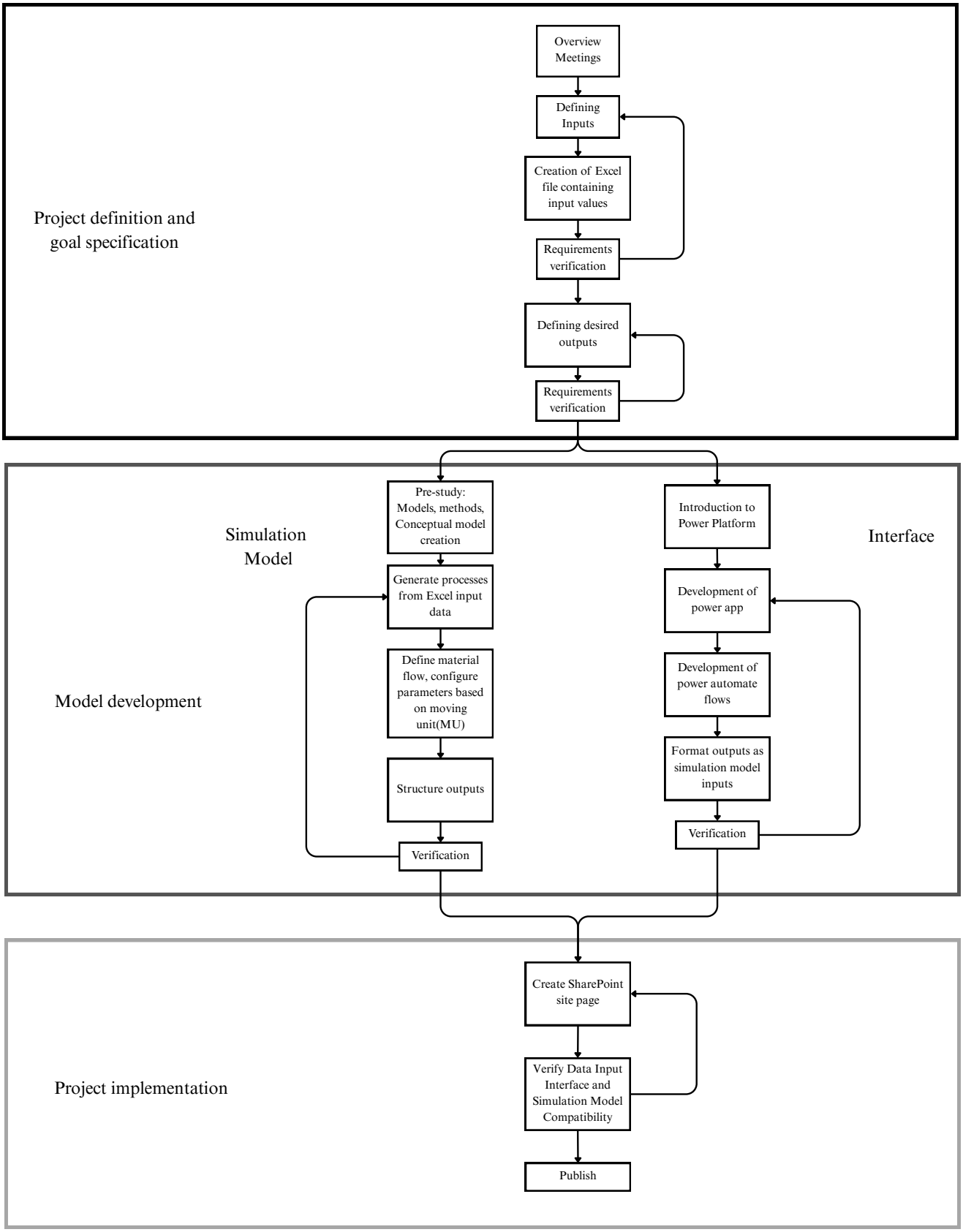


Figure 3.1: Overall Project Workflow

3.2 Literature Review

The literature was thoroughly searched across several scientific databases using Chalmers Discovery Services to ensure the reliability of the sources. The objective was to examine existing research and methodologies related to DES models to identify current challenges and software limitations. Additionally, literature on user interfaces, data storage, and Microsoft tools for data sharing was explored to assess low-code/no-code platforms like Microsoft Power Apps for developing flexible, user-centric applications. The process employed for literature review is summarized in Table 3.1.

Table 3.1: Literature Review Process

Literature review process	
Database	Scopus, Google Scholar, ScienceDirect
Information Source	Scientific articles, conference papers, case studies, and books
Search keywords	"Discrete event simulation", "Interactive Simulation Interfaces", "User-Friendly Simulation Tools", "Microsoft 365 Tools", "Power App"
Publishing year	DES: from 1986, all others from 1994.
Screening procedure	The relevance of each source was initially assessed by reviewing the abstract, introduction, and conclusion to evaluate alignment with the research topic. Relevant sources were then examined in more detail to ensure they contributed valuable insights to the study's objectives.

The search keywords were combined with Boolean operators such as OR/AND to refine the search. In addition, further sources were discovered by reviewing the reference lists of the articles found through the database search, which led to additional pertinent books and papers.

3.3 Qualitative Study

Qualitative research generally explores and provides deeper insights into real-world problems, investigating the "how" and "why" aspects [23]. For this study, 4 semi-structured interviews were conducted with individuals in roles relevant to the research questions and thesis aim. Semi-structured interviews use open-ended questions, allowing for flexibility and more in-depth exploration of the interviewee's thoughts and perspectives [23].

Different questions were used depending on the role of the interviewee. The goal of the interviews was to gain an understanding of the current state of the organization and identify challenges related to data sharing, operations, and the simulation strategy. The interviews aimed to gather insights into existing problems and limitations, allowing the project team to better understand how a DES model could contribute to addressing these challenges. Another key focus was to understand which inputs

and outputs are necessary to include in the DES model to develop a generic representation of the bearing production lines. The interviewees is briefly described in Table 3.2.

Table 3.2: Interviewees Description

Interviewees Description			
Role	**Job Title**	**Years at SKF**	**Years in Current Role**
Simulation Expert	Lean Digital Process Champion	4 years	4 years
Automation Engineer	Transformation Specialist	2.5 years	1 year
Operations Manager	Program Lead – Scalable Manufacturing Development	24 years	1 year
Process Engineer	M&PD Machine & Machining, Project Manager of Internal Production Line Benchmarking	17 years	8 years

To identify the relevant input parameters and configurations for the DES model, an interview was conducted with an internal simulation expert at the company. The interviewee brought extensive experience from previous simulation projects within SKF's bearing production, as well as in-depth knowledge of the capabilities and limitations of the Plant Simulation software. To determine the most important output parameters for the simulation model, all interviewees were asked to share their perspectives on the outputs they considered most critical. The automation engineer, who recently completed an internal pre-study on simulation tool selection and is currently working to scale up the use of simulations within the company, was selected to provide insights from an organizational development perspective. The operations manager, with extensive experience across various roles and direct involvement in internal production line benchmarking, contributed a broad managerial viewpoint. Additionally, the project manager of the internal production lines benchmarking project, with deep expertise in machining processes and a long tenure at the company, offered specialized insights based on their technical and project management experience.

When the interviews were conducted, they were transcribed to accurately capture the respondents' answers. A coding methodology was then applied to link the transcribed text to the research questions. Text relevant to Research Question 1 was highlighted in one color, a different color was used for Question 2, and so on. The highlighted sections were then summarized and analyzed to identify agreements and disagreements among the respondents, highlight key points, and draw conclusions.

By collecting perspectives from individuals within different fields, roles, and expertise, the study provided valuable input and outputs for the development of a DES model that aligns with the organization's needs, while also understanding the current situation within the organization.

3.4 Quantitative Study

To produce a bearing, several processes are involved. The two main components are the outer and inner rings, but other components may also be included depending on the type of bearing. To determine which processes should be included in the simulation model, a quantitative study was conducted to identify recurring machines and stations in conventional bearing production operations at SKF. The scope of the thesis focused on the production of inner rings, outer rings, and the assembly of bearings, thereby excluding components such as balls, cages, and rollers. To gather the quantitative data, meetings were held with production line representatives as well as production and process engineers, primarily through verbal discussions. Additionally, several employees across different roles at SKF were contacted to obtain production line layouts, including both CAD drawings and flowchart representations, formats commonly used at SKF to document and present line flows.

Once the data had been collected through meeting notes, CAD drawings, and flowchart layouts, it was documented in data tables. The station data were organized separately for the inner rings, outer rings, and final assembly flows. For each production line, the number of times each machine or station appeared was recorded. An occurrence percentage was then calculated to rank the stations from most to least frequently used, to determine the order in which the stations should be presented in the graphical user interface (GUI) for improved user-friendliness.

3.5 Development of Simulation Model

To develop the generic simulation model, Banks' methodology for simulation studies was used as a reference approach. This approach provides a set of guidelines for conducting a simulation study, summarized in Figure 3.2. This thesis study focuses solely on the first seven steps of the methodology, as no further experiments were conducted to investigate or analyze the model.

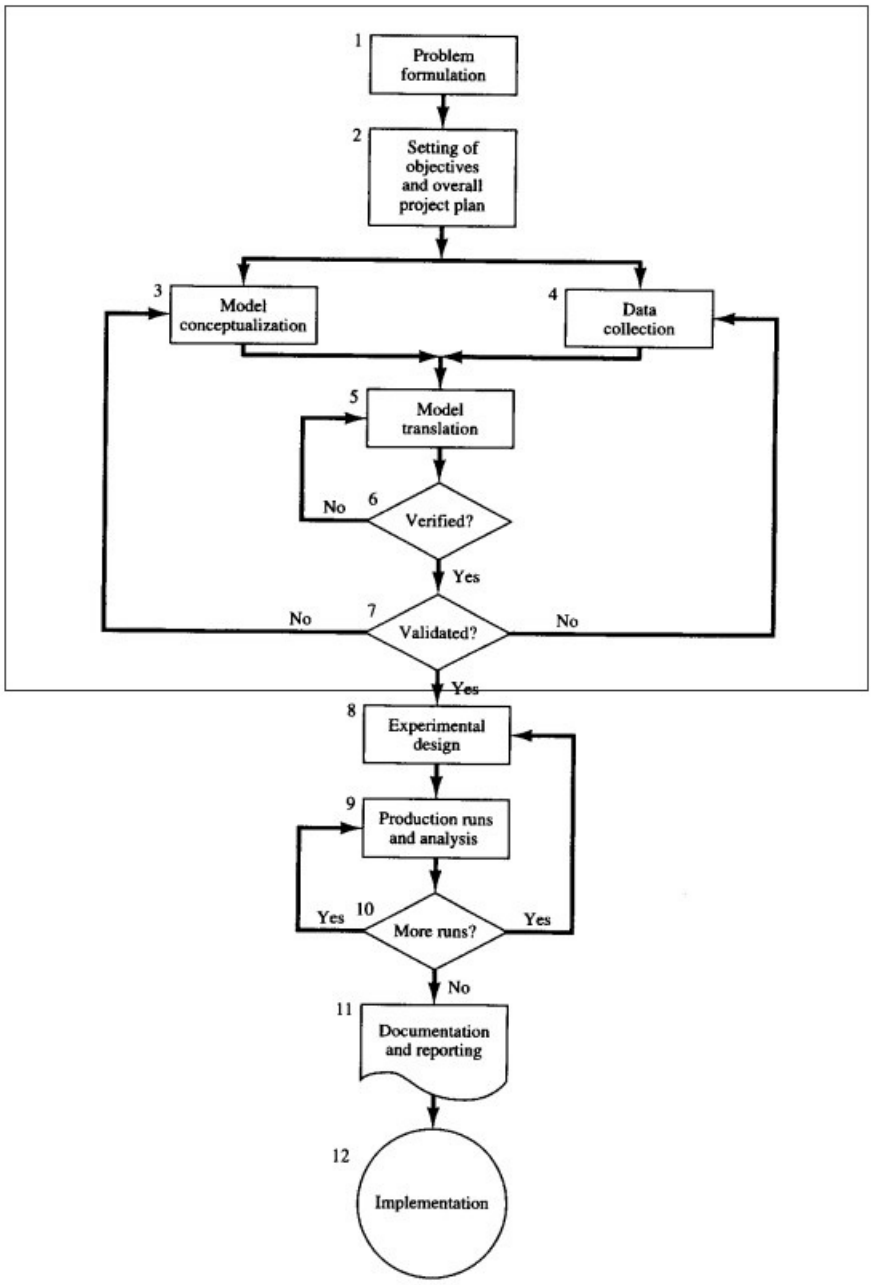


Figure 3.2: Banks Methodology for a Simulation Study [2].

According to [2], a simulation study should begin with a problem formulation, where the issue is clearly defined and understood by both the analyst and the client. Next, the objectives and project plan are established, outlining the study's goals, scenarios, required resources, and timeline. In this study, the problem formulation and objectives were developed in collaboration with company stakeholders, while the thesis group was responsible for establishing the project plan. The conceptual model was then developed as an abstract representation of the system to be simulated. Initially, flowcharts with simple box diagrams were created to outline how the model would work. Gradually, additional details were incorporated, specifying inputs, machines, and the material flow within the model. The information necessary to define the

production line components was collected through the quantitative study and the qualitative study through interviews.

Once the conceptual simulation model was finalized, a detailed flow diagram was created to represent the entire system and data flow, from the interface to the generation model, describing how the generic model would function. The conceptual model was then translated into an operational model using Tecnomatix Plant Simulation and its scripting language SimTalk, which enables the implementation of custom behavior and complex logic to, e.g., objects and data tables in the models.

Verification, ensuring that the model functions as intended, was performed iteratively using the debugger function in Plant Simulation. Verification was conducted each time a new method was created to ensure correctness in the programming and model behavior. Additionally, repeated meetings were held with the company's simulation expert to further verify the model's performance.

4
Results

This chapter presents the findings from the literature review, as well as the qualitative and quantitative studies. It also introduces the concept developed to support internal information sharing and circularity, accompanied by a detailed description of how the interface in Power Apps functions, how the simulation model operates, and the inputs identified from the qualitative study.

4.1 Results from Literature Review

DES serves as a strategic decision-making tool by providing certainty before critical investments [31, 33, 34]. It effectively analyzes complex systems [33], enabling performance evaluation, bottleneck identification [31], and optimal resource allocation without real-world disruptions [35].

User interfaces in DES systems significantly impact learning time, performance, and error rates, yet current DES tools lack intuitive data input methods and seamless data integration, hindering usability [32, 27]. Microsoft tools like Power Apps, Power Automate, and SharePoint offer integrated, user-friendly platforms that enhance data input and knowledge sharing through low-code solutions and customizable interfaces [48, 38, 44]. Power Apps, SharePoint, Power Automate, and Siemens Tecnomatix Plant Simulation can all be integrated seamlessly with Excel.

4.1.1 Challenges and Limitations in Using and Implementing DES

Literature discussing the challenges of DES has primarily focused on the complexities involved in developing DES models. The model-building process requires substantial training and experience [2, 31, 33], making it difficult for users without a strong simulation background. To address this, [16] highlights the need to either cultivate a more simulation-educated workforce or develop plug-and-play simulation environments that allow users to focus on decision-making rather than the complexities of the modeling process. Additionally, the lack of standardization and the diversity of available software further complicate the adoption and implementation of DES [17].

Another significant obstacle is the incomplete and often conflicting knowledge of production systems, which can hinder accurate model development [17]. When modeling complex real-world systems, many simplifications need to be done, which

can lead to models that do not accurately represent the system. Manufacturing environments rely on multiple competing resources, such as machines, workers, and material-handling devices, making it difficult to determine which factors most significantly impact performance [24].

A critical challenge is also the input data analysis, as the accuracy of a simulation depends on how well the input data aligns with the real-world system. Insufficient resources allocated to modeling and analysis may result in inadequate models for the task [2, 4, 16]. Collecting, validating, and analyzing input data is time-intensive, often consuming over a third of the project timeline [25, 33]. Additionally, there is no standardized method for gathering the required data in manufacturing, making the process inconsistent and resource-demanding. Without high-quality data, model accuracy and reliability suffer, limiting the effectiveness of simulation-driven decision-making [24]. To reduce the input-data collection time, it is essential to create a software toolkit that can automatically transfer process parameters from the data pool to simulation models [25].

Interpreting simulation results can also be challenging. Since most simulation outputs are random variables, distinguishing between system interrelationships and mere randomness can be difficult [2, 31]. Additionally, critical assumptions hidden within the model may lead to deviations from reality, making validation a complex process [4].

4.2 Results from Qualitative study

The qualitative study provided insights into challenges related to data and information sharing, identified problems in the current situation, and outlined how the simulation model should be configured to function effectively as a generic simulation model.

4.2.1 The Support of Knowledge and Data Sharing in Global Manufacturing with Discrete Event Simulation

The findings from interviews indicate that knowledge and data sharing across the global manufacturing network could be further improved. Although certain production lines are internally recognized as high-performing, the documented reasons behind their success can be further developed for clarification. Existing documentation provides limited insight into the underlying processes, making it difficult for other sites to precisely replicate improvements. Although individual factories possess valuable knowledge that could benefit the broader organization, efforts to share this knowledge effectively are still ongoing. Additionally, factories with high-performing production lines often face a resource burden, as they are expected to support other sites without clear incentives or compensation. To address this imbalance, the operations manager suggests offering reciprocal support, for example, by developing simulation models free of charge for these factories, to promote mutual benefit and

encourage more balanced contributions across the network.

DES has been proposed as a practical solution to further standardize and facilitate this exchange. By modeling production lines for internal benchmarking, DES can offer a visual and accessible way to communicate best practices and demonstrate optimal setups. These models would represent production line layouts, machine configurations, and include key operational parameters such as buffer capacities, tool usage, and cycle times. The aim is to support knowledge transfer without adding to the operational burden of the benchmark factories.

The operations manager, process and automation engineers describe a generally collaborative company culture at SKF. However, the process and automation engineers address that global organizations that have a regional structure and factory-level competitiveness can in general complicate data sharing.

The automation engineer describes that with the continued work on the introduction of digital tools and sensors, actual machine performance becomes more transparent, which can show discrepancies between estimated and real values. This increased transparency is essential for developing DES models and improving operations.

All interviewees communicate a strong belief in the potential use of simulation as a tool to bridge knowledge gaps and benefit collaboration. If used effectively, DES can highlight what works best, explain why it works, and support other factories in applying the same improvements. With centralized governance in the distribution and use of simulation models, SKF can ensure consistent application and avoid fragmented site-specific decision-making.

4.2.2 Developing a Generic Model for Simulating SKF's Bearing Production Lines with DES

The interview with the simulation expert provided valuable insight of the optimal configuration of the generic simulation model, identifying key input parameters such as product types, material families, cycle times, and setup times. Parameters such as net output, throughput time, and OEE were identified as relevant output parameters.

4.2.2.1 Simulation Configuration and Input Parameters

During the interview, the simulation expert presented an internal case example featuring a document with production data. This document included product details and historical production information. The expert explained that such documents can vary slightly between sites. As a global company, maintaining a standardized format for production data across all locations can be challenging. However, at SKF, there is an internal project aimed at standardizing this type of information.

The simulation expert recommended the development of a template to be used across

factories, rather than adapting the model to the variety of factory's data structures. It would be more effective to provide a user-friendly template that guides data input in a consistent format. Such a template would allow factories to easily define the types of products they produce, the machines used, the cycle times, and other relevant parameters needed for the simulation model.

In Plant Simulation, the cycle time may include activities during which the machine itself is not actively processing—such as when an operator is performing tasks around the machine. Although the machine is technically "locked," it is not in operation. In the context of this model, using processing time as an input parameter is more appropriate, even though the term cycle time is often used. It is also important to note that different products may require different processing times. In most cases, these processing times can be entered as fixed values, rather than as statistical distributions (e.g., normal or uniform), because the machines tend to be highly precise and the variation in processing time is minimal—especially for small-sized products, where the duration may be only seconds or minutes. However, for larger-sized products, the processing or cycle time may extend to several hours, and variation becomes more significant. In such cases, using boundaries or ranges for processing time might be more appropriate.

It was emphasized that the simulation model will be more accurate and relevant for low-mix, high-volume production environments. These environments are more standardized and, therefore, better suited for the development of a generic model.

Setup time is another important parameter to consider. Currently, two distinct types of setup times are used. The first type occurs when changing a tool inside the machine—for example, after processing approximately 1,000 units, the grinding wheel must be replaced. The second type of setup time is product-related and occurs when changing from one product type to another. This changeover is typically associated with the batch size.

The most common production strategy is sequential batch processing—starting with the first product type, then moving on to the second, third, and so on. Most machines process one piece at a time, but it was noted that the model should also allow for flexibility in machine capacity, in case certain machines can handle multiple parts simultaneously. Another recommended feature of the input template is the ability to specify scrap rates per machine, typically expressed as a percentage. This allows for a more accurate reflection of production losses in the simulation.

Information about material families is also commonly available. For example, a typical sequence might involve products from families A, A, B. When switching between products within the same material family (e.g., from A to A), the required setup time is usually shorter. However, changing from one material family to another (e.g., from A to B) tends to require longer setup times due to greater machine adjustments. This sequencing based on material family is frequently practiced in the factories, although incorporating material family data into the model can remain

optional depending on the available data and level of detail desired.

Machine failures should also be considered in the model. The expert suggested using a simplified approach in Plant Simulation, where machine availability is expressed as a percentage (e.g., 99%). Additionally, a standard failure duration time can be assigned. Failures are typically independent of the product type, making this abstraction feasible. A short description or expected failure rate can be defined for each machine in the input template.

In some cases, there is connectivity between machines through systems such as link conveyors, which act as buffers. For example, if machine 2 fails, but a link conveyor buffer exists between machine 1 and machine 2, production can temporarily continue without interruption. The buffer capacity—determined by its physical length—can allow upstream machines to keep running for a limited time, providing the operator time to resolve the issue and minimizing downtime. For this the layout and the distance between the machines are important to enter in the template. This type of buffer system is commonly used in production lines and may be valuable to incorporate into the simulation model conceptually.

The automation engineer highlighted that it would be beneficial to continuously educate about certain processes related to production development. To further promote understanding of the benefits of Non-Destructive Testing (NDT), it was considered valuable to include NDT as an optional feature in the simulation model. Even if it was only for visual purposes, the interest and curiosity for NDT might increase.

Finally, it was acknowledged that additional production-specific details exist, such as defined work, which refers to structured descriptions of operator activities. However, incorporating such detailed human-related data may exceed the scope and abstraction level of the current simulation model. Likewise, certain machines may require special handling, but accounting for these exceptions would require a level of accuracy and complexity that is not practical for a generic simulation model.

The simulation expert also emphasized the value of offering two distinct modes within the model. One mode would allow users to input detailed production plan data—such as lot sizes, product types, and material families—enabling a more tailored and precise simulation. The second mode would serve as a simplified alternative, allowing users to quickly build and explore basic models without the need for extensive input.

4.2.2.2 Output Parameters

To understand which outputs are considered most valuable from a simulation model, insights were gathered from all interviewees with varying roles and perspectives within the organization. The common theme across the interviews was that the most relevant outputs are those linked to core production performance indicators.

The attitude toward simulation varies depending on the maturity level of the factory. In factories where digital tools and data-driven decision-making are already well integrated, there is generally greater openness to simulation. However, in less mature environments, management endorsement plays a critical role in driving adoption. To build trust and broaden the use of simulation across the company, it is important that upper management actively promotes it and supports its integration into development projects. One key to building this trust is to demonstrate tangible value, for example, by showing real project outcomes where simulation has led to improvements in production lead time, resource utilization, or cost savings.

Among the most frequently mentioned outputs were capacity utilization, net output, and resetting times—all of which relate to the overall efficiency and productivity of the production system. Respondents highlighted that simulation results should communicate benefits in numerical terms. For example, outputs such as production lead time, Overall Equipment Effectiveness (OEE), and throughput time were considered critical for evaluating process performance. The process engineer noted that being able to demonstrate, for instance, a 50% reduction in buffer size or material waste through simulation results can provide strong decision support. Other commonly desired outputs included cost savings and scrap reduction.

The interviews also revealed that output preferences vary depending on the user's role. For instance, higher-level managers are more interested in resource utilization and overall system efficiency, while production managers are likely to focus on net output and more operational metrics. This suggests that the model should be flexible enough to cater to different user needs and allow for customized reporting.

Additional aspects, such as energy consumption and cost of production, were also mentioned as increasingly relevant, particularly if the model can estimate costs based on machine usage over time.

All the identified output parameters are summarized in Figure 4.1.

Table 4.1: Simulation Model Outputs and Application Context

Output	**Application Context**
Net output	Evaluating overall production performance and meeting production targets.
Production lead time	Estimating delivery schedules and optimizing workflow processes.
Throughput time	Evaluating production flow and identifying process delays.
Capacity utilization	Assessing system efficiency and identifying bottlenecks in production.
Resetting times	Analyzing setup and changeover processes to reduce downtime.
OEE	Measuring machine performance and identifying areas for improvement.
Material waste reduction	Assessing waste reduction strategies to lower production costs.
Cost savings	Demonstrating financial impact from process improvements.
Resource utilization	Allocating resources effectively for maximum productivity.
System efficiency	Monitoring overall operational performance and identifying inefficiencies.
Energy consumption	Evaluating energy usage to reduce costs and improve sustainability.
Cost of production	Estimating total costs based on material, labor, and machine usage.

4.2.3 Benefits of Utilizing a Generic Simulation Model with Unambiguous Input Parameters

The generic simulation model could serve as a foundation for rapidly creating simulations of production lines. Such a model can function both as a decision-support tool for lines in need of improvement, and as an aid for the simulated production lines themselves. One of the key advantages is that the factories can independently run simulations in a user-friendly and low-resource manner. This self-sufficiency not only empowers the individual factory but also allows the results and models to be shared and utilized by others within the organization.

It was emphasized during the interview with the project manager that the effort put into building a model must benefit the factory that develops it, in addition to others who may use it. Without this mutual value, there would be little incentive for factories to invest time and resources into model creation. Rather than building a new model from scratch each time, the generic simulation model of an internal benchmarking production line is intended to be reused as a base for future simulations. Since many lines produce similar products and follow comparable processes, they do not differ significantly in structure. This enables efficient adaptation of the base model with minimal adjustments, making it possible to generate new simulations without requiring extensive effort or resources.

The automation and process engineer describes simulation as a form of insurance, a tool that provides confidence in decision-making by validating expected outcomes before implementation. While simulation offers the opportunity for process improvement, its first and foremost function is to confirm whether a proposed change will deliver the intended results. In cases where issues are identified during the simulation phase, they can be addressed proactively, preventing potential disruptions in the actual production. This statement is also supported by the operations manager, who discusses how simulation can significantly accelerate the process of preparing investment cases. By visualizing and testing different scenarios based on input data, simulation provides valuable decision support for determining which alternative to pursue. This preventive capability not only enhances operational reliability but can also result in measurable benefits, such as cost savings or reductions in throughput time.

An important topic raised during the interviews was the quality of input data. While simulation tools can offer powerful insights, their effectiveness relies heavily on having reliable and standardized data that can be easily imported into the model.

Developing simulation models typically requires a significant level of expertise, which can pose a barrier to widespread adoption. To further support the scaling of simulation across the organization, it was highlighted that the usability of the model interface plays a crucial role. While the underlying models may need to reflect complex processes, the user experience should be simplified to avoid cognitive overload. Simplified views or guided interfaces could allow users to interact with the model more intuitively, without needing deep technical expertise in simulation software such as Plant Simulation.

Moreover, the discussion with the operations manager emphasized the importance of reusability in simulation modeling. Structuring models in a modular way, with configurable building blocks, would enable users to easily adapt existing simulations to new cases. A simplified setup process would allow users to build or modify simulations more efficiently within their day-to-day work. Although the current state is far from making simulation a routine activity, the long-term goal remains to integrate simulation tools into everyday decision-making at all levels of production.

The company's simulation strategy aims to integrate simulation tools as a natural part of production development projects. As one interviewee expressed: "Every time we have an improvement project, we will use simulations before we implement it."

4.3 Results from Quantitative Study

The quantitative study was conducted to gather information about the machines and stations present in a sample of randomly selected production lines at SKF. After analyzing the lines, recurring stations were identified and their frequency of occurrence was documented.

The studied lines varied in their configurations. Some included only the production of inner rings or outer rings, while others combined both. Additional variations involved lines with inner ring production and final assembly, outer ring production and assembly, or lines that incorporated the entire process, producing both inner and outer rings along with final assembly, all within the same production line. If an analyzed line included inner rings and outer rings production as well as a final assembly of the two rings, with additional bearing components, the stations for the line were separately documented for each of the line sections. For example, if the station "Face Grinding" was present only in the inner and outer ring lines but not in the final assembly, it would be recorded as present for the inner and outer ring sections only.

The production lines collected from meetings and layout data were analyzed and are presented in Figures 4.1–4.3. Since the frequency of station occurrences varied across the three line types, the stations are arranged from left to right in descending order of frequency. This highlights which stations are more commonly used in the bearing production lines and which are less frequent. In this study, the frequency with which a station appears will not determine whether it is included as an input option, but rather will influence the order in which stations are presented to the user.

For the outer rings stations, the gathered data is presented in Figure 4.1. As seen in the figure, the number of different collected stations was 16, the most frequently recurring station being "Face Grinding".

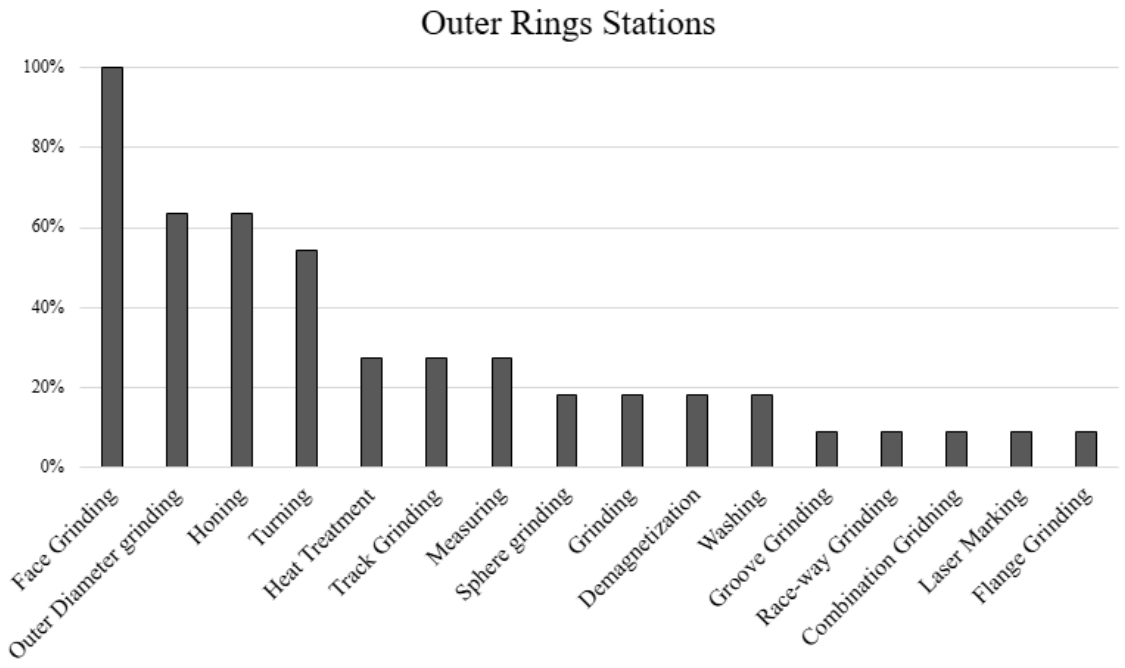


Figure 4.1: Occurrences for Machines and Stations for lines Including Outer Rings Production

The gathered data for the inner rings stations is presented in Figure 4.2. Shown here is that the number of different stations collected for lines containing inner rings was 17, and the most frequently recurring stations were "Face Grinding" and "Honing".

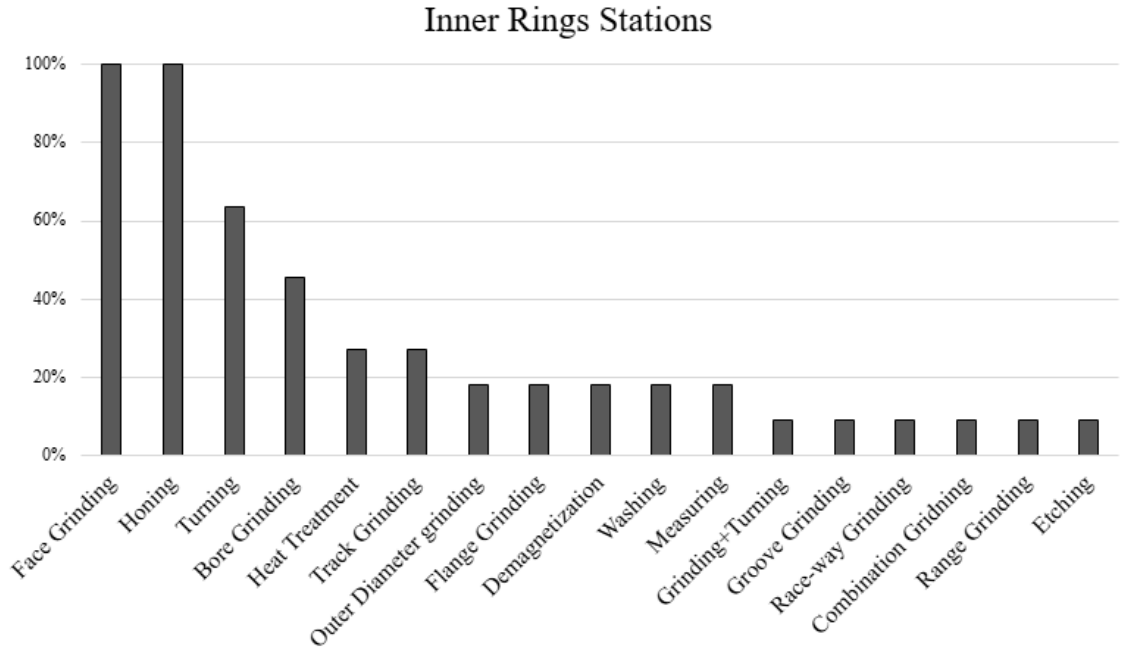


Figure 4.2: Occurrences for Machines and Stations for Lines Including Inner Rings Production

As for the stations present in the final assembly lines, the gathered data is presented in Figure 4.3. The number of stations collected for the assembly lines was 9, and the most frequently recurring stations were "Assembly" and "Packaging". What was also recognized in the study was the fact that the "Assembly" stations were always present as the first station in line for the production lines containing a final assembly line.

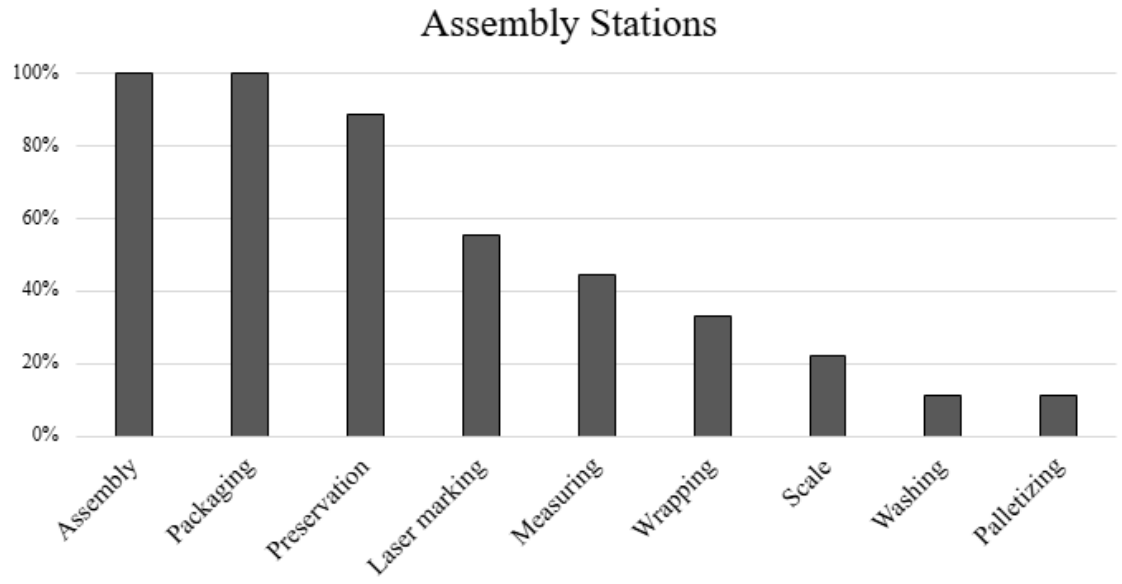


Figure 4.3: Occurrences for Machines and Stations for Lines Including Assembly

4.4 Developed Concept to Support Information Sharing

The overall concept for data sharing and information circularity with the use of a generic DES model, is illustrated in Figure 4.4. SharePoint serves as the central platform for accessing both the data input interface and the DES model. To support this functionality, a dedicated SharePoint site page has been developed.

The site page includes a title and a brief introduction outlining its purpose and objectives. As the user moves down the page, they encounter an embedded Power App. This application guides the user through a step-by-step input process. Initially, the user is asked to enter a production line name and select a production setup. Based on these selections, a tailored set of parameter fields is generated within the app for the user to complete.

Once the inputs are submitted, Power Automate is triggered to process the data. It generates an Excel file containing the specified parameters, an empty Excel file for storing output values in, along with a copy of the developed generic simulation model. After completing all steps in the Power App, the user is directed downwards in the SharePoint site page to access the generated files.

At this stage, the user is presented with a set of shared folders within SharePoint, where both the Excel input file and the simulation model can be accessed. The files are automatically named based on the specified line name, allowing for easy identification among multiple files created by other users.

Next, the user opens the Siemens Tecnomatix Plant Simulation software, locates the previously generated folder and opens the simulation file with the designated file name. When the simulation file is opened in Plant Simulation, the user is asked to select the newly created Excel file, containing the input parameters defined in the application interface. The simulation model is then automatically configured with the appropriate processes and the defined material flow. The resulting outputs for the specific simulation are displayed within Plant Simulation in an HTML file, and simultaneously documented in the Excel outputs file.

When inputs have been defined and the simulation has been run, benchmarking users can access both the the simulation file for production line comparison and the output file for performance evaluation.

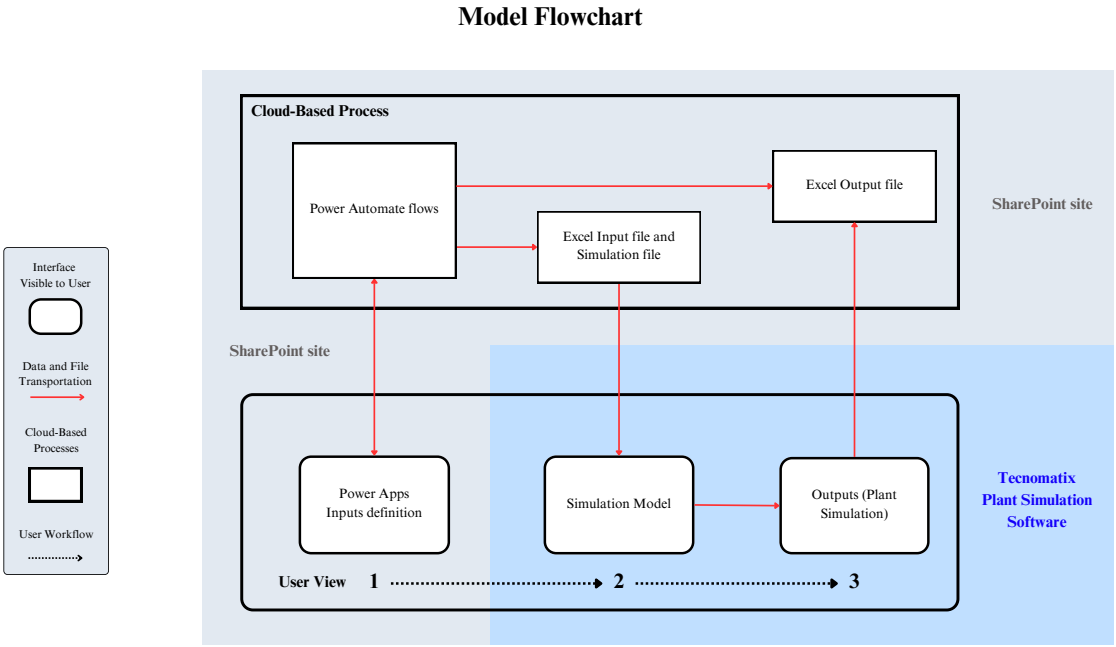


Figure 4.4: Model Functionality Flowchart

4.4.1 User Interface for Defining Simulation Input Parameters

The initial interface presented to the user in Power Apps is shown in Figure 4.5. This screen serves as the foundation for defining the simulation operation and for initiating the creation of the corresponding Excel file, which will be named according to the user-defined production line. Within this screen, the user is advised to specify

several parameters for the simulation. These include the layout type of the line, the specific bearing names and lot sizes, whether non-destructive testing (NDT) will be relevant to add to the simulation model, and whether the processing times at the machines and stations should vary based on individual bearing types or remain static regardless of bearing type.

Starting from the top, the user inserts the name of the production line that is to be simulated. When the button "Lock in" is pressed, the inserted line name will be sent as an input to the Power Automate flow "Create Files" and actively triggers it to run. The Power Automate flow can be viewed in Figure 4.6. The Power Automate flow takes the operation name and initializes a variable containing both the name of the line, followed by the exact date and time. This approach ensures that each instance of file creation remains uniquely identifiable, even in cases where the same line name is reused at different times.

Following this, a dedicated folder is automatically generated within the associated SharePoint location corresponding to the Power Apps environment. Inside this newly created folder, three files are generated: one Microsoft Excel file for input data, one Microsoft Excel file for output data and one Plant Simulation file containing the simulation model. All files that are created are based on predefined template files to ensure the correct format. The simulation file that is created within the developed folder, is the same for every type of user specific input data, serving as a generic model of varying inputs. Both the folder and files are systematically named using the production line name, date and time of creation, to facilitate clear identification and efficient retrieval of the relevant files at a later stage. The last step of the "Create Files" [4.6] flow is to send the folder name variable back to the application interface to effectively access the right location of the Excel file to insert data, defined in the interface dynamically.

The second action the user makes on the first page is to check the boxes of which type of production line it is, if it includes an inner ring production line, an outer ring production line, an assembly line, or any variation of the boxes that are checked. Depending on which of the boxes are checked, it will determine which of the Power Apps screens will be shown to the user when inserting data. The quantitative study revealed a significant variation in different bearing production lines at SKF, which led to the need to develop a simulation model compatible with seven distinct production configurations. The scenarios are described in the following:

- **Single-Production lines:**
  - Inner Ring Line
  - Outer Ring Line
  - Assembly Line
- **Dual-Production lines:**
  - Outer Ring + Inner Ring Line
  - Outer Ring + Assembly Line
  - Inner Ring + Assembly Line
- **Triple- Production lines:**
  - Outer Ring + Inner Ring + Assembly Line

Additionally, the last selections for the user to make on this page are: If the simulation will include specific bearing names and batch sizes, whether Non-Destructive-Testing (NDT) will be included in the simulation. If the option to include specific bearing names and batch sizes is selected, the user will not provide a specific machine processing time at a later stage but rather bearing-dependent machine processing times.

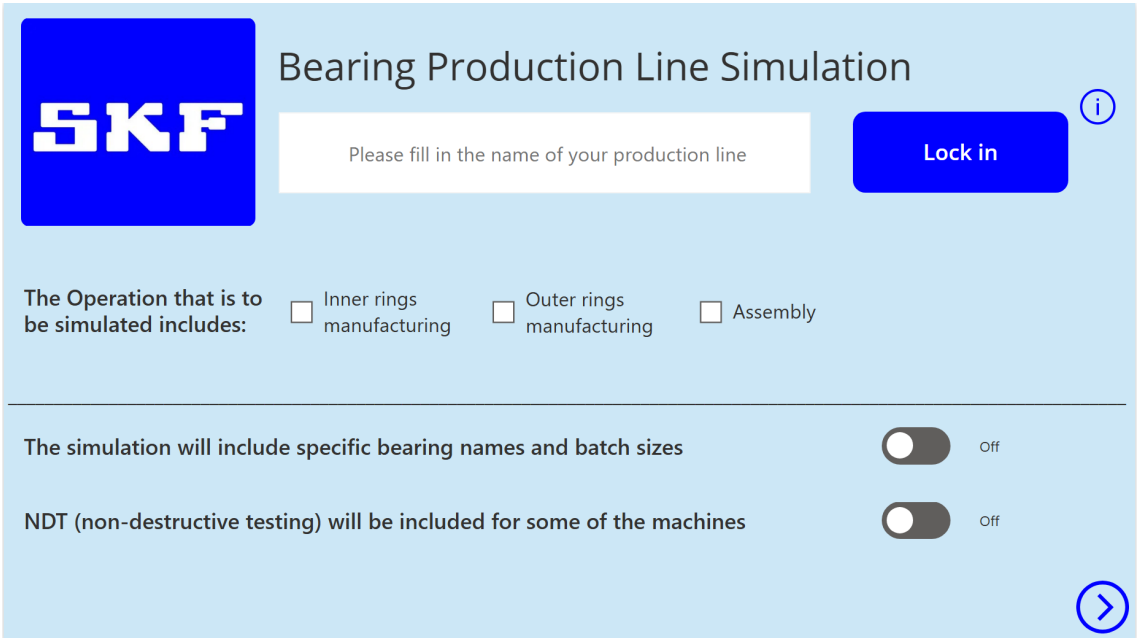


Figure 4.5: UI for Power Apps Start Screen

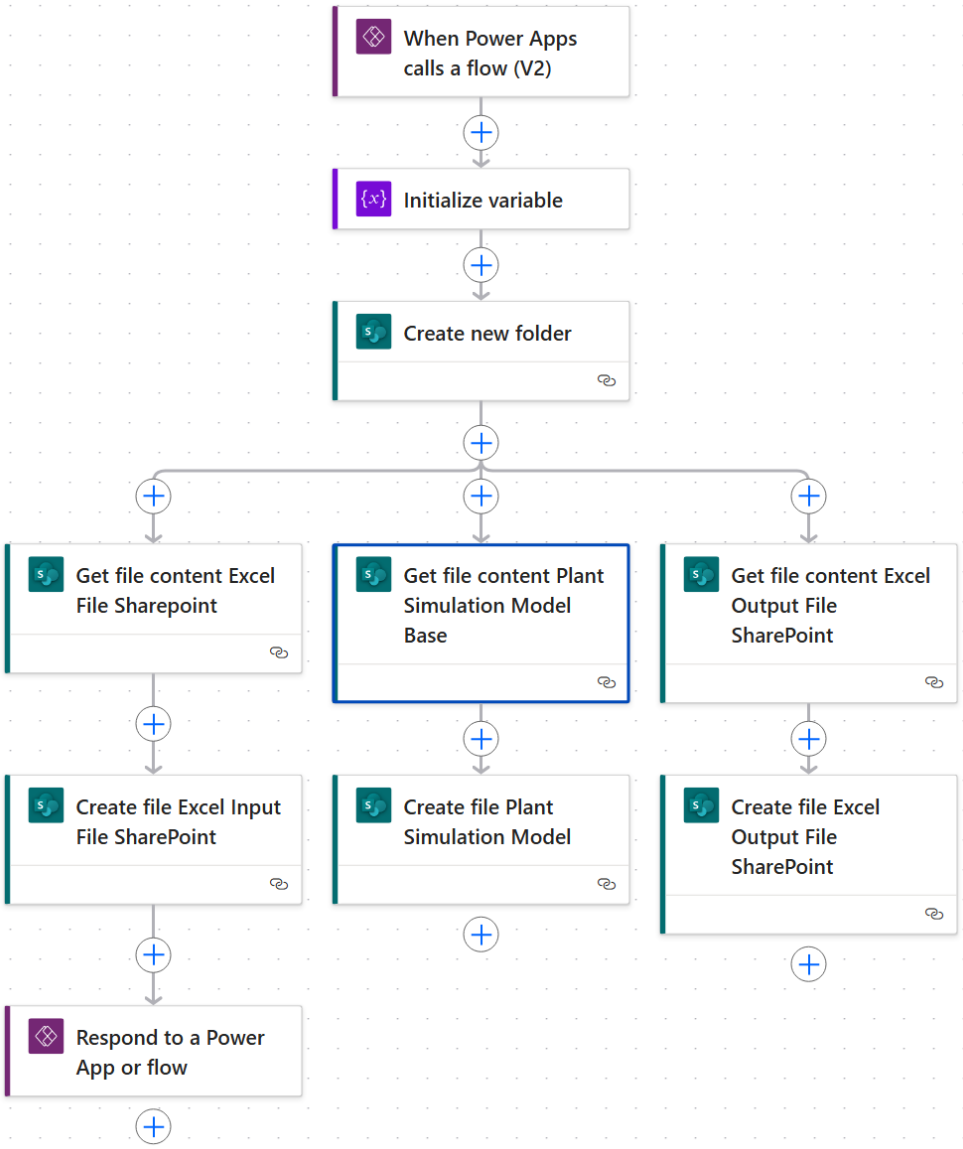


Figure 4.6: Power Automate Flow for Creating Excel and Plant Simulation Files

The second, third, and fourth interface of the Power Apps are where the user inserts machine and station input data. Depending on what was selected on the first screen, the user pages are visible in the order, inner rings line, outer rings line, and then assembly line. If a line is not checked on the first screen, the page is not shown to the user. The same structure and likewise content is present for all of the production line input screens.

The second interface page is shown in Figure 4.7. The user is then asked to add a station, buffer, or NDT station (in this case NDT has been selected to include on the first screen). When adding a station, the user is first asked to define what type the machine it is, which is selected from a drop-down list. The drop-down list of available machines and stations was based on the insights from the quantitative study. The list of available machines dynamically changes depending on the selected

line combination. Additionally, the station that is added has to be given a name, processing time, availability rate, mean time to repair (MTTR), scrap rate, and capacity of the station. When adding a buffer or an NDT station to the line, only the name and capacity will be asked to define, as the rest will be set to zero by default, since the rest of the data is irrelevant to them.

When one of the stations is added to the table seen on the right side of the screen in Figure 4.7, the Power Automate flow "Add Row" is triggered manually. The logic of this flow is presented in Figure 4.8. The inputs that are sent to the flow when triggering it are; the name of the SharePoint folder of where the previously created Excel file has been created, in which line the station is added to (inner ring line in Figure 4.8), as well as all the input data added to the table when the button gets pressed. For pressing the buttons "Add buffer", "Add NDT", and "Remove previous station or buffer", there are individual Power Automate flows with similar logic to the flow for adding stations. By structuring it like this, the information provided by the user is shown on the screen they are working in, and at the same time, to the designated production line Excel file.

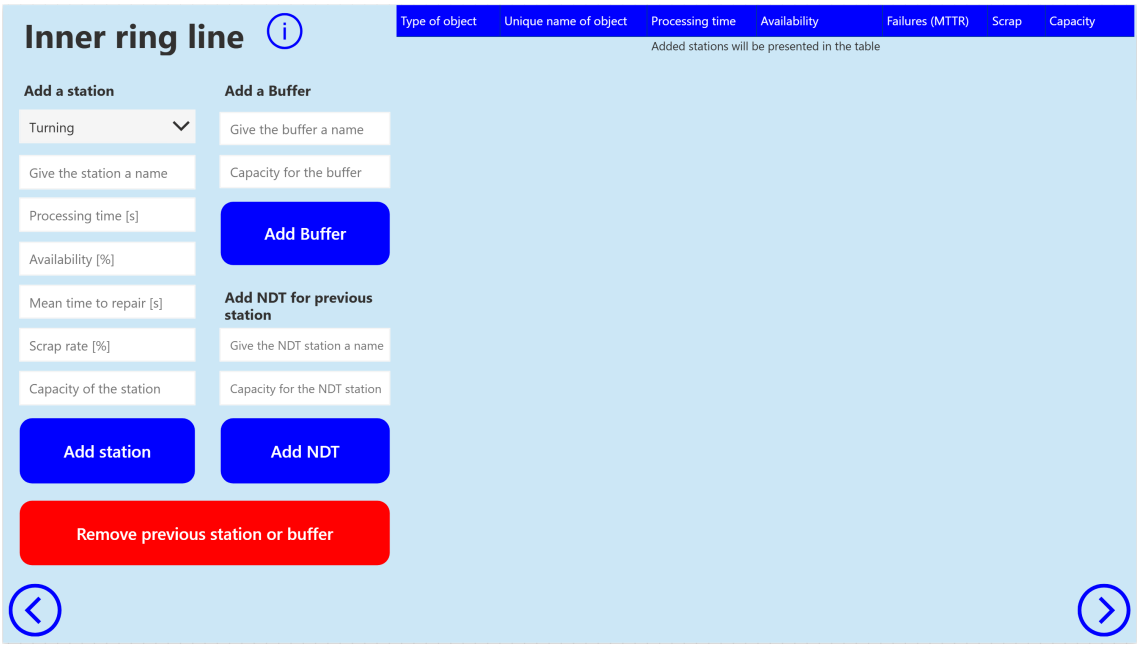


Figure 4.7: UI for Power Apps Inner Ring Line Screen

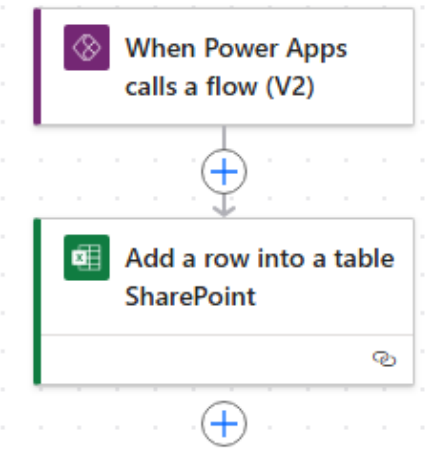


Figure 4.8: Power Automate Flow for Adding a Row to a Table in Excel

The fifth page of the application is for defining the bearings and their batch sizes. It has a very similar logic and structure as the previous three pages, but with individual Power Automate flows for adding and removing bearings to a designated table in the Excel file. As for the last two pages of the Power application, they have a bit different structure than the ones before, the page for inserting Setup time for the machines is shown in Figure 4.9, and a similar structure is used for the processing time input screen. The Figure 4.9 is provided with a set of example machines, as can be seen on the left side of the screen. The left side list on the screen acts as a selector panel, and when a station is pressed, the text input boxes on the right side change dynamically to show the setup times for the selected machine. The input text boxes on the right side of the screen display all the required setup times that the user needs to enter. Once a setup time is provided in the correct format, it is marked with a check to indicate a successful validation.

In the example presented in the figure, the specified bearings have been assigned to a material family. Each machine has specific setup times for switching between bearings of the same or different material families. This approach avoids requiring the user to define setup times for every bearing-to-bearing transition for each machine, as this would result in an unmanageable amount of data entry.

The reason for making the last two pages of the Power Apps different to the previous ones, was that both the number of stations added to the simulation as well as the different bearings that are to be manufactured, are two data entry's that are dynamic and allow the user to add without limitation. As the number of stations and bearings, especially different material family types, increases in the approach shown in Figure 4.9, the lists on both the left and right sides of the screen become longer. However, thanks to the scrolling function, the interface can handle lists of any length without affecting usability. This ensures the application remains flexible and user-friendly, even as complexity grows.

Figure 4.9: UI for Power Apps Setup Time Screen

4.4.2 Simulation model

To ensure the simulation model is user-friendly for individuals without a background in simulation, it includes clear, step-by-step instructions in the Plant Simulation program. The first three steps are visualized in Figure 4.10

Step 1: The user begins by importing an Excel file. When the "Import Data" button is clicked, a text box appears, guiding the user to select the Excel file that contains the production line input data. Once the file is selected, the production layout with configured parameters is automatically generated.

Step 2: Although the layout is autogenerated, users have the option to customize it. By dragging and dropping machines into the desired positions, the user can modify the layout to better suit specific needs.

Step 3: To run the simulation, the user simply clicks the "Start/Stop Simulation" button. This button also allows the user to pause the material flow at any point. If needed, the "Reset Simulation" button can be used to reset the material flow while preserving the current layout configuration. The run-time variable demonstrates the time it takes to produce the defined batches.

Figure 4.10: Step-by-step Instructions for Simulation Model: Step 1, 2 and 3

Step 4: Step 4 involves the simulation evaluation phase, where users can specify the number of iterations for the experiment. By clicking on the output icons, users can choose whether to include specific outputs in the evaluation. If an icon is green, that output is included in the evaluation. The available outputs include Net output, throughput volume, and production lead time. Then a report of the chosen outputs is created in Plant Simulation.

Step 5: The last step is the choice to send the evaluation result evaluation to an Excel file. The report created in Plant simulation can be downloaded as a HTML-file, but to stay consistent the user can send the outputs to Excel. By pushing the button "Send Output", the outputs are generated to the created Excel output file that is stored in the same folder as the simulation model and input file. Steps 4 and 5 are demonstrated in Figure 4.11.

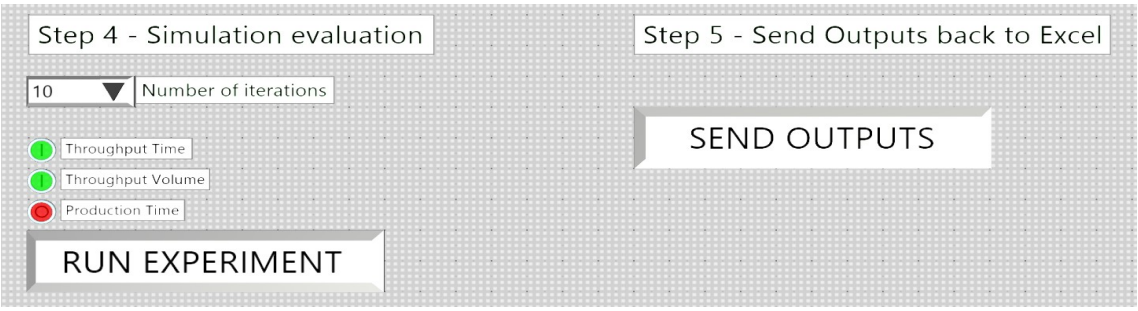


Figure 4.11: Step-by-step Instructions for Simulation Model: Step 4 and 5

The simulation inputs and configuration are based on findings from the qualitative and quantitative study. The simulation model includes two modes of input. The first mode is based on the product name and batch size. All inputs for this mode are summarized in the table 4.2.

Table 4.2: Input Parameters for the Simulation Model

Category	**Parameters**	**Details**
Product Data	• Product type • Batch size • Material family	• Affects setup time, processing time, and sequencing.
Machine Data	• Machine type • Processing time • Set-up time • Scrap rate per machine • Machine availability • Machine capacity • Failure duration	• Defined processing type and name • Varies by product type and machine [s] • Varies by product data and machine [s] • Per machine [%] • Per machine [%] • Per machine [Parts] • Mean time to repair [s]
Production Strategy	• Sequential batch processing	• Standard approach across factories
Buffers	• Buffer capacity between machines	• Buffers working as flex link conveyors

The product data category includes the product type to be produced, the batch size (number of units per product type), and the material family to which the product belongs. The system checks the product name and material family when a new batch reaches the machines. The setup can be adjusted based on whether the previous product belonged to the same material family or not.

The machine type specifies the processing type and a unique machine name. Processing time is configured based on both the machine name and product name. Scrap rate, machine availability, capacity, and Mean Time to Repair (MTTR) are defined per machine and remain consistent across all batches. The production strategy follows a sequential batch processing approach, producing one batch of a specific product type at a time. When all batches are produced, the simulation stops.

In the second, simpler mode, the model simulates an unspecified product. This mode allows for the input of only a few parameters: machine type, processing time, scrap rate, availability, capacity, and MTTR. These parameters remain constant throughout the entire simulation. The simulation continues indefinitely until the user decides to stop it.

As shown in Figure 4.11, the available outputs in the generic simulation model are Net Output, Production Lead Time, and Throughput Time. However, due to time

constraints, not all outputs identified in the qualitative study were implemented in the simulation model.

4.5 Verification of Results

The model was tested for every Production Line layout combination, together with a randomly selected set of input parameters. The simulation was also tested for both the mode where bearing names and bearing batch sizes was defined and the mode when no bearings was defined. By doing this, it was possible to confirm the interoperability and functionality between the developed interface and the simulation model. The interface input-simulation model combinations were continuously tested and verified, and the results are presented in Table 4.3.

Table 4.3: Verification of Interface and Simulation Model Interoperability

Production Line / Simulation Functionality	Import File	Start, Stop and Reset Simulation	Simulate and Receive Outputs Report
Inner Rings, Outer Rings and Assembly line	OK	OK	OK
Inner Rings and Outer Rings	OK	OK	OK
Inner Rings and Assembly line	OK	OK	OK
Outer Rings and Assembly line	OK	OK	OK
Inner Rings	OK	OK	OK
Outer Rings	OK	OK	OK
Without Specified Bearings	OK	OK	OK
With Specified Bearings	OK	OK	OK

4.6 Enhancing Information Circularity with the use of DES

While the literature provides substantial insights into information circularity within the circular economy, a gap remains regarding how information can be shared and

stored circularly within an organization to support knowledge and information sharing. In this thesis, circular information is defined as information that can be gathered from one part of the organization and reused for another purpose in a different part of the organization. This concept is illustrated in connection with discrete event simulation in Figure 4.12.

When a production line requires simulation, its representatives can easily enter the necessary input parameters into the interface, generate the model, and receive the outputs. These outputs can then be used to evaluate and analyze the production line, serving as a foundation for decision-making and future investments. All input, simulation, and output files are stored in SharePoint, making them accessible to everyone in the organization. This information can be used for internal benchmarking and performance comparisons. For example, if another production line seeks improvement, it can access the database, perform internal benchmarking, and create its own simulation model to test various scenarios and compare results. Through this circular flow of information, the organization builds a comprehensive database containing valuable insights across different production lines.

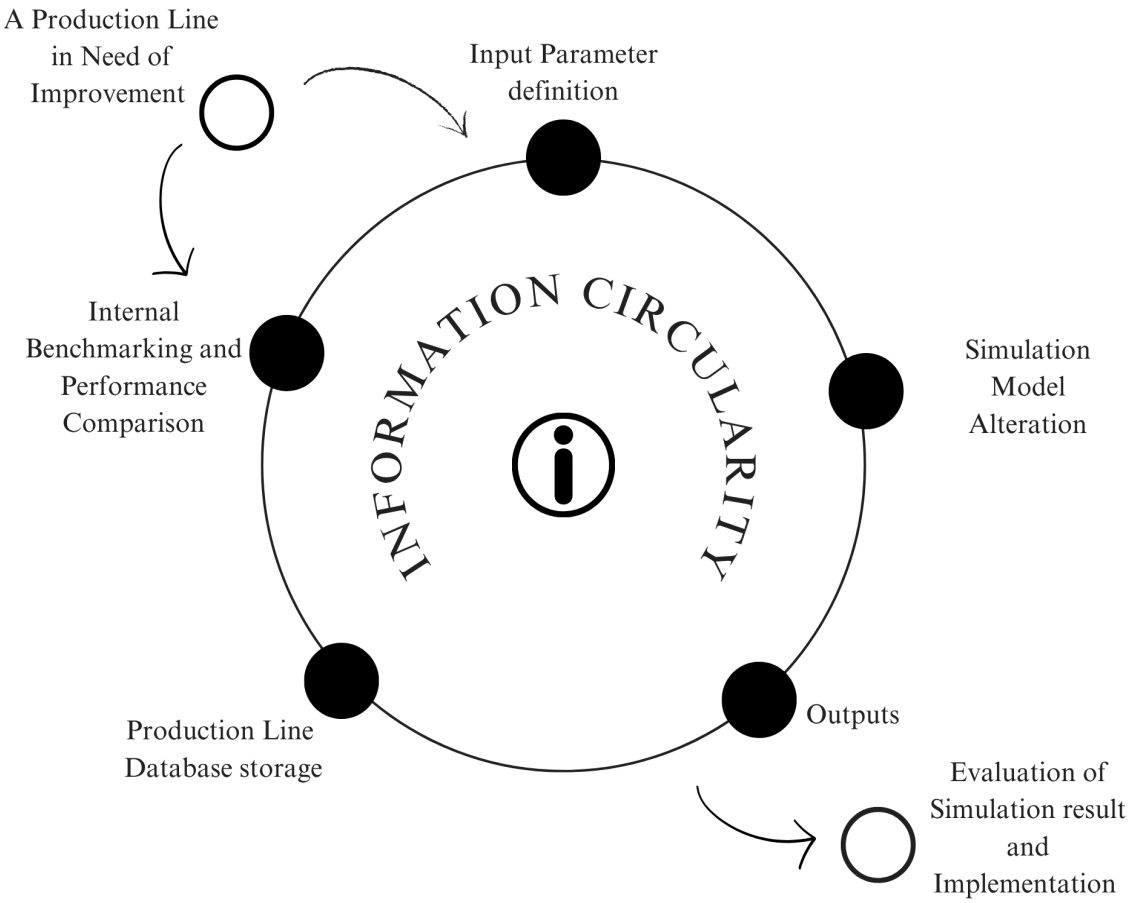


Figure 4.12: Enhancing Information Circularity with DES

5
Discussion

This chapter presents the results and contributions of this thesis, highlighting key findings and their implications. It also addresses the study's limitations and offers recommendations for future research.

5.1 Answering RQ1

Findings from both the literature and interviews show that DES can support data and information sharing by providing a common platform for internal benchmarking, decision-making, and improved communication across roles and sites. While the literature focused on general benefits of DES, the interviews additionally emphasized the value of sharing simulation models and results within the organization, an advantage not mentioned in the reviewed publications.

By modeling real-world randomness and time-based events, DES enables a deeper understanding of production systems [12]. These capabilities can be leveraged to standardize and share operational knowledge across sites by developing simulation models of internal benchmarking production lines that visually and interactively represent optimal operations. Interviews revealed an internal improvement potential in standardization and structure in documenting and sharing best practices. Storing these models in a shared environment makes them more accessible and tangible for everyone in the organization, streamlining the process by enabling the reuse of existing operational solutions rather than recreating them. The stored models include information about the production layout, machine parameters, and input/output configurations for the given setup. This also enhances the transferability of expert knowledge across locations.

The use of simulation models, particularly when integrated with sensor data, promotes transparency in reported performance metrics. With simulation-driven insights, factories can benchmark against verifiable digital models, fostering a trustworthy and unified approach to performance assessment.

As simulation models are generated based on user-defined input data, the need for recurring meetings and traveling may decrease. By leveraging a structure where production line representatives are incentivized to define and share production parameters to receive a DES model with value-adding outputs, the overall efficiency of production-related knowledge sharing can be improved, while also promoting greater

engagement from those closest to the production context. Using a SharePoint site page helps eliminate the unnecessary need for meetings and travel by enabling efficient and structured cloud-based collaboration across teams and departments [45]. The integration of Power Automate flows further enhances operational efficiency within SharePoint by automating routine tasks and triggering actions in response to user inputs or system events. This automation not only optimizes workflows, but also improves responsiveness and reduces the need for time-consuming, routine-based meetings where important information may otherwise be overlooked [44].

The literature states that Power Apps empowers knowledge managers to adopt a more strategic role in leveraging organizational information as a key asset and contributing to innovation [46]. Combining DES, Power App, and SharePoint enables efficient data and knowledge sharing of bearing production parameters, along with a visualized model for deeper understanding and analysis of the system.

5.2 Answering RQ2

The lack of a standardized document for production data was highlighted during interviews, where stakeholders indicated a need for more consistent data storage and information management practices. Rather than adapting the simulation model to each factory's unique data structure, the project team developed a user-friendly input interface in Power Apps that guides users in entering data systematically. This interface serves as a tool for generating Excel files in a standardized format, ensuring compatibility with both the DES model and other Microsoft services. Power App's intuitive interface simplifies data entry for end users, while SharePoint provides a centralized repository for storing input data and simulation outputs, along with the simulation model file. This configuration not only addresses the data standardization issue but also supports ongoing model circularity by making historical data accessible for future simulations.

5.2.1 Configuration for the Generic Simulation model

The configuration for the generic simulation model was based on the interview with the simulation expert. For the machines, Processing Time was used as an input instead of Cycle Time, since SKF's internal definition of Cycle Time is more similar to what in the Plant Simulation program is called Processing Time. Since it was decided to limit the simulation model to low-mix, high-value production environments, the larger bearings with higher variation in processing times were not considered.

To allow for multiple parts handling machines, all processes in the simulation are parallel stations since ordinary stations can only handle one part at a time.

To cover the conveyor link system used by several production lines, buffers were decided to work as the conveyor link in the simulation. The design is of course different, but the function is the same. It was decided to have buffers instead since it would be to detailed to import all layout data and the exact distance between

machines. Now, depending on which size of the bearing produced, the user can estimate how many parts should be located in the conveyor link and write that number as the buffer capacity instead. Since it only considers low-mix production lines, the buffer sizes are fixed for all lot sizes and can not be changed depending on product type.

Based on the simulation experts emphasis, two modes for simulating were created. This dual-mode functionality would increase usability and flexibility, making the model suitable for both exploratory use and more data-driven simulations.

Experiment manager, which is a tool that enables users to systematically run multiple simulation scenarios, was used for generating output values, since the literature review stated how important it is to run a simulation several times to account for the probability distributions and involved randomness.

5.3 Answering RQ3

Both the theoretical background and the interviews discussed the transition from mass production to mass customization, highlighting the need for flexible production [5]. For SKF to maintain competitiveness, they continuously needs to adapt to this transition by implementing advanced manufacturing technologies and decision-making tools to navigate the dynamic market demands. The interviews shared insights about the vision of having simulation as a requirement before investments or new production projects, but also discussed the challenges related to the company's size, the simulation knowledge background, and resource limitations.

The literature review also provided some challenges and limitations of using and implementing DES. The most identified challenge was the model-building procedure, since building an accurate model requires substantial training and experience [2, 31, 33], and a plug-and-play simulation was highlighted to allow the user to focus on decision-making rather than the complexity of building the model [17]. The literature also stated that collection, validation and analysis of inputs consumes over a third of a simulation project timeline [25, 33], and the interviews confirmed that the demanding time and resources it takes for the factories to develop simulation models are a constraint.

The generic model allows the user to focus on decision-making, testing, and analyzing without requiring simulation knowledge background. By providing a reusable model foundation, users no longer need to build simulations from scratch. Instead, existing models can be quickly adapted with minimal effort, allowing production sites to input their local process data and parameters through a simplified interface. When combined with intuitive user interfaces or simplified model views, even non-expert users can interact with the model, explore scenarios, and gain insights without needing to understand the full underlying complexity. This modular and reusable approach means that fewer resources are needed for model development and validation, which is particularly valuable in organizations where simulation competence is

still being developed. As noted by interviewees, lowering the resource burden also helps reduce resistance from factories that might otherwise be reluctant to invest in model development. Furthermore, the interviews discussed how simulation serves as a form of "insurance," allowing teams to validate assumptions before implementation. When simulations can be set up quickly and run reliably using standard input formats, they become practical tools for day-to-day decision support.

Another highlighted obstacle in the literature review was the incomplete and often conflicting knowledge of the production system to develop an accurate model [17]. By reducing the need for simulation background knowledge, the generic model can be used by an operator or production manager with good knowledge about the production system and be developed in close interaction with the real system.

Additionally, the use of unambiguous input parameters minimizes common data-related challenges. The quantitative study shared the determined frequency of the stations for each of the production lines, which gave the order in which the stations should be presented in the GUI, to minimize confusion and time. The literature highlights how simulation accuracy depends heavily on the quality and consistency of input data [17, 24], and how data collection is often fragmented and time-consuming [24]. Interviewees echoed this, stressing the need for standardized data formats that can be directly imported into models. When input parameters are clearly defined and consistently structured, it not only reduces input errors and model inconsistencies but also facilitates faster setup times and more reliable simulation outcomes.

5.4 Contribution of the Thesis

The thesis work has provided a contribution both towards SKF and the industry, but also more from an academical and scientific perspective. The contributions are differentiated and presented in this section.

5.4.1 Scientific Contributions

The scientific contributions of this thesis primarily relate to the utilization of generic DES models, particularly within large organizations, the implementation of plug-and-play simulation approaches, and the demonstrated benefits of using user-friendly, accessible interfaces to improve knowledge sharing and reduce human-related data input errors.

While generic DES models are frequently discussed as a means to enhance production efficiency, the integration of systems that allow users to easily develop such models with varying input data for changing production layouts is less common in DES software. These systems, which do not require extensive simulation expertise, are still relatively rare in the field. As shown in the results chapter (4.1), utilizing an intuitive interface external to the simulation software allows different production sites and lines within the same organization to easily generate DES models when the production setups manufacture similar products. The results demonstrated that a

robust foundation for structuring input parameters is essential, as even minor errors can significantly impact the simulation. For Tecnomatix Plant Simulation, which utilizes the advanced programming language SimTalk, ideal for object-oriented programming, and allows for the extraction of table data from Microsoft Excel, it is possible to create a solid foundation for unambiguous data definition. This is achieved by leveraging some of the low-code tools integrated in Microsoft 365, such as Power Apps, Power Automate, and SharePoint.

As Collins et al. [16] discusses, for an organization to advance in the use of simulation, they should consider incorporating plug-and-play simulation environments, allowing users to focus more on decision-making and tasks unrelated to the simulation development itself. Based on these suggestions, utilizing software that can collaborate interoperably with each other, even if they are not on the same platform, is a great alternative when developing a company-specific plug-and-play simulation. As presented in the results chapter (4.3 - 4.4), when faced with a problem similar to the one of SKF for quick bearing simulation without prior simulation experience, incorporating a combination of Microsoft 365 tools, such as those in the Power Platform, together with a DES software like Tecnomatix Plant Simulation, which utilizes data tables, programming, and works seamlessly with Microsoft for importing and extracting data, should be considered.

Lastly, this thesis argues that user-friendly interfaces are an effective method for improving knowledge and information sharing, making it more circular, and reducing human-related data input errors and mistakes. The claim that user-friendly UIs reduce system errors is repeatedly supported in the literature. For instance, [32] discusses comprehensible UIs as a more general need for effective DES performance. Similarly, both [27] and [36] highlight that proper UI design can reduce user errors. In the SKF case, the use of software to design user-specific interfaces for data input enables the development of clear and unambiguous UIs, thereby eliminating the possibility of data input errors. In the meantime, the developed UI for the SKF bearing simulation not only ensures seamless data input and quick simulation creation but also facilitates knowledge and information sharing. The defined input data is automatically stored in a cloud system, allowing other users to access it and run the simulation and comparing it with their own. This capability enables organizational benchmarking. Users can define input data, run the simulation, and validate whether or not the results are satisfactory, and if not, they can modify the input data to achieve better performance. This iterative workflow exemplifies efficient simulation circularity, allowing users to continuously refine and improve their simulations based on real-world comparison and desired outcomes.

5.4.2 Industrial Contributions

This thesis offers several industrial contributions to SKF. Although SKF is the primary focus, the insights and findings are also relevant and potentially valuable to other global manufacturing companies. One of the main contributions is the establishment of a framework for information circularity, which helps organizations

reduce duplicated efforts, improves the quality of decision making, and promotes transparency and cross-factory collaboration. Additionally, it supports continuous internal improvement across the organization.

The developed concept and the generic model support information circularity by providing a standardized framework for developing and storing simulation models, along with their input and output parameter files. The user-friendly interface of the generic model significantly reduces the lead time for creating simulation models, since people with a strong knowledge of the production system can use the model without requiring extensive simulation expertise. If further customization is needed, the internal simulation team can support the process without starting from scratch—streamlining development and minimizing resource consumption. This approach reduces the need for frequent meetings, travel, and cross-departmental communication to gather input data, thereby minimizing miscommunications and accelerating the modeling process. Furthermore, reducing unnecessary travel and resource usage contributes positively to SKF's sustainability goals. The model also supports SKF's broader objective of increasing the use of simulation across the organization.

By integrating data sharing and visual simulation representations, the model also supports the internal production line benchmarking project and reduces the need for physical site visits. Furthermore, production line representatives receive valuable simulation outputs that provide actionable insights while simultaneously contributing data that fosters greater knowledge and information sharing across the company. Lastly, the template-driven approach to data input can serve as a stepping stone toward more standardized data structures across SKF's production sites, facilitating long-term data harmonization efforts.

When using a SharePoint site as a knowledge base for creating, storing, and sharing data, such as the one described in the results chapter, certain guidelines were identified to ensure it functions effectively. When using automation flows to generate files in a SharePoint folder, like the one in Figure 4.6, it shows beneficial to dynamically name files based either on inputs specified by the user or user-related naming. This approach facilitates simple file identification among multiple files created by various users. Additionally, restricting users' ability to delete and move files within SharePoint is critical for efficient file management, particularly when files are intended to be automatically generated from predefined structures. This also enables a robust and standardized method for information sharing, ensuring that data and information are not lost due to the movement or deletion of files. Storing simulation input and output files in a well-structured manner supports efficient benchmarking of production line performance, both between different line representatives and between line representatives and simulation experts. This practice helps to reduce the time spent on the tedious task of repeatedly defining and redefining production input values, particularly for the company's simulation experts.

5.5 Limitations and Future Recommendations

The thesis work has been limited to some extent, in this subchapter, the limitations and future recommendations will be discussed. Whether or not the future recommendations are considered to contribute to future research or towards industry will no be specified.

One limitation of the simulation was that it only considered bearings produced in high-volume and low-variation, the simulation expert at SKF described in the qualitative study. To also simulate low-volume and high-variation, the already developed generic model needs to be revised and evaluated to see if this could be added to its current structure. To consider this case, a new quantitative study to identify the machines in these production lines would be recommended.

Some other general future recommendations for the simulation development can be to add workers and AGVs, as this can be relevant for many of the SKF productions. The input structure and simulation is limited to having parallel inner and outer lines, and not for cases where the two are sharing some of the stations. This could be considered for the future, but as of the quantitative study, no production line where this occurred was identified.

SKF is currently working on having a machine catalog within Plant Simulation, where machine graphics in the form of STP files will be used, as well as defined machine performance data. If this machine catalog were to be done, it would become highly relevant to incorporate it in the simulation model as well a list presented within the Power Apps interface when selecting machines and stations, so that the user can select already existing SKF machines for comparison and to perform analyses of machine integration and investments.

The focus of the model creation has been on making a robust structure for data definition, input data structure, and model creation based on the defined data. A foundational framework for generating outputs within the simulation model was also developed. However, the output evaluation was limited to the KPIs: "Throughput Time", "Net Output", and "Production Lead Time". These KPIs were addressed because they were identified in the qualitative study as some of the most important performance indicators. However, some KPI measures that were evaluated as important but still not included in the simulation were, see 4. These outputs can be included in the simulation model in future work. KPIs such as cost savings and scrap reduction were identified in the interviews as desired outputs. However, since determining these metrics requires a comparison between two simulations, they couldn't be included in the model. The simulation only provides insights based on one set of input parameters per evaluation. An additional future recommendation for output handling is to integrate data visualization and analysis tools, such as Power BI from the Power Platform, after exporting the results to the Outputs Excel file. This would enable visual presentation of production line performance directly within the SharePoint site, allowing for rapid evaluation and comparison of different production lines.

While the current simulation model enables the user to simulate two modes, with or without a production plan of specific product batches, there is still no option to define a time schedule. As the simulation will be used partly for evaluating how much time will be spent on producing the specified batches, for the case without product batches, there is currently no sufficient structure for extracting valuable output KPIs. By incorporating a system that creates a production plan based on a time schedule rather than product batches, users will be able to extract KPI data (such as "Net Output") relevant for planning future productions.

An additional future recommendation will be to perform a comprehensive evaluation study of the usability and performance of the simulation model. What should be included and evaluated in such a study is the usability of the UI, whether or not it is intuitive to an arbitrary worker at SKF, and whether the generic structure of the model works for every production line at SKF for bearing manufacturing.

5.6 Future Trends in DES for Manufacturing

The increasing demand for flexible manufacturing, highlighted both in the literature and in interviews, and complex products requires the integration of advanced technologies alongside simulation [26]. Two key concepts shaping modern manufacturing are Industry 4.0 and Smart Manufacturing. Industry 4.0 encompasses the broader transformation of industries through the integration of digital and physical technologies, while Smart Manufacturing leverages tools such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and robotics to create an efficient, interconnected manufacturing environment [25]. For SKF, aligning with these trends is essential to maintaining its competitive edge.

The rapid advancements in cloud computing, big data, IoT, and AI have significantly impacted manufacturing, driving the evolution of Smart Manufacturing systems. Integrating DES with IoT platforms enables the combination of simulated and real-time data, allowing for a more comprehensive analysis of manufacturing processes[25]. IoT platforms facilitate real-time data collection, which can be directly incorporated into DES models to enhance their accuracy and relevance. By incorporating real-time data from production systems, SKF's simulation models could evolve from a static tool to a dynamic decision-making asset, enhancing predictive capabilities and supporting ongoing optimization efforts [25].

The integration of AI and data analytics further strengthens the interaction between DES and IoT. Machine learning algorithms can process both real-time and simulated data, continuously updating parameters to improve the accuracy of DES models. AI-driven analytics assist in validating and calibrating simulation parameters, thereby increasing the reliability of simulation results [25]. Moreover, AI enhances decision-making by analyzing DES-generated insights to optimize manufacturing operations and predict potential disruptions. This integration fosters the development of self-learning systems that refine their performance over time based

on historical and real-time data [25].

Recent research has also focused on integrating extended reality, Virtual Reality (VR) and Augmented Reality (AR), with DES to enhance production simulation tools. VR and AR offer immersive visualization platforms for DES, allowing users to interact with simulation models through headsets and GUIs. This integration provides a dynamic way to test complex datasets, interact with real objects, and improve communication efficiency [25]. These technologies can display simulation results, optimizations, and digital twins (DT) in real-time, enabling user interaction with digital systems [25]. AR has proven valuable in industrial applications such as maintenance, assembly, training, quality control, and monitoring, though its role as a GUI for DTs is still evolving [26].

DT technology is another key building block in Smart Manufacturing and Industry 4.0. A DT is a virtual representation of a physical system, driven by real-time data [30]. While SKF's current simulation models focuses on predefined scenarios, integrating DT capabilities could transform it into a real-time monitoring and decision-making tool. This would enable the company to simulate "what-if" scenarios and assess "what-now" situations simultaneously, aligning its operations with best practices in digital manufacturing.

Overall, DES serves as a critical tool for navigating the transition to Industry 4.0, positioning SKF to stay at the forefront of industry advancements and maintain its competitive edge. To fully leverage these advancements, it is important for SKF to continue spreading simulation globally and to further develop its simulation strategy, ensuring consistent application and alignment with emerging digital manufacturing practices.

6
Conclusion

This thesis has demonstrated how a generic and user-friendly DES model can serve as a strategic enabler of information circularity, while supporting knowledge sharing, internal benchmarking, and continuous improvement within a global manufacturing organization. By integrating Tecnomatix Plant Simulation with Microsoft Power Platform tools, a simulation framework was developed that allows users, without simulation experience, to define production scenarios through a guided interface, significantly lowering the threshold for simulation usage.

Through qualitative interviews and quantitative analysis of production lines at SKF, essential requirements for simulation model inputs, outputs, and usability were identified. The results confirmed that using unambiguous and standardized input parameters improves the accuracy, efficiency, and usability of simulation models. Furthermore, providing a simplified interface for data input and model generation allows users to independently explore production changes, test improvement initiatives, and evaluate production investments, without the need of simulation experience.

The concept developed in this thesis supports SKF's long-term ambition to make simulation an integrated part of daily operations and development projects. It provides a scalable and replicable approach to enhancing information circularity between factories, enabling efficient sharing of digital assets and reducing knowledge silos. While the implementation was limited to a proof-of-concept stage using fictitious cases, the underlying structure provides a solid foundation for future industrial integration and expansion.

Going forward, improving model flexibility for high-mix environments, integrating real-time data, and incorporating human factors such as operator interaction are recommended areas for development. By continuing to lower the technical barriers to simulation and embedding it into organizational routines, companies can unlock significant value in decision-making, training, and operational optimization.

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