Effective Digitization in Brownfield Factories
A conceptualized model for technology transfer to brownfield production factories through smart factory lab

HARSHAVARDHAN GAJANAN NAIK

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Harshavardhan Gajanan Naik

Academic Supervisor: Gunilla Franzén Sivard
Industry Supervisor: Dennis Sjölin
Abstract

The exploration of Smart Factories and Industry 4.0 technologies has indeed sparked curiosity and interest in the industrial world. The potential of these advancements to revolutionize manufacturing processes, enhance efficiency, and drive innovation is immense. However, there is a gap in research when it comes to the practical implementation of these advanced technologies in real-world production settings, especially in already established factories so called Brownfield Factories.

This thesis work was conducted within one such brownfield factory to comprehend the tangible challenges associated with transferring smart technologies. Within this specific company, a laboratory had already been established for testing novel smart technologies in the context of production and logistics. The aim in companies is to test smart technologies in a controlled environment without causing any disruption to the ongoing profit-generating production processes. This laboratory setup also serves the additional purpose of educating the personnel within traditional production facilities about the upcoming smart technologies in the market. The Lab showcases the potential of new and emerging technologies in addressing long-standing issues with a fresh perspective, thereby inspiring innovation. The central approach of this thesis revolves around the establishment of a standardized laboratory work process through which smart technology can be tested in a structured way.

In this context, an illustrative example of a technology, namely “Virtual Training for Assembly Operators,” was chosen as a case study to explore and comprehend the challenges associated with technology transfer. This case study also played a pivotal role in assessing the credibility of the standard technology transfer model formulated within the company. Notably, it was deduced that knowledge and competence are two key obstacles impeding the smooth transfer of technology. Building upon the insights garnered from the case study on virtual training technology and drawing from interviews with engineers and managers employed at the case company, a refined technology transfer process named the “Smart Factory Lab Process” was developed. This process aims to enable the effective transfer of smart technologies, informed by the lessons learned from the practical application of technology in real-world scenarios.

Keywords: Digitalization, Industry 4.0, Technology Transfer, Virtual Training, Brownfield Factories, Process
Sammanfattning

Utvecklingen inom smarta fabriker och Industri 4.0-teknik har väckt nyfikenhet och stort intresse i den industriella världen. Potentialen för denna teknik att revolutionera tillverkningsprocesser, förbättra effektiviteten och driva innovation är enorm. Det finns dock en lucka i forskningen när det gäller den praktiska implementeringen av dessa avancerade tekniker i verkliga produktionsmiljöer, särskilt i redan etablerade fabriker, så kallade Brownfield Factories.


I detta sammanhang valdes ett illustrativt exempel på en teknik, nämligen ”Virtual Training for Assembly Operators”, som en fallstudie för att utforska och förstå de utmaningar som är förknippade med tekniköverföring. Denna fallstudie spelade också en avgörande roll för att bedöma trovärdigheten hos den standardmodell för tekniköverföring som formulerats inom företaget. Framför allt drogs slutsatsen att kunskap och kompetens är två viktiga hinder för en smidig tekniköverföring. Med utgångspunkt i insikterna från fallstudien om virtuell utbildningsteknik och omfattande intervjuer med ingenjörer och chefer som var anställda på fallföretaget, utvecklades en förfinad tekniköverföringsprocess som kallas ”Smart Factory Lab Process” minutiöst. Denna process syftar till att möjliggöra en effektiv överföring av smart teknik, med utgångspunkt i de lärdomar som dragits från den praktiska tillämpningen av teknik i verkliga scenarier.
Foreword

This thesis was conducted as part of Masters Program - Production Engineering and Management at KTH Royal Institute of Technology. It was performed at automotive manufacturing company based in Sweden.

I would like to thank Engineering manager at the case company, Mr Dennis Sjölin for giving us this opportunity and also supervising during my thesis tenure. Further I would also like to thank Franz A Waker, Jim Tolman, Lars Hansson and the entire team of Smart Factory Lab at case company to support me with all the tools and knowledge required to accomplish my thesis.

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# Contents

1 Introduction  
1.1 Background .......................... 1  
1.2 Problem Formulation .................. 2  
1.3 Purpose ............................. 2  
1.4 Methodology .......................... 3  
1.5 Scope and Delimitation ................. 5  

2 Frame of Reference  
2.1 Defining Smart Factory ................. 6  
2.1.1 Brownfield and Greenfield Factories .......... 7  
2.1.2 Internet of Things (IoT) .................. 8  
2.1.3 Industry 4.0 ....................... 9  
2.2 Technology Transfer/Tech Implementation .... 11  
2.2.1 Definition of Technology Transfer .......... 11  
2.2.2 Problems associated with Technology Transfer .. 11  
2.2.3 Technology Transfer Models (TT) .......... 12  
2.3 Test Beds .......................... 14  
2.4 Produktion 2030 ........................ 15  
2.5 Technology Push and Market Pull ......... 15  
2.6 Collaboration between Two Departments in a company 16  
2.7 Pilot ............................. 16  
2.8 Virtual Training ........................ 17  

3 Methodology .......................... 18  
3.1 Type of data .......................... 18  
3.1.1 Primary data ....................... 18  
3.1.2 Secondary data ...................... 18  
3.2 Research approach ..................... 18  
3.2.1 Qualitative approach ................. 18  
3.2.2 Quantitative approach ............... 19  
3.3 Semi structured Interviews .............. 19  
3.4 Scientific approach .................... 20  

4 Mapping the Current Status ............... 21  
4.1 Final Assembly Plant MS ............... 21  
4.2 Defining Smart Factory Lab (SFL) .......... 24  
4.2.1 Smart Factory Lab Vision and Mission .... 25  
4.2.2 Current functioning of the lab ............ 26  
4.3 Initiating Smart Factory Lab Process ....... 28  

5 Case Study .......................... 31  
5.1 Idea Management ....................... 32  
5.1.1 Decision Point -2 (DP-2) ............... 33  
5.2 Sprint Planning ....................... 34  
5.2.1 Decision Point -1 (DP-1) ............... 36  
5.3 Prestudy .......................... 37
5.3.1 Study the current operator training process ........................................... 37
5.3.2 Evaluation of different Virtual training technologies ................................. 40
5.3.3 Design of experiment and conducting Subjective Evaluation ..................... 41
  5.3.3.1 The process of creating training material (content) and preparing the tools
  for the evaluation involved several key steps: ........................................... 41
  5.3.3.2 Design for the Evaluation .............................................................. 41
  5.3.3.3 The questionnaire prepared for the test: ......................................... 42
  5.3.3.4 Evaluation Results and analysis .................................................... 43
5.3.4 Analysis of the Prestudy ........................................................................ 49
  5.3.4.1 Vizendo (Virtual/Desktop) Training: .............................................. 49
  5.3.4.2 VR (Virtual reality) Training: ......................................................... 50
  5.3.4.3 Delimitations in the Case Study: .................................................... 50
5.3.5 Decision Point 0 (DP 0) ................................................................. 50
5.4 SPS, the process to implement the technology in production after the Pre-study .... 51

6 Results and Analysis .............................................................................. 52
  6.1 Smart Factory Lab (SFL) ........................................................................ 52
  6.2 Smart Factory Lab Process (SFL Process) .............................................. 53
    6.2.1 IDEA Management ........................................................................ 54
    6.2.2 Project Planning ........................................................................... 56
    6.2.3 Pre-Study ..................................................................................... 58
  6.3 Suggested SFL process .......................................................................... 59
  6.4 Research Questions Answered ............................................................... 60
    6.4.1 What are the major constraints for the technology transfer? .............. 60
    6.4.2 What is the strategy to overcome the constraints and effectively transfer the tech-
    nology? ......................................................................................... 60

7 Discussion and Conclusion ..................................................................... 62
  7.1 Discussion ......................................................................................... 62
  7.2 Conclusion ....................................................................................... 63

8 Bibliography ......................................................................................... 65
List of Figures

1.1 Research Strategy ................................................................. 4
2.1 Stages of Industrial Revolution[77] ........................................ 10
2.2 The Bar-Zakay Model of technology Transfer[63] ....................... 13
2.3 Technology Transfer Life Cycle Approach for Planning and Implementing Technology Transfer [63] ......................... 14
4.1 This House explains how various parts of the Production System are connected – The figure presented has been sourced from the internal documentation available on the Case company intranet ............................................. 23
4.2 Smart Factory Pyramid adopted by case company shows the steps towards a predictable future ......................................................... 25
4.3 Illustration of pedal car used in Smart factory Lab ...................... 27
4.4 Illustration of Initiated First Draft of Smart factory Lab Process .......... 28
4.5 Illustration of Initiated First Draft of Smart factory Lab Process .......... 30
5.1 Assignment Directive ................................................................. 35
5.2 Element Sheet used by the the operator in production. Image Source:Case company’s web ........................................................................ 38
5.3 Training Framework for assembly operations [49] ....................... 39
5.4 Responses Chart ........................................................................ 43
5.5 Experience of respondents ........................................................... 43
5.6 Question 1. ........................................................................ 44
5.7 Question 2. ........................................................................ 44
5.8 Question 3. ........................................................................ 45
5.9 Question 4. ........................................................................ 45
5.10 Question 5. .......................................................................... 46
5.11 Question 6. .......................................................................... 46
5.12 Question 7. .......................................................................... 47
5.13 Question 8. .......................................................................... 47
5.14 Question 9. .......................................................................... 48
5.15 Question 10. ....................................................................... 48
5.16 Question 11. ....................................................................... 49
6.1 Table for steps involved in idea management ............................... 54
6.2 Table for steps involved in sprint planning .................................... 56
6.3 Table for steps involved in pre-study .......................................... 58
6.4 Smart Factory Lab Process along with Case company’s Production System process ........ 59
Chapter 1

Introduction

In this section background information of the study and the problem formulation is explained. Further, the purpose of the study and the research questions, methodology are documented. This section also contains the limitations set for the entire research work.

1.1 Background

The escalating global demand for various products necessitates increased production capacity, which may not be adequately met by simply expanding the number of production facilities. Instead, the focus has shifted towards enhancing efficiency and implementing smart production technologies within existing facilities to boost productivity.

Since the coining of the term "Industry 4.0" in 2011, there has been a growing emphasis on so-called smart technologies (further defined in Chapter 2.1.1). Although research on these technologies has been ongoing both before and after 2011, their full integration into actual industries remains somewhat limited. This research aims to explore the potential reasons for the under utilization of products and technologies developed in factories and uncover the barriers to their effective implementation in full scale production.

Conducting a study in an existing factory within a century-old company poses significant challenges, particularly when it involves altering the factory’s established working methods. In this study, the case company is, a truck manufacturer with a rich history of almost a century, driven by a core principle of prioritizing customer needs. The research is conducted at one of their factories known as the Final Assembly Plant, responsible for assembling the final truck. Case company operates in a manner where independent production units (PRUs) procure components required for final truck production from other component production units, such as Gearbox Assembly Plant, Engine Assembly, Cabin Assembly, and more. These independent PRUs may exhibit varying levels of technological advancement and automation. In this report, the company where the study was conducted, will be referred to as the "case company". This name change is to adhere to standard research practices.

The case company’s support functions, including the Industrial Engineering department, play a crucial role in assisting the independent PRUs with technical support, such as establishing assembly standards and methods, and providing guidance on tightening techniques for various fasteners etc. The Industrial Engineering department also recently established the Smart Factory Laboratory (SFL) to explore smart technologies. The case company envisions enhancing its factories and progressing towards smart manufacturing, with the help of internal support functions like the Industrial Engineering department, which houses the Smart Factory Laboratory. Detailed information about the Smart Factory Lab and its functions can be found in Chapter 4.2.

This thesis focuses on the study conducted specifically for the Final Assembly Plant, where the level of automation is relatively lower compared to other PRUs. This is due to the Final Assembly’s unique challenges in handling a much larger number of truck variants compared to sub-components like the Gearbox Assembly. Additionally, the Final Assembly’s tact time is higher than that of other assembly plants.
1.2 Problem Formulation

With the rapid growth of smart technologies in the field of production engineering and manufacturing, it has become imperative for the case company to advance and stay at the cutting edge with production tools, ensuring a competitive advantage in adapting to the 4th industrial revolution.

The Thesis Supervisor, who is also a Technical Manager, emphasizes the tremendous potential of smart technologies. However, the company is yet to discover an effective way to integrate these technologies into production processes and leverage them for higher productivity. This discussion serves as the starting point for the thesis, where the Technical Manager highlights the need to identify hindrances in technology transfer and find viable solutions. Initiatives like the Smart Factory Lab have been introduced to assist Case company’s production advancement, but barriers to effective technology transfer still need to be identified and addressed.

The case company, has undertaken various initiatives to drive digitization, including the establishment of the Smart Factory Laboratory. The proximity of this new lab to the final assembly plant offers considerable advantages, such as reduced logistical activity and increased access to personnel from the final assembly plant.

The Smart Factory Lab serves as a test bed for experimenting with new technologies, enabling early assessment of their advantages and disadvantages to avoid unnecessary implementation and changes in existing infrastructure within its production units. Beyond being a test bed, the Smart Factory Lab serves as a technology consultant and knowledge source on smart technologies for all Production Units within the company, including the Final Assembly plant. Having recognized the potential of smart technologies showcased in the SFL, personnel at the Final Assembly plant aspire to see more of these technologies integrated into real production. Therefore, they seek an effective way to transfer these technologies from the lab to the production line. In this regard, the Final Assembly plant takes the lead by commissioning this thesis work on behalf of all production units.

Despite the establishment of the Smart Factory Lab in the case company and the open environment for exploring smart technologies outside the company, only a limited number of these technologies have been fully implemented in full-scale production. Even though their high potential was identified during early-stage testing in the Smart Factory Laboratory, the transfer of such technologies to full-scale production remains limited. The thesis aims to understand the current methods followed in the SFL to procure, test, and develop smart technologies, as well as the process of transferring these technologies to production units. Historically, only few such technology transfer has occurred from or through the Smart Factory Lab to the production units, given the novelty of the SFL concept. This gap between the newly established SFL and the existing production units needs to be addressed, and key issues and constraints related to technology transfer must be identified to bridge this gap effectively.

1.3 Purpose

The purpose of this research is to investigate and understand the existing gap, constraints, and barriers between the established Smart Factory Lab and the Final Assembly Plant for the effective transfer of smart technologies that are tested, adapted, or developed within the laboratory.

Research question

How to enable effective transfer of Smart Technologies into the production (Final Assembly plant) from Smart Factory Lab where the technology is tested and adapted/developed for Case company?

1. What are the major constrains for the technology transfer?

The research question aims to investigate the barriers and limitations that impede the effective transfer of smart technologies from the Smart Factory Lab (SFL) to the production units, particularly the Final Assembly Plant, within the case company. Despite the SFL’s primary objective
of advancing the case company’s production capabilities towards smart manufacturing, it operates as an independent organization under the Production Logistics (PL) department, which is a larger umbrella within the company. As a relatively new entity in the case company, the SFL is currently in the process of gradually integrating with other departments of Production.

In contrast, the production units are well-established factories with established processes. However, there has been a noticeable scarcity of technology transfers from the SFL to any of the production units, and specifically, the Final Assembly Plant. Therefore, the research seeks to identify the various constraints that hinder the seamless transfer of smart technologies from the SFL to the production units.

2. What is strategy to overcome the constraints and effectively transfer the technology?

The second research question seeks to develop a strategy for the efficient transfer of smart technologies from the Smart Factory Lab (SFL) to Case company’s Production Units (PRUs), particularly the Final Assembly Plant. By understanding the constraints that hinder technology transfer, the study aims to propose a practical approach to integrate the SFL with existing production processes.

1.4 Methodology

The initial phase of the thesis involved gaining a comprehensive understanding of the problem through discussions with the thesis supervisor and formulating the purpose and research questions (Chapter 1.3). Since the issue at hand pertained to organizational challenges rather than conventional technical faults, extensive efforts were made to comprehend the intricacies. This required conducting numerous interviews and engaging in QA sessions with personnel from the case company. The focus was on achieving clarity in problem formulation, which laid the foundation for the subsequent stages of the thesis work.

As an external observer and thesis student, a crucial aspect of the early phase of the research involved understanding the operational structure of both the Smart Factory Lab and the final assembly. Notable distinctions between the two organizations were evident - the final assembly had an established standards for production of trucks, while the Smart Factory Lab was a novel entity focused on innovation and yet to define its operational framework. Detailed mapping of the current state and working methods of both entities was conducted, including their respective roles, daily tasks, and overall vision and mission (Chapter 4.1 and 4.2).

At the case company, emphasis was placed on principles such as standardization. This meant that any complex activities involving multiple individuals or departments required a well-defined process to streamline roles and activities. For the Smart Factory Lab, a theoretical process for technology transfer had already been formulated by senior employees. However, since the lab was still in its early stages of establishment, this technology transfer process had not been tested or implemented for any smart technology in production from the Smart Factory Lab (further elaborated in Chapter 4.3).

Additionally, an literature study was conducted, focusing on addressing similar problems related to technology transfer, organizational challenges, and collaborations between two organizations. This research revealed relevant previous thesis works, particularly on the topic of digitization within the same case company. These findings provided valuable insights into the current state of operations and shed light on potential solutions and strategies for effective technology transfer (Chapter 2).

After extensive brainstorming regarding the strategy to address the research questions, it was concluded that conducting a case study would be an effective approach to test the existing theoretical process for technology transfer (the one created by the senior employees, as explained in Chapter 4.3). For the case study, the specific problem chosen from the final assembly plant was "training the new operators," which was intended to be solved using the virtual training technology available in the Smart Factory Lab. This case study aimed to demonstrate the process of identifying a production problem, finding a solution through smart technologies, and transferring that technology from the Smart Factory Lab to the production environment (Final Assembly Plant).
The case study was instrumental in comprehensively analyzing each step involved in the process of technology transfer and how the Smart Factory Lab collaborated to provide smart technology solutions. The theoretical process for technology transfer, known as the "Smart Factory Lab process" within the case company, was put to the test using the aforementioned case study (elaborated in Chapter 5). Based on the results of this test, the intention was to refine and optimize the Smart Factory Lab process and seek approval from the case company management to implement the improved process throughout the organization, utilizing the insights gained from this thesis work.

![Figure 1.1: Research Strategy](image)

The case study provided valuable insights into the major constraints hindering technology transfer, thereby addressing research question 1 (explained in Chapter 6.4.1). Additionally, leveraging the inputs and findings from the case study, the existing theoretical Smart Factory Lab process was enhanced and transformed into a practical process for the case company's daily operations, addressing research question 2 (detailed in Chapter 6.4.2).

In this thesis, the process of using the Smart Factory Lab as a medium to introduce advanced technologies to existing factories, also known as brownfield factories, is documented. By leveraging insights from the literature study, mapping Case company's current state, and conducting the case study, valuable knowledge was accumulated. The thesis concludes with a comprehensive discussion and conclusion of the overall findings and outcomes (Chapter 7.2). This research paves the way for effective technology transfer and fosters the advancement of smart manufacturing in the case company and beyond.
1.5 Scope and Delimitation

This research focuses solely on a single and comprehensive case study of technology transfer within a large automotive manufacturing company based in Sweden, referred to as the case company. The study involves a genuine attempt to implement a smart technology from the Smart Factory Lab (SFL) into the production unit, specifically the Final Assembly Plant, to gain insights into the practical challenges of the implementation process. As such, all the data and information collected pertain only to this specific case company.

The investigation mainly centers on two key units of the case company: the Final Assembly Plant, where the entire product receives its final form, and the Smart Factory Lab, a laboratory setting dedicated to supporting production units. Although interviews and involvement of personnel from other relevant units occurred, the primary focus remained on these two units.

Given that the case company is an established and sizeable organization with numerous production units, it is classified as a brownfield company. Consequently, the Smart Factory Lab process developed in this research is specifically tailored and generalized for similar brownfield organizations.

This research adopts a qualitative approach, and there is no quantitative research conducted. All deductions and conclusions are drawn from in-depth qualitative data gathered through interviews and observations. Due to resource limitations, the researcher played multiple roles, acting both as the Smart Factory Lab operation lead and personnel involved in the technology development in the lab.

While this study provides valuable insights for the case company and offers a potential model for technology transfer in brownfield companies, its scope is restricted to this specific context. Generalizing the findings to other organizations may require further research and validation through additional case studies in diverse industrial settings.
Chapter 2

Frame of Reference

In this chapter, the frame of reference for the research is presented. The frame of reference provides a theoretical foundation and background for the study, allowing a deeper understanding of the concepts and principles relevant to the research. The frame of reference encompasses relevant theories, concepts, and previous studies that are essential for addressing the research questions and achieving the research objectives.

2.1 Defining Smart Factory

Smart factories are a prominent aspect of Industry 4.0, representing the evolution of manufacturing processes in the 21st century[39]. At its core, a smart factory is an autonomous production facility equipped with advanced sensors and technologies, geared towards providing support to both human workers and machines in their tasks. This integration of sensors and technologies enables seamless coordination and interaction between various systems within the factory, leading to increased efficiency and responsiveness to dynamic demands, changing supply chain conditions, and evolving customer requirements[16].

Smart factory is described by quick adjustments to changes in the market; it moreover empowers goods to be produced into smaller batches, which are changed in accordance with customer’s needs in a productive and beneficial way. The purpose of the smart factory is to achieve the paradigm of sustainable production, which would have an impact on organization, culture as well as lifestyle[76].

It ought to be noticed that a Smart Factory is a unit described by an ideal progression of information, a capacity to change in accordance with different requirements effectively and a significant level of data security and which plays the unique job of the customers into thought. Owing to the technologies utilized, systems in a Smart Factory monitor and are equipped for utilizing acquired real-time data so as to build up a model of virtual reality. As per this idea, the unit is outfitted with a decentralized system ready to make decisions all alone, react to current and exact information and notify seniors if important[4].

It is the change within the industries to connect individual and isolated department to make it a system of Systems (SoS) which will enable smooth functioning of the entire organisation in an integrated path which matches the requirements of the end user[24]. The end goal of these factories is to interconnect every operation within manufacturing and thus optimise each of them in a manner to produce higher end quality and quantity for lesser cost[24]. It is also required from the manufacturers to invest in both advanced technologies as well as the skilled technical talents to harness the advantages from the factories of the future. Digitization is one of the very important factor when it comes future factories.

Smart factory has smart artifacts as the fundamental components. While the present computer numerical control (CNC) machines for the most part have 3C abilities, the smart machines ought to have additional autonomy and sociality capacities. This implies the smart machines can settle on choices without anyone else as opposed to being directly instructed, and they can haggle with one another and with the smart products. Accordingly, the autonomy and sociality capacities are the key empowering agents for the execution of a self-organized manufacturing system. The research on MAS that is a part of AI technology can give some valuable outcomes, for example, the ontology method and the contract net
protocol (CNP)[69]. Be that as it may, further research is as yet expected to accomplish the autonomous manufacturing system engineering rather than progressive or mediator ones.

Smart factories should not be brought into service without considering the security. The smart factory endures greater security issues than traditional Internet applications[61, 62]. On one hand, we ought to protect different information of suppliers, customers and commercial strategies. These types of information are usually stored in the public cloud rather than private data center of the enterprise. These confidential materials might be revealed, for instance, by hackers, which may cause colossal profit loss or even legal differences. Then again, the machines and other physical items and even individuals themselves are associated with the cloud. At the point when control mechanism is broken, direct property loss may occur by these objects working in a damaging way.

Cyber security domain generally uses encryption and approval, which will be yet beneficial in Industry 4.0 or smart factory applications; still these mechanisms are insufficient. At this point, there is no approach to make an absolute software system. Even the exceptionally well-known software is enduring unlimited loopholes[56]. New mechanisms for smart factory which are especially designed for it should be developed; and before these works out as expected, some conservative methods might be useful choices.

Digitization includes implementation of IoT, intelligent apps, using AI to solve the current problem and paving the way forward by 3D printing which eventually covers the aspects of future factories and drive towards industry 4.0. In Artificial Intelligence, the program can sense and adopt to new circumstances on its own. Machine Learning relies on vast amount of data input on which results improve to make minimum human requirement. In Deep Learning multilayered neural network learn from huge amount of data. These various digital tools contributes for flexible production systems by performing specific tasks like predictive maintenance, accident prevention, track and restore inventory, tracking the product journey and getting real time feedback.

In addition to mentioned technologies, there are more enabling hardware technologies in Smart Factory: First, Collaborative robots (cobots). These devices acts as assistant to the human operators for helping them in performing tasks on strenuous characteristics[9]. Second, Augmented reality is another enabling hardware which allows computer created objects to co-exist with existing surrounding real environment[9]. Third, Additive manufacturing is also known as 3D-printing, which allows for the on demand production of customized products or equipment. So, it has the potential to make the production processes very flexible[9].

2.1.1 Brownfield and Greenfield Factories

The modern approach in most EU countries, looks to draw in new inward investment capacity and occupations, and to advance the effect of the so called ‘demonstration effect’ of ‘greenfield’ development strategies sought after in the new plants of inward investors on existing or ‘brownfield’ plants[55]. This strategy has been particularly apparent in the automobile industries in the UK portrayed by low efficiency, low quality, shop floor militancy as well as lacking control labour costs and weak management[50].

New technologies always have new challenges associated to implementation in to the industrial reality, both social and technological[73]. Hence the factories are categorized into two different kinds of factories: Brownfield and Greenfield factories. There are several differences between the challenges in a brownfield factory and a greenfield factory. Brownfield stands for all our existing factories with all it’s conventional equipment and facilities. The opposite of that is “Greenfield” where a factory is designed and built completely new. Such greenfield factories are easy to develop it’s self to future factories by integrating all the nice and smart machines of state of art and the future. Further more, For greenfield sites, it is possible to adopt smart technologies without significant drawback. This in contrast to brownfield sites that are encumbered with existing systems and protocols[54]. [20] argues that the investment in a Smart Factory and the IT systems that come with is much more difficult for brownfield compared to greenfield.

Increased competition and rationalization of capacity has prompted due to overcapacity, fundamentally among the existing producers of ‘brownfield’ plants which have further to go to become competitive or to shut down and set up ‘greenfield’ plants somewhere else. Further, the transplant capacity has been sustained, depending upon its locational eligibility, by an entire array of national and European grant
measures, which have possibly been caught by existing makers when they have been contributing rather than experiencing the present retrenchment[19].

To begin with, 'brownfield' plants are set apart by socially developed attitudes, approaches and conventions which have been amassed by the workforce, management and the trade unions through their combined experiences in the plant. Second, the pace at which adjustment to react to the ‘demonstration effect’ is predicted to happen is arriving at powerful effective limits, especially given the historically and socially built latency inside 'brownfield' plants. These contain the changing of employment specifications inside teams quicker than training or workforce capability can stay up with and the failure of training to give the essential workforce skills with regards to labour shedding[30].

2.1.2 Internet of Things (IoT)

The global industrial landscape has drastically transformed over the years due to technological advancements and innovations. The aim of the fourth industrial revolution is to modify the innovative technologies to transform traditional industries to smart industries. The Internet of Things (or IoT) is rapidly growing technology that drastically contributed to Industry 4.0 realization[44].

The Internet of Things (or IoT) is a web of interconnected computing devices involving seamless interaction between the devices to achieve an optimal task. The scope of this technology is broadening a way beyond machine-to-machine communication. It works with several arrays of networking protocols, applications and network domains[36].

The term ‘Internet of Things’ or ‘Internet of Objects’ has originated to characterize electrical or electronic devices of varying capabilities and sizes, that are associated with the Internet. The extent of the connections is ever-expanding to past simply machine-to-machine communication (M2M). IoT devices utilize a wide array of network domains, networking protocols and applications[36]. The rising predominance of IoT technology is encouraged by physical objects being connected to the Internet by different kinds of short-range wireless technologies, for example, sensor networks, ZigBee, RFID and through location-based technologies[26]. IoT will have the effect of the Internet much more extensive, individual and private in day to day life[23].

IoT will make the impact of the Internet even more pervasive, personal and intimate in daily life[23]. Development of IoT is seen as a potential solution in achieving Industry 4.0 [64]. Productivity of manufacturing technologies can be enhanced through IoT equipped with real-time analytics. This involves ubiquitous IoT systems in place with processing capabilities of cloud computing able to deliver analytics that boost decision making process [58].

The number of Internet connected things in the near future would be profoundly larger than the number of individuals. The objects surround our environments will be connected to the Internet in some form. The physical and ICT worlds would be coordinated together giving a vision past the domain of the traditional networks. The communication won’t be individuals to individuals; it’s not going to be individuals accessing information. It’s going to be about machines conversing with different machines for the benefit of individuals[72]. Diverse communication technologies and items, for example, cellular phone, from GSM to HSDPA, ZigBee, WiFi, satellite, Bluetooth, Ethernet, WiMAX, and so forth would become parts of the IoT domain and be implanted with M2M capabilities[18]. The most principal side of the IoT vision is the consideration of smart things. These objects are seamlessly linked with the Internet and fitted with computing, remote monitoring, intelligence, sensing and control capabilities.

IoT incorporates three principle demands: the initial, a common understanding of the situation of its clients and their applications. Besides, software architecture and pervasive communication systems to cover and procedure relevant information, and ultimately, the analytics tools in IoT that focuses on autonomous and intelligent behavior[33]. Significantly, the principle idea of IoT can be expressed as promoting the communication between anything from anyplace whenever through context-aware applications. In like manner, IoT has depended on RFID and sensor network technologies in the executions. For example, IBM organization utilized IoT in Norwegian Sea oil platforms, by deploying sensors at seabed that are utilized to gather real information to make decision drill in the ocean[2]. Then again, the IoT environment like numerous networks experiencing the set of challenges which fundamentally influence their
performance some of them are common and others, are exceptional; these challenges can be divided into two categories, specifically, i) General challenges: which incorporate common difficulties among IoT and conventional networks, for example, heterogeneity, scalability, communication, virtualization, security, QoS and data mining; and ii) Special challenges, for example, RFID and WSN.

IoT points for executing independent, strong and secure associations and information/data exchange between devices and real-world applications. In expansion, it contributes to the fulfillment of machine-to-machine communication and interconnectivity as well as to the integration of insights into devices. Hence, devices will be able to handle data and information and make real-time autonomous human-like intelligent decisions without requiring and human association and/or intercession[42]. Consequently, it can contribute to making a possibly way better world for individuals in which the “things” around them know what they like, what they need and what they require unequivocal enlightening from humans[59].

Common applications of the IoT are monitoring and controlling systems. Information about the environment or networked objects are gathered (sensed or calculated), sent to an intelligent system (centralized or distributed) and afterward the correct decision is made. This permits continuously following the working conduct, reconfiguring working parameters, and along these lines automatically modifying the resulting performance of the system. IoT technology also benefits health care systems to give effective care services. Body Area Network (BAN) is a case of data analytics wherein the patient’s condition or behaviour is continually monitored. For example, networked in-body Nano sensors[6]. In the business area, intelligent systems are used to find and resolve business issues so as to make an appropriate reaction and accomplish customer’s fulfillment[45]. However, smart banking, infrastructure monitoring, information exchange sharing, crowd monitoring, water measurement, enterprises collaboration, smart transportation and more others are only instances of IoT applications. In near future, an outrageous increment in smart applications is expected to invade our lives.

2.1.3 Industry 4.0

Industrial evolution is the best example of this increasingly rapid development. The utilization of mechanical machines and steam-powered engines revolutionized the way of working within the late 18th century, and also the first technological revolution was born. The second technological revolution started during the turn of the 20th century, as electricity among other technologies was growing in prevalence and enabled production. The third revolution befell during the later stages of the 20th century as electronics and IT changed the face of the industry [40]. The term Industry 4.0 was first mentioned in 2011 so as to spot the fourth technological revolution by the German government in their initiative “High-Tech Strategy 2020 Action Plan” [40, 65]).

The future of global manufacturing is definitely Industry 4.0. It is the era of digitalized company, digitalized products and automation – the fourth phase of industrial revolution or Industry 4.0. Nonetheless, the academics field is yet unfit to characterize the approach as Industry 4.0 is the fundamental term referring to the fourth industrial revolution. This causes trouble in recognizing its components. There are 9 characteristics for the industry as Cyber-Physical System (CPS), Internet of Things (IoT), Internet of Services (IoS), Big Data and Analytics, Augmented Reality, Autonomous Robots, Additive Manufacturing (3D Printing), Cloud Computing (CM) and Simulation[29].

The forth industrial revolution, and hence the 4.0, will come about via the Internet of Things and the Internet of services becoming integrated with the manufacturing environment[28]. Many workers utilize computerized-numerical-control (CNC) machining centers and other means of industrial automation on the shop floor or they assemble products with tools. Automated pro-duction like welding or painting by robots is separated from the human workers because robots are not able to sense the presence of workers and the current setup of automated manufacturing cells is too dangerous for workers[27]. In general Industry 4.0 fosters factories of the future which has been also called smart factories. Evolution of Industry 4.0 can be visualised by the figure 2.1
Industry 4.0 is characterized as an amalgamation of advanced technologies where the internet is broadly used to assist certain technologies, for example, embedded systems. It serves a job to incorporate and consolidate the intelligent machines, physical objects, human actors manufacturing lines and processes, making new kinds of technical data, systematic systems and high agility value chains[67]. Industry 4.0 can be characterized into three components. The first is horizontal integration. It brings the idea of new type of worldwide value chain networks. The second is vertical integration. The idea is to accomplish progressive subsystems at the production line to deliver a simple to configure and high flexibility production line. The last classification is engineering integration along the entire value chain from the earliest starting point as far as possible to aid the customization of products[76].

For the introduction of industry 4.0, the things that are needed are Factory 4.0, Software for data processing - Big Data, Internet of Things (IOT), Cyber Security (Information Security), Logistics 4.0, Mass Customization (a large number of custom), High-quality team of employees and experienced team of partners. Factory 4.0 which includes Robots, Advanced Manufacturing System, 3D Printing / Additive Manufacturing, Autonomous Vehicle (unmanned vehicles), Sensors (sensors - data collections), Cyber Security (Information Security), Industrial mobile devices (platform) and Nanotechnology / advanced materials[46].

Industry 4.0 can occur due the networked systems which provides connectivity for local decentralized information processing; progressive miniaturization allowing small, low- cost and high-performance sensors and actuators; auto-ID for customized product manufacturing which creates unique identification and links to the virtual world; intelligent field devices using software that allows for the global dynamic distribution of functionality is an integral part of the system integration; and Mobile Device Management (MDM): man-machine interfaces for intuitive operation of complex systems without special training[81]. With an exceptionally goal-oriented potential, Industry 4.0 guarantees increased flexibility, better quality, mass customization, increased speed and improved productivity in manufacturing[80] empowering factories to adapt to the global challenges and customized needs and still to stay beneficial. Ongoing trends like globalization of business sectors and pressures of meet customer needs demand production equipment and processes that have the option to adapt to new products and product variations more flexibly[14] to increase competitive strength.

Emerging information and communications technologies that will shape the future smart factory can facilitate the implementation of appropriate production modes to achieve these objectives. For instance, sensors, networked machines, and computers can effectively communicate with each other and users continuously, making manufacturing processes more transparent and monitorable, thereby reducing failure rates and resulting in higher quality and efficiency. Another trend is the closer collaboration between manufacturing companies and service providers, integrating products and services[17]. They can offer
their expertise or various services instead of just final products, enabling other companies or partners to leverage their skills and knowledge to develop their own products[41].

Industry 4.0 could further support Lean Production’s requirement for flexible, modular production. For several years, Smart factories have demonstrated modular working stations based on standardized physical and IT interfaces, which can be flexibly reconfigured for new production lines[43]. In summary, Industry 4.0 is expected to possess the ability to digitally integrate entire value chains, catering to individual customer requirements while remaining profitable. Additionally, Industry 4.0 enables production to accommodate last-minute changes[37].

2.2 Technology Transfer/Tech Implementation

Technology has been a boon to industries since the inception of the industrial era. It serves as a means to harness internal technological assets and also to tap into the external market. Technology transfer has significantly contributed to global technological advancement in multiple ways[63].

2.2.1 Definition of Technology Transfer

The concept of technology transfer can be defined as the process of transferring technology from one entity to another[68]. These entities can encompass a wide range, including laboratories, technical universities, private research entities, or any source engaged in technology development. Conversely, the recipients of technology are typically firms requiring such technological advancements for various purposes, essentially referring to the end consumers of these technologies.

Alternatively, technology transfer can also be defined as a process encompassing the sharing of knowledge, skills, methods, samples, and manufacturing technologies and facilities among governments and other institutions[79]. This definition offers a more comprehensive view by incorporating essential elements like knowledge and skills, which are crucial for successful technology transfer. According to research by UNSD, global technology trade turnover was a mere 2.7 billion in the mid-1960s, but it witnessed a substantial increase, surpassing 100 billion by the early 1990s.

Technology transfer can be categorized into two distinct types: vertical and horizontal. In the vertical scenario, technology is transferred from fundamental and foundational research. This research is subsequently applied in practical real-world situations, leading to the development of products and services. On the other hand, horizontal transfer involves the application of technology from one sector to another, allowing technology to be utilized in different contexts and ways[68].

2.2.2 Problems associated with Technology Transfer

There are several issues and hindrances that can arise during technology transfer projects. These include:

- Problems during the planning stage, such as underestimating the difficulties of transferring technology to a developing country, poor market demand forecasting, and incompatible objectives between the transferor and transferee [63].
- Problems during negotiations, such as differences in negotiation approaches, lack of trust, and inability to reach agreements on pricing, product, and marketing strategies[63].
- Problems during technology transfer implementation, such as a shortage of experienced technology transfer managers, lack of trust in transferor developed systems by the transferee, and cost overruns due to poor implementation[63].
- Corporate capability issues, such as inadequate skills, ineffective management, and language barriers that inhibit effective communication between transferor and transferee personnel[63].
The assumption that technology transfer is a relatively predictable process, which oversimplifies the magnitude of the problem faced by small and medium enterprises in planning and implementing technology transfer projects [63].

It is important to note that these issues are not exhaustive and may vary depending on the specific context of the technology transfer project.

Other perspectives about the issues in technology transfer [71]:

- Intellectual property (IP) protection: The organization transferring the technology needs to ensure that its IP is protected. This can be a challenge, as IP laws vary from country to country.
- Cultural differences: When transferring technology between organizations in different cultures, there can be a number of challenges, such as different communication styles, different expectations, and different understandings of risk.
- Lack of trust: In some cases, the organization transferring the technology may not trust the organization receiving the technology. This can be a major barrier to technology transfer.
- Different goals and objectives: The organization transferring the technology may have different goals and objectives than the organization receiving the technology. This can lead to conflict and make it difficult to reach an agreement on the terms of the technology transfer.
- Lack of resources: The organization transferring the technology may not have the resources to effectively transfer the technology. This can include a lack of funding, a lack of qualified staff, or a lack of time.
- Lack of communication: Communication is essential for successful technology transfer. However, communication can be a challenge, especially when the organizations involved are in different countries/cultures.

2.2.3 Technology Transfer Models (TT)

Technology Transfer (TT) models play a crucial role in providing a comprehensive approach for firms to effectively incorporate new technologies. These models are divided into two categories: qualitative and quantitative.

Qualitative models primarily aim to outline the activities associated with managing TT, as well as identifying factors and considerations that can impact the success and effectiveness of the technology transfer process. In contrast, quantitative models seek to quantify important parameters within TT and analyse them to minimize conflicts between technology transfer parties. In this context, our emphasis is placed on qualitative models rather than quantitative ones.

Various Qualitative Models:

(a) The Bar-Zakay Model:

The Bar-Zakay model presents a comprehensive technology transfer (TT) approach grounded in project management principles. It specifies detailed activities for implementation, highlighting the significance of skill acquisition in technological forecasting, long-range planning, and project-related intelligence for both the transferor and transferee. Key insights drawn from the Bar-Zakay model include the necessity for an exhaustive examination of the entire TT process from initial “search” to subsequent “post-implementation” stages. A process-oriented strategy is crucial for planning and executing TT projects. Incorporating milestones and decision points is essential to reinforce activities, rectify errors, or even terminate the project if needed [63].
(b) **The Behrman and Wallender Model:**

This model outlines a seven-stage process for international technology transfer, which may hold more relevance for multinational corporations[63]. These stages are as follows:

I Manufacturing proposal and planning: This involves deciding the location, preparing a business case, and conducting resource assessments.

II Deciding on product design technologies to transfer.

III Specifying plant details for production and addressing construction and infrastructure needs.

IV Plant construction and production start-up.

V Adapting processes and products as required, and enhancing production systems to fit local conditions.

VI Improving the transferred product’s technology using local expertise.

VII Providing external support to strengthen the relationship between the transferor and transferee.

The insights that can be drawn from this model include the importance of involving the transferee in the planning and implementation of a technology transfer project right from the beginning. Additionally, the model emphasizes that a technology transfer project’s scope extends beyond production commencement. For successful technology transfer, measures must be in place to ensure the assimilation of the transferred technology[63].

(c) **TTLC (Technology Transfer Life Cycle) approach.**

The TTLC approach takes a holistic view of a TT project from its “conception” right up to its “conclusion” and is based on the recognition of the fact that a life cycle of a TT project can be looked at from a process perspective as consisting of six major stages as follows.

I Identifying the technology needed and making a business case to obtain corporate approval

II Searching for possible technology sources and assessing offers
III Negotiating with short-listed suppliers and finalizing the deal
IV Preparing a TT implementation plan
V Implementing and assimilating
VI Assessing the impact of the TT project[63]

Key Insights from this model:

- Implementing Gates after each stage is crucial.
- The TTLC approach encompasses a holistic consideration of a TT project and incorporates the wisdom shared by various researchers and practitioners through their technology transfer models.
- Structured for Small and Medium-sized Enterprises (SMEs), the TTLC approach helps mitigate many common challenges faced when planning and executing a TT project.
- It fosters cross-functional collaboration in TT project planning and management, ensuring important tasks are neither overlooked nor handled carelessly.
- A single empowered team is responsible throughout the project, reducing conflicts. Not all projects need to go through all stages; low-risk projects can progress quickly to later stages.
- This approach shouldn’t be viewed as a bureaucratic system; rather, it facilitates the development of a streamlined process with a clear, agreed-upon, and visible roadmap[62], [63].

2.3 Test Beds

A testbed refers to a physical or virtual setting where collaboration between companies, academia, and other organizations takes place for the development, testing, and implementation of novel products, services, processes, or organizational solutions within specific domains. It provides an avenue for exploring new technologies, materials, or processes in a controlled environment. Industrial testbeds offer the chance to experiment with innovations, mitigating the risks associated with untested technologies before their integration into actual production or products[60]. Testbeds encompass diverse environments, typically categorized into three levels: laboratory, simulated, and real environments. While the first two are predominantly utilized by academia, institutes, and industry, the third level predominantly involves the public sector[74].
The testbed encompasses smart manufacturing toolkits, advanced open platforms, analytics, controls, and sensors. It serves as a distinctive validation and testing arena for Industry 4.0 and smart production advancements, particularly for small and medium-sized enterprises in collaboration with OEMs and other global entities. The smart factory testbed integrates real-time data streams from remote machining operations, intelligent workstations for smart assembly, augmented reality, AI-linked visual inspection, and a reconfigurable factory cell. The envisioned testbed concept aims to formulate reference frameworks that tackle these concerns and furnish a data resource for other researchers to develop and authenticate smart manufacturing technologies[34].

2.4 Produktion 2030

The manufacturing sector stands as a foundational element of Sweden’s economy and a significant source of employment. Many Swedish manufacturing firms have embraced the prospects presented by digitalization. In the face of escalating competition within the global market, enhancing competitiveness becomes pivotal to safeguard the interests of stakeholders. In line with this, Production 2030 emerges as a national initiative and agenda focused on strategic innovation, research, and education to bolster the competitive landscape of Swedish production by 2030[48].

2.5 Technology Push and Market Pull

The growing significance of a knowledge-based economy as a catalyst for economic advancement has induced a shift in the functions of universities and public Research and Development (RD) institutions, as well as their engagement with the business sector through the movement of technology from academia to the market[51]. Technology transfer, in essence, involves the conveyance of specialized technical expertise and knowledge from sources possessing such capabilities, such as RD institutions and universities, to recipients who lack these competencies and do not originate the technology themselves, i.e., customers[47].

Nonetheless, this process, commencing with a novel concept and culminating in the introduction of a new technology to the market, unfolds across multiple consecutive stages, each exerting an influence on the others and possessing distinct attributes. In theoretical terms, there exist several methodologies to conceptualize technology transfer[66, 7], with the linear model of innovation being the most uncomplicated and commonly employed [7]. This model establishes a linear linkage connecting the successive phases of innovation and is often delineated through two distinct categories of innovation strategies: technology push and market pull.

The "market pull" strategy strives to offer products that fulfill existing market demands. Conversely, the "technology push" strategy endeavors to generate market interest in new products rooted in innovative solutions. Technology push involves being driven by emerging technologies or novel amalgamations of existing technologies to create innovative products or solutions for the market. In contrast, market pull is propelled by customer needs, relying on intensive interactions between the marketing team and customers[21].

At the organizational level, a debate persists regarding the comparative effectiveness of a market-pull or technology-push strategy. Technology-push oriented companies are structured to commercialize particular technologies, generating product concepts from established or emerging technologies[15]. This approach often entails a resource-intensive "probe and learn" process for market entry, necessitating revised marketing strategies, the adoption of specific upper-management approaches, and a readiness to challenge existing manufacturing capacities[35]. Conversely, the term market-pull is seldom discussed in isolation at the organizational level but is closely linked to incremental innovation. It’s observed in various specific contexts such as lead-user driven innovation and front-end innovation, among others[75]. Market-pull oriented firms devise and produce products to address identified market requirements within established market segments[15].

However, some studies contend that the division between market-pull and technology-push is unnecessary, and that a successful firm should ideally strike a balance between its technological focus and effective management practices[53].
2.6 Collaboration between Two Departments in a company

Collaboration between two departments involves more than mere cooperation among different teams. It encompasses a shared vision, mutual respect, and a thorough understanding of each other’s roles within a project, all with the objective of achieving exceptional business outcomes and providing an outstanding customer experience. This collective effort is ultimately geared towards the development of new products.

In today’s competitive landscape, successful new product development is crucial for firms aiming to either maintain or enhance their competitive advantage[5]. Introducing new products holds significance because product life cycles are contracting due to intensified competition, globalization, rapid technological advancements, and frequent shifts in customer preferences[78]. However, venturing into product innovation also entails a substantial risk, as market success rates average around 45 percentage in the US, Europe, and Japan[32]. Recognizing the imperative of product innovation and the inherent risks, researchers have emphasized the importance of elucidating the factors that influence the level of success a new product can achieve. These factors are diverse, encompassing aspects like the collaborative efforts of various functional areas involved in the development process[70].

Firms often encounter challenges in collaboration, frequently attributed to what can be termed as ”translation difficulties.” These collaboration challenges can be categorized into several types. One such challenge is the lack of a common language or framework, which is commonly referred to as a translation difficulty. This arises due to varying thought worlds across different functional departments, each often using different terminologies. Additionally, there can be interpretative issues, where departments such as logistics, marketing, and production might interpret data or facts differently. Moreover, differences in processes or organizational routines within firms can be significant barriers. These processes, whether formally outlined in company policies or informally ingrained in the organizational culture, can diverge between departments and might not be mutually compatible. Such barriers, arising from differing processes, can hinder the essential collective action required for innovation to flourish[22].

Working teams often face challenges in aligning their focus with a project and being motivated to collaborate across different departments, especially when they lack a clear understanding of how their contributions impact the broader perspective. To address this, initiating a cross-departmental meeting at the project’s outset and inviting the initiative group to participate in discussions and establish the project’s vision can prove beneficial.

Confusion arises when colleagues do not share a common understanding of the terminologies used in inter-departmental communication. Enhancing cross-functional communication can be achieved by establishing a standardized language that is introduced during the onboarding process for new team members. The relationships among department heads play a role in influencing how effectively colleagues collaborate, underscoring the importance of cultivating a culture of collaboration within the leadership team[12].

2.7 Pilot

A pilot line represents a pre-commercial production line that generates limited quantities of newly developed technology-based products or utilizes emerging production technology. Its purpose is to serve as an intermediate step between research and full commercialization, addressing the gap that arises when laboratory-proven technology is not yet suitable for practical application[11]. Pilot studies are crucial in bridging this gap and facilitating the transition of technology into real-world application. They are especially significant in projects that impact customer interactions with product or service offerings, as they provide insights into customer perceptions and reactions. However, the methodology employed in these pilot studies often lacks precision and thoroughness, presenting opportunities for enhancement. Existing literature offers limited guidance on how pilot studies should be leveraged to determine the feasibility of proceeding with a proposed technology project[57].
2.8 Virtual Training

In a production line, each new operator doesn’t start with full training; even those with prior experience in similar tasks require a training process. This training encompasses familiarizing operators with the new work environment, acquiring fresh knowledge, understanding safety protocols, and gaining practical experience that directly influences their performance on the line. The primary objective of this training is to cultivate task-specific competencies within each individual. A well-designed training process aligns with the company’s overall strategy, imparts industry-standard skills to operators, and serves as a significant motivational factor[10].

Each company establishes a training policy that shapes the nature of ongoing learning and enhancement within the work environment. The progression of knowledge and competency among the workforce significantly influences the company’s achievements in its domain. Hence, it’s imperative to incorporate swift and effective training techniques for operators, enabling them to attain proficiency in various stations (assembly stations for example) relevant to their production area[10].

An innovative enhancement to the existing training approach involves the integration of novel smart technologies into the training process, particularly through the incorporation of Virtual Training. Within this context, Virtual Training encompasses Virtual Reality, Augmented Reality, and Desktop Training. Conventional operator training typically occurs on the production line, often leading to productivity losses. Additionally, unskilled operators might make errors that result in substantial losses, especially when dealing with high-value components or parts[13].

The technology survey encompassed four questions:

- Ease of use of the technology
- Clear benefits observed with the technology
- Relevance of the technology to one’s job
- Likelihood of recommending the technology to others.

The most robust and noteworthy correlation was identified between ease of use and likelihood of recommendation (0.939). This indicates that respondents found the tools easy to comprehend and operate, and they would also be inclined to suggest these tools to others[25].

The Smart Factory concept represents a fully interconnected and adaptable manufacturing system that links physical systems, operational data, and human resources to manage manufacturing, maintenance, inventory, and supply chain activities. An important advantage of Virtual Training within the workplace is its capacity to enable employees to engage with tasks and situations that might be too hazardous to replicate in reality. These situations can be precisely recreated within a controlled environment to better prepare personnel for actual scenarios. Virtual Training employs computer-based simulators to meticulously emulate hands-on equipment, providing a level of detail that creates a sensation of using the real equipment. Trainees can perform tasks using virtual trainers that mirror their real-world job duties[3].
Chapter 3
Methodology

3.1 Type of data

This research employs a combination of primary and secondary data collection methods. Secondary data serves as the foundational framework that provides context to the research, aiding in mitigating certain limitations inherent in primary data collection, such as constrained sample size. Integrating a comprehensive mixture of primary and secondary data sources is crucial, as it offers a more comprehensive perspective on the research question and helps alleviate limitations associated with each data type.

3.1.1 Primary data

Primary data consists of any new information that is collected directly from the source by the researcher. Since first hand data is collected, it enables greater accuracy and better control over variables. It also ensures that the information collected is the most recent, unlike some secondary sources which may have lost relevance over time. However, one must be cautious extrapolating the findings of primary data, especially a limited sample size to the universe. Primary data also tends to be more time consuming and has limited reach compared to more extensive studies undertaken by larger organizations. Primary data can further be categorized into qualitative and quantitative data, employing methods such as focus group discussions, interviews, ethnographies and questionnaires respectively. Nowadays, social media also acts a source of direct data which can be searched for and then analysed. In this study, we use primary data in the form of expert interviews and questionnaires.

3.1.2 Secondary data

Secondary data consists of existing information that is collected by others. It is public in nature and is easily accessible. Going through already established research in the field of inquiry always adds to the contextual understanding of the topic, and thus frame research instruments accordingly. In addition, secondary data helps add credibility to the primary findings. Secondary sources include trade publications and scientific journals as well as government and private company data. However, the credibility of secondary sources must be checked before employing them into current research.

3.2 Research approach

The research methodologies employed in this study can be broadly categorized into qualitative and quantitative approaches. In this particular research, a predominant focus has been placed on qualitative methodologies as the means to attain the defined objectives.

3.2.1 Qualitative approach

Qualitative methodologies are typically employed with a smaller number of participants due to their time-intensive nature and their focus on in-depth exploration of the research subject. These methods primarily capture intangible aspects such as opinions and motivations, rather than aiming for precise data measurement. Within a qualitative approach, it’s crucial for the moderator or interviewer to guide
discussions smoothly toward the relevant topic, maintaining a neutral stance to avoid introducing bias into respondents’ perspectives.

Throughout the study, ensuring researcher objectivity is essential, but it becomes particularly critical during interactions with participants and the subsequent analysis and interpretation of the collected data. Qualitative methodologies encompass a range of techniques, including Focus Group Discussions, Depth Interviews, and innovative approaches such as monitoring social media, making observations, and conducting ethnographies. For the present research, Depth Interviews have been selected as the most suitable method, aligning closely with the research objectives and meeting the study’s specific requirements.

### 3.2.2 Quantitative approach

In contrast, quantitative methods are focused on measuring data and presenting it numerically using statistical tools like tables, graphs, and charts. These methods typically involve larger sample sizes and aim to minimize errors due to the objective and standardized nature of the data. Quantitative research employs a structured approach, in contrast to the spontaneity and flexibility often seen in qualitative research.

Quantitative methodologies are commonly implemented through surveys or questionnaires, which may incorporate rating scales (example: Likert scale) to quantify motivations and viewpoints. In line with the objectives of this study, we have conducted quantitative data collection through questionnaires. A Likert scale is a psychometric scale commonly used in questionnaires, and is the most widely used scale in survey research, such as that conducted by market research and social science. The Likert scale is named after its inventor, psychologist Rensis Likert [38]. A Likert scale typically consists of a series of statements, each of which is rated on a scale from 1 to 5 (or sometimes 1 to 7) in terms of the extent to which the respondent agrees or disagrees with the statement. The possible responses are typically labeled:

1. Strongly disagree
2. Disagree
3. Neither agree nor disagree
4. Agree
5. Strongly agree

The Likert scale is a versatile tool that can be used to measure a variety of attitudes, beliefs, and opinions. It is relatively easy to administer and score, and it is widely accepted by researchers. However, the Likert scale has some limitations, such as its susceptibility to response bias and its inability to measure the intensity of respondents’ opinions.

### 3.3 Semi structured Interviews

Data collection involves acquiring the necessary information to address specific research questions outlined in the initial stages of a research project [52]. Semi-structured interviews were chosen as the data collection method to gather focused qualitative and descriptive data. They are considered ideal due to their focused and structured nature on specific topics, yet flexible enough to pose open-ended questions, allowing participants to provide descriptive responses [31].

Prepared questions follow a progression from broad to complex, recorded via mobile phone, and subsequently analysed to extract pertinent information. However, it’s notable that with semi-structured interviews, the gathered information is influenced by the interviewer’s skill in asking relevant questions [1]. In this context, the objective was to comprehend the perspectives of participants, who were case company employees associated with two distinct organizations within the company [31]. By analysing these interviews, insights into the participants’ knowledge levels and their perceptions of the organization under scrutiny will be gained.
3.4 Scientific approach

Given that theories and observations are the two pillars of science, scientific research operates at two levels: a theoretical level and an empirical level. The theoretical level is concerned with developing abstract concepts about natural or social phenomena and the relationships between those concepts (i.e., building “theories”). The empirical level is concerned with testing the theoretical concepts and relationships to evaluate how well they reflect our observations of reality. The ultimate goal is to enhance theories over time, making them more refined and better aligned with observed reality, leading to the advancement of science. Scientific research involves a continuous back-and-forth movement between theory and observations. Both theory and observations are indispensable components of scientific research. Relying solely on observations for making inferences while disregarding theory is not considered valid scientific research[8].

Deductive and Inductive

Inference is the process of drawing conclusions from known facts or evidence. There are mainly two types of inferences: inductive inferences and deductive inferences. The primary difference between inductive and deductive reasoning lies in their objectives. Inductive reasoning aims to develop theories, progressing from specific observations to broad generalizations. Conversely, deductive reasoning aims to test existing theories, moving from broad generalizations to specific observations.

Inductive inference primarily involves amplifying knowledge to derive conclusions that go beyond the existing knowledge. However, conclusions derived from solid inductive inferences, even with true premises, remain fallible and might be incorrect. When there is a lack of prior literature on a topic, inductive research is often conducted due to the absence of a theory to validate. The inductive approach consists of three stages: observation, identifying patterns, and forming a theory. An inherent limitation of the inductive approach is that conclusions drawn from it can never be definitively proven but can be invalidated.

On the other hand, deductive inference mainly revolves around clarifying knowledge by organizing and reconfiguring existing information without introducing new content. Conclusions resulting from valid deductive inferences with true premises are inherently true. When conducting deductive research, a pre-existing theory (usually the outcome of inductive research) serves as the starting point. Deductive reasoning involves testing these theories. If no theory exists yet, deductive research cannot be conducted. The deductive research approach comprises four stages: beginning with an existing theory, formulating a hypothesis based on the theory, collecting data to test the hypothesis, and analyzing the outcomes. The limitation of a deductive approach lies in the requirement that the conclusions of deductive reasoning can only be true if all the premises established in the inductive study are accurate and well-defined. Both approaches are utilized in various research types, and it’s not uncommon to combine them within a single comprehensive study.
Chapter 4

Mapping the Current Status

Under this section, Current situation in company and the problems to be solved is analysed. First of all, it is important to understand the case company and its way of working and the organisation in general. Also it is important to understand in detail about way of working of each target departments for the study in the case company and also understand the stakeholders for this research work. Effort has been made to understand various affected departments in detail by conducting interviews with personnel working in each of those departments. In this section, information from various documents in Case company Web is also gathered and explained with respect to the thesis work.

This thesis is undertaken at a substantial Manufacturing Company boasting a workforce of more than 50 thousand employees and a global presence spanning over 100 countries. It operates manufacturing facilities in multiple countries worldwide to cater to customers across the globe, with its headquarters situated in Sweden. Renowned for its technological innovation, the case company excels in producing advanced products like Trucks and Buses. Additionally, the company engages in the production and distribution of marine engines and other automotive components.

Managing large-scale production entails intricate challenges, prompting the introduction of numerous directives and standards within case company. These standards encompass documents that outline established methodologies or technical specifications for tools and products crafted in the production facility. Given the magnitude of the company, it becomes apparent that establishing standard procedures for all tasks is crucial to achieve optimal productivity. Therefore, this research strives to formulate a comprehensive standard that guides diverse departments in the seamless integration and adoption of smart technologies.

4.1 Final Assembly Plant MS

Case company operates various manufacturing units worldwide, including the Final Assembly Plant situated in Sweden. Within this facility, the internal logistics systems facilitate the delivery of components essential for truck and bus production. These components are then integrated within two extensive assembly lines, culminating in the production of complete truck and bus chassis, hence the name “final assembly.”

The majority of assembly tasks within the final assembly plant are carried out manually by operators, utilizing electric and pneumatic tightening tools. Automation, such as robots or automated guided vehicles (AGVs), is minimally employed. During interviews, production engineers expressed a strong interest in incorporating new technologies to address existing efficiency issues and enhance overall production management. Current problem-solving methods rely on traditional approaches, lacking a comprehensive perspective that could integrate modern and smart solutions. A notable instance pertains to the training of Assembly Operators. High turnover among operators results in the loss of tacit knowledge and extends the time required for training new employees in the same tasks. Smart technologies like virtual training or Virtual Reality (VR) training hold promise for rapid training. However, these technologies remain unimplemented, lacking both application and a corresponding case study to explore their potential advantages. As a result, the case company is presently not capitalizing on these advantageous opportunities.
The majority of assembly tasks within the final assembly plant are carried out manually by operators, utilizing electric and pneumatic tightening tools. Automation, such as robots or automated guided vehicles (AGVs), is minimally employed. During interviews, production engineers expressed a strong interest in incorporating new technologies to address existing efficiency issues and enhance overall production management. Current problem-solving methods rely on traditional approaches, lacking a comprehensive perspective that could integrate modern and smart solutions. A notable instance pertains to the training of Assembly Operators. High turnover among operators results in the loss of tacit knowledge and extends the time required for training new employees in the same tasks. Smart technologies like virtual training or Virtual Reality (VR) training hold promise for rapid training. However, these technologies remain unimplemented, lacking both application and a corresponding case study to explore their potential advantages. As a result, the case company is presently not capitalizing on these advantageous opportunities.

Standardization is a crucial operational approach adopted by the case company. Standardising the work that tasks are described and executed in a same way every time so that the problem can be detected and solved – as emphasized in the Case company’s Production System Booklet. For instance, during the assembly of a tire onto a truck, a defined standard outlines the precise assembly sequence and appropriate tools, along with the rationale underlying this procedure. Multiple standards may pertain to a single area, such as inspecting tire quality before assembly. This standardization extends to activities like tool procurement by production engineers, who follow established procedures to enhance efficiency. This structured process assists employees in making informed investment decisions. These processes have matured over time and are deeply integrated in the organizational culture. In instances where novel tasks lack established standards, new standards are formulated. Every unit within the case company is accountable for devising its own standards, subject to higher-level approval. In scenarios involving multiple stakeholders in standard development, administrative complexity escalates, necessitating assembly of authorizing entities, collectively making decisions in the meetings.

The Assembly plant located in Sweden represents a production facility operating under the guidance of the Case company’s Production System (SPS). Drawing inspiration from the renowned Toyota Production System, SPS has been seamlessly customized to suit the case company’s operations. The comprehensive overview of the Case company’s Production System, along with its core principles and priorities, is depicted in Figure 4.1. Emphasized in one of the SPS documents is the notion that this production system fosters a unified mindset among all stakeholders, striving collectively for optimal outcomes.
A study has introduced a specific maturity model for assessing the final assembly unit’s maturity level, drawing from an existing model. This model’s applicability was verified within the context of the heavy automotive industry and subsequently customized to align with the distinctive attributes of final assembly, particularly its prominent manual assembly operations. The study indicates that while the final assembly unit may currently lack sophisticated technologies, the prevailing attitude among the workforce is receptive to the integration of such advanced technologies\[37\].

The Final Assembly Plant at the Case Company regularly undertakes projects aimed at enhancing the Assembly Line. These projects encompass upgrades to tools, equipment, and at times, even the entire assembly line itself. Each project is overseen by a dedicated project team, tasked with facilitating the implementation of changes and improvements. Furthermore, these project teams play a vital role in the integration of new parts, components, and products into the assembly line for production purposes.

In instances of new product introductions, substantial investments are often required, particularly when significant design alterations are involved. For instance, if a design change is made to the gearbox housing together with case company’s Research and Development (RD) department, the existing lifting tool in the final assembly might no longer be suitable for the new design. This could necessitate the acquisition of a new lifting tool to accommodate the updated design. Similarly, the launch of an entirely new truck generation may prompt adjustments to the production process. The factory’s existing setup might not be compatible with the new product structure, resulting in the need for multiple investments to facilitate the successful integration of the new product.

Distinct processes exist for procuring tools and equipment, as well as for introducing new products onto the assembly line. These processes are meticulously outlined, featuring comprehensive steps and checklists that aid project managers in efficiently overseeing project realization. Continuous improvements to these processes are made based on insights gained from prior projects, ensuring ongoing enhancement and refinement. A notable observation regarding the Final Assembly Plant pertains to the approach taken when investing in machines or technology on a smaller scale. In such cases, there tends to be a lack of
coordination among these individual investments. However, when a significant investment is made under the purview of a single project manager, coordination is often achieved at the factory level. Nonetheless, this coordination might not extend to the broader company (Case Company) level.

This coordination gap becomes particularly evident when dealing with smart technologies. Smart technology offers numerous benefits, and its capabilities can be harnessed even when deployed at a local level without the need for integration with other factories. However, a crucial aspect of many smart technologies is their reliance on data. If this data is not centrally integrated or if the smart technologies are not scaled up to operate at the company-wide level, the technology’s complete range of benefits might not be fully realized.

Based on my preliminary investigation of the Final Assembly Plant, it’s evident that there has been a lack of adoption of Smart technologies so far and the reasons for this are outlined as follows:

- Absence of Digitization Strategy: The factory lacks a comprehensive digitization roadmap, which leaves project managers and other decision-makers without specific guidelines for integrating smart technologies.

- Limited Awareness: There is a lack of awareness about the existing smart technologies themselves. This lack of knowledge serves as a barrier to their adoption.

- Competence Gap: The factory lacks the necessary expertise and skills to effectively handle and manage smart technologies, hindering their implementation.

In light of these factors, it’s clear that there are significant challenges to introducing smart technologies within the Final Assembly Plant. The prevailing consensus within the Case Company is that numerous production challenges could be effectively addressed through the implementation of smart technologies. Moreover, there’s a recognition of the need for an “Expert Unit” specializing in Smart Technologies to guide and streamline their integration into production processes. To meet this need, the company has established the Smart Factory Lab (as detailed in Chapter 4.2) with the aim of facilitating the adoption of these technologies within existing production facilities.

However, it’s apparent that the Smart Factory Lab currently lacks an established process for seamlessly introducing or transferring these technologies to the factories. Consequently, there is a pressing requirement to establish a clear-cut process for the assimilation of smart technologies within Production Units, such as the Final Assembly, as well as a collaborative framework for technology transfer in conjunction with the Smart Factory Lab.

### 4.2 Defining Smart Factory Lab (SFL)

Amid the growing recognition and anticipation surrounding Industry 4.0, the Case Company, embarked on a proactive journey to align with this transformative concept. A significant stride in this direction was the establishment of the Smart Factory Laboratory (SFL). Recognizing the distinctiveness of these emerging technologies from the existing technological landscape, Case company realized the imperative to create a dedicated space for their integration. Consequently, the SFL was conceived as an initial testing and showcasing ground for these advanced technologies within the broader context of Case company.

In 2017, the inception of SFL took shape as a project and case study aimed at deciphering the implications of the fourth industrial revolution for case company. Concurrently, scattered smart technology projects were already underway throughout Case company, laying the foundation for the convergence that would define SFL. The decision to unify these endeavours under the banner of the Smart Factory Lab presented an apt solution, facilitating streamlined project monitoring and management within a cohesive framework.

This endeavour marked case company’s one of the inaugural stride towards standardization of smart technology integration and implementation, ushering the organization into Industry 4.0. The nascent nature of SFL meant that it did not initially possess a designated physical space. Following iterative relocations, SFL found its home adjacent to the final assembly plant. This spatial proximity piqued curiosity among the assembly plant personnel, ultimately catalysing the inception of this very thesis
work. With an allocated space of 400 square meters for the lab and over 100 square meters for office facilities, SFL operates with a dedicated team under the leadership of a team manager. The core team collaborates closely with company’s IT department to secure essential IT competencies. Moreover, SFL attracts personnel from various other departments within the company who rotate through the lab, engaging in projects of varying durations. Aligned with case company’s organizational structure, SFL falls under global Industrial Development department.

SFL’s collaborative ethos extends beyond, with external companies like Ericsson and Atlas Copco contributing their technological expertise. These external companies frequently present their cutting-edge products and services, which are subsequently evaluated, tailored, and tested to align with case company’s operational requirements. In a testament to its broader industry connectivity, SFL also hosts employees from fellow VW Group member MAN, fostering knowledge exchange and cross-sharing of expertise.

4.2.1 Smart Factory Lab Vision and Mission

"A connected manufacturing engineering and operational environment for predicting and optimizing processes" - Smart Factory Vision

The vision of the Case Company’s smart factory closely aligns with the ongoing global developments in digitization and Industry 4.0. A central theme in this vision is the seamless integration of all operational activities. This entails the digital standardization and interconnectivity of all factory operations, encompassing real-time or frequent data acquisition and subsequent analysis. The overarching goal of this data-driven approach is to anticipate future trends and employ these insights to enhance safety, productivity, and more, as illustrated in Figure 4.2.

Figure 4.2: Smart Factory Pyramid adopted by case company shows the steps towards a predictable future

However, the vision statement goes beyond this to encompass the connection of manufacturing engineering processes with operational production aspects. This envisions a comprehensive modernization of not only the production methods but also the manner in which processes are adapted, new products are introduced, operations are altered, and tools and equipment are deployed. These components are intended to be synergistically linked, culminating in a highly sophisticated Smart Factory environment.
The Smart Factory Mission succinctly captures the purpose of the Smart Factory Lab: "Adapting, evaluating and demonstrating production and logistics technologies in the Case company and its partner brand’s environment. Technologies that move the truck and bus production towards the Smart Factory Vision." This mission statement effectively communicates the lab’s raison d’être and its intended direction to all stakeholders. Its scope encompasses both external technologies and those originating within the lab itself. The sources of these technologies vary, including external companies offering solutions, universities conducting cutting-edge research, and others.

For technologies sourced externally, customization and adaptation are often necessary to align with case company’s stringent safety standards and other requirements. Rigorous evaluation is a cornerstone of the lab’s function. Given limited smart technology expertise within case company, the lab has adopted a standardized evaluation process. This evaluation framework is anchored in case company’s priorities as defined in the SPS house: Safety, Health, Environment (SHE), Quality, Delivery, and Cost. Therefore, the evaluation conducted by the Smart Factory Lab gauges how a technology impacts these vital priorities.

In addition to evaluation, the lab also assumes the role of demonstrating technologies within a controlled laboratory setting. These demonstrations target engineers, decision-makers, and anyone interested in smart technologies. Even collaborating companies like Ericsson and Atlas Copco express interest in these showcases.

The Smart Factory Lab aspires to be a central knowledge hub that evolves into a pivotal coordinator of all smart technologies within the case company. By doing so, it envisions playing a guiding role in determining the suitability of new technologies for implementation. In essence, the lab endeavours to become the compass steering decisions regarding the adoption of pertinent smart technologies.

4.2.2 Current functioning of the lab

The Smart Factory Lab operates within a substantial laboratory area that effectively replicates real production conditions. The showcased pedal car, illustrated in Figure 4.3, serves as a simple model for assembly testing. The pedal car’s assembly involves uncomplicated steps, making it an apt platform for evaluating novel smart production technologies. The entire lab space is strategically organized into distinct sectors, each dedicated to specific domains like Assembly, Factory Layout, Machining, and Logistics. Within these sections, a collection of prototype technologies materialize, comprising both hardware and software components. The lab’s overall setup mimics that of a pedal car assembly line, with each workstation hosting an array of undergoing smart technology tests.
Illustrative Project Initiation Scenarios at SFL:

Scenario 1: A project was set in motion by Person A after witnessing a technology demonstration (at SFL demo event) that resonated with their production facility’s challenges. This initiation led to direct contact with Smart Factory Lab (SFL) through phone communication, followed by scheduled meetings. The project centred on a pilot implementation solely within one PRU, where the technology’s suitability was assessed. Eventually, a local project manager within the PRU decided to implement the technology in their operational context.

Scenario 2: In this instance, a project was instigated independently outside of SFL, originating from a production engineering group within a PRU. Recognizing the applicability of a smart technology to address a specific issue, the Engineering group pursued the technology’s acquisition directly from an external supplier, with SFL involvement only occurring at a later stage. However, due to project management challenges, the initiative stalled temporarily. Subsequently, the project was reactivated with SFL’s engagement.

In the aforementioned scenarios, several significant discussions occurred between PRUs and SFL, which regrettably went undocumented as learning experiences. The available expertise within SFL was at times overlooked. Up to this juncture, there has been a lack of a structured procedure for adopting, evaluating, and demonstrating technologies. Here, I am referring to a standardized approach that encompasses the handling of technologies within the lab. While managing a couple of technology projects might be manageable without a standard process, envisioning a lab responsible for the entirety of Case company’s production system highlights the need for a systematic approach. With numerous technologies requiring adaptation, evaluation, and demonstration for over 20 production units worldwide, a standardized operational framework for the lab is indispensable.

Considering the vast scope of technologies and associated individual projects, a standardized way of working is imperative. This structured approach will be referred to as the Smart Factory Lab process (SFL process), serving as the framework for the lab’s operations. Further elaboration on the SFL process will follow in subsequent discussions.
4.3 Initiating Smart Factory Lab Process

During the initial phase of this thesis project, extensive efforts were undertaken through a series of semi-structured interviews to gain insights into the current operations of the Smart Factory Lab (SFL) and its existing workflows. The information presented here is a result of these interviews.

While the concept of the Smart Factory Lab is not foreign to the Final Assembly Plant, interactions between the lab and the assembly plant have been somewhat limited. Consequently, knowledge exchange between the two entities remains limited. Given the physical proximity of the lab to the Final Assembly Plant, there is a compelling need to enhance the connection and cultivate a renewed synergy between these departments. Achieving this synergy necessitates the formulation of an effective communication strategy, and what better way to achieve this than through a well-designed process at case company.

The SFL process is a three step approach outlined by a senior project manager at the case company. It comprises three distinct phases: Idea Management, Sprint Planning, and Pre-study. This process also includes three decision points, as depicted in Figure 4.4. It’s important to note that this three-step process pertains exclusively to activities within the Smart Factory Lab. However, the process of technology transfer doesn’t culminate with the lab’s activities alone. The implementation of a new technology in actual production entails additional steps. For this reason, case company has adapted an existing internal process from its repository, known as the SPS process. The SPS process, although traditionally used for introducing new methodologies or leadership skills, has now been expanded to encompass technology introductions as well. Both the Smart Factory Lab (SFL) and the SPS process will be further elaborated in detail within the context of this thesis.

The first step in the SFL process is **Idea Management**, where the generation of ideas takes place. Inputs and ideas from various stakeholders within the company are carefully analyzed. The ideas, use cases, focus areas, and infrastructure needs are then compiled into a comprehensive list and prioritized based on their business value. Subsequently, items from the list are proposed to be taken forward to the next sprint.

A pivotal aspect of the decision-making process, known as Decision Point -2 (DP-2), determines whether the generated idea should be accepted into the Smart Factory Lab or not. Drawing inspiration from the production’s ANDON system, which employs beacon lights of different colours to indicate various statuses of stations or machines during production, the SFL process employs a similar concept. A green highlight signifies a GO/OK decision, a yellow highlight indicates the need for revaluation and decision in the next sprint, and a red highlight represents a NOGO/Not-OK decision, leading to pausing or archiving the proposed case.

These questions are essential for consideration during the decision-making phase subsequent to the Idea management

- Is realistic to test the idea?
- Did we test this before? Is it enough changes to test again?
- Prioritisation done according to valid priorities?
Are the demands on input for the sprint planning phase fulfilled?

The next step involves Sprint Planning for the selected ideas derived from the gross list. These ideas are organized into pre-studies when deemed necessary. Decision factors encompass elements like the availability of human resources and funds for the technology transfer project, meeting input prerequisites for the subsequent process step, among others, which influence the progression of the project. The project’s advancement is then subject to the decision of pre-established decision groups, such as the Steering Group.

These questions are essential for consideration during the decision-making phase subsequent to the Sprint Planning:

- Manning and funds available?
- AD (Assignment or Project Directive including evaluation criteria) for the pre-study ready?
- Are the demands on input for the pre-study phase fulfilled?

In the Pre-study step, activities planned in the sprint should be executed. Appropriate stakeholders are to be involved in this phase; which includes technicians from PRU, people from the university etc. This phase consist of functions like purchasing and work safety department; Decision points in this step were evaluation and demonstration of results from the pre-study, again to check if input requirements for the next process were fulfilled. The project if approved by the decision group would be handed over this to the next phase, which is the implementation phase of the Project in Production Units and that process is suggested to follow the existing SPS Process.

During the Pre-study phase, the planned activities outlined in the sprint are executed. Essential stakeholders, including technicians from PRU, individuals from the university, and relevant departments within case company, like purchasing and work safety, are engaged. This phase encompasses functions such as assessment and demonstration of outcomes from the pre-study, ensuring that the input prerequisites for the subsequent process step are fulfilled. If the project gains approval from the decision-making group, it proceeds to the next phase – the Project/technology Implementation in Production Units – which is suggested to follow the existing SPS Process.

These questions are essential for consideration during the decision-making phase subsequent to the pre-study:

- Is the result from the pre-study evaluated?
- Is the result from the pre-study demonstrated?
- Are the demands on input to the SPS-process fulfilled?
- Are we ready to hand over to the SPS process?

The governing bodies responsible for decision-making within Smart Factory Lab are the SFL council and the SFL steering group. The Smart Factory Council consists of representatives from the Smart Factory Lab Operations team (SFO), Smart Factory Lab Personnel, Development group representatives, IT (information technology) department representatives, and Research networks within the case company. This council functions as a technical assistance group, ensuring that projects align with technical scope. Conversely, the SFL steering group operates at a managerial level and holds the authority to approve both project concepts and associated budget (costs and expenses). This group comprises Managers from TE (industrial development department), as well as representatives from development groups, IT, purchasing, and work unions etc.

In summary, the decision-making process at each stage is structured around decision points. DP-2 serves as the Idea Management decision point, involving an initial assessment of the idea’s potential for investment and effort, with the SFL council as the decision forum. Following Sprint Planning, DP-1 involves the SFL steering group evaluating financial and resource considerations. The Pre-study phase encompasses DP 0, and the SFL steering group acts as the decision-making body. Fulfilment of prerequisites for entering the subsequent phase (SPS Process) is crucial for this decision point. Figure 4.5 illustrates the comprehensive process for implementing a smart technology in a PRU at case company through the collaboration with Smart Factory Lab.
This section elaborated on the present state of the digitization initiative for the case company’s Production Units, facilitated by the newly established Smart Factory Lab. The outlined Smart Factory Lab process has not yet been implemented within the case company. It stands as an initial conceptualization of a process that has yet to undergo practical testing for the implementation of smart technologies. The subsequent phase of this thesis aims to carry out the case study within a real-world use case. Through testing, refinement, and potential modifications, the objective is to contribute to the establishment of standardized protocols for the introduction of smart technologies.
Chapter 5

Case Study

Since its establishment in 2017, the Smart Factory Lab has conducted numerous tests on various technologies, with only a limited number making their way into actual production. Additionally, the technologies that have been implemented in production did not follow standardized procedures; rather, their implementation occurred on a case-by-case basis without adhering to a predefined process like the Smart Factory Lab Process.

Establishing a standardized operating procedure within the Smart Factory Lab would greatly facilitate the scaling up of technology testing, showcasing, and subsequent transfer to actual production. In this context, senior project managers at Case company conceived a theoretical model based on their process expertise. However, to align this theoretical process more effectively with the company’s actual operations, further refinement is necessary. Thus, a real-life production challenge was chosen to be addressed through a smart technology solution, using the conceptualized Smart Factory Lab Process as a framework.

One goal of conducting this case study is to find the inconsistencies in the process developed. There are lots of practical details that the process can miss if a detailed study has not been conducted. So effort has been made with this case study to understand the real problems when testing and implementing smart technologies from a laboratory environment into the real production environment using the smart factory lab process. To begin with, each of the steps in the conceptualised SFL process are described briefly. Further, the selected production case is run through each of those process steps. Practical know-how found while running the case through each of these process steps is documented and elaborated.

The objective of this case study is to uncover any inconsistencies within the developed process. Practical nuances that might have been overlooked in the process development could become apparent through a comprehensive examination. Thus, this case study aims to comprehend the genuine challenges when testing and implementing smart technologies from a lab setting into actual production using the Smart Factory Lab (SFL) process. The initial step involves providing concise descriptions for each stage in the conceptualized SFL process. Subsequently, the chosen production issue is taken through these process stages. Practical insights gained during the execution of the case within each process stage are meticulously recorded and detailed.

As the case study progressed through each of the SFL process steps, the primary emphasis was placed on meticulously scrutinizing the intricacies of these procedural stages, with a greater focus on the procedural aspects rather than the specifics of the solution pertaining to the production issue. To provide clarity, for the chosen production challenge "Training the assembly operators," the central attention was dedicated to comprehending the nuanced steps within the followed process (SFL process) for devising an smart solution, rather than delving into the minutiae of the actual training solution for operators. The principal objective of this case study remains the identification of any potential disparities within the process and subsequently enhancing its efficiency and effectiveness.
5.1 Idea Management

According to the concept of the Smart Factory Lab Process, the Idea Management phase functions as a funnelling process. During this stage, a diverse array of inputs such as ideas, use cases, new technologies, smart tools, and products are channelled into a consolidated list. These inputs are subsequently evaluated and prioritized based on their potential Business Value. This initial phase marks the inception of collaboration between the Smart Factory Lab and the Production Units. Business cases can be generated from various sources, encompassing:

- **Ideas**: These encompass conceptual solutions, often rooted in smart technology, aimed at addressing production challenges.
- **Use Cases**: Referring to novel applications of existing smart technologies, repurposed to tackle new challenges.
- **New Technologies**: These are innovative solutions adaptable for addressing the case company’s challenges.
- **Smart Tools and Products**: Encompassing software or hardware tools designed to enhance production, development, operations, and maintenance processes.

This collaborative stage serves as a foundational step in aligning the Smart Factory Lab’s capabilities with the needs and opportunities of the Production Units.

The initial step involved selecting a Case Study to undergo the SFL process. Identifying suitable business case for the case study required gaining a comprehensive understanding of the production challenges within the final assembly factory through a smart factory lens. This necessitated conducting multiple factory tours (Go and See) to observe live production processes on-site. Additionally, Idea Management entailed deliberations involving Smart Factory personnel, Final Assembly Managers, and designated individuals responsible for assignments in the Final Assembly department.

From the challenges identified, one issue was chosen as the focus: training the assembly operators. Although there existed a standardized method for operator training in assembly tasks, this existing approach was time-consuming and resource-intensive. Given the predominantly manual operations in the final assembly plant, where various automated tools like nut-runners are employed, effective training in both manual and automated assembly tasks was crucial. The existing training process required 2-4 weeks to fully train a new employee in a specific assembly station. Each assembly station, referred to as a "position," requires one operator to complete tasks in each cycle. Training checklists were available to guide this process. Moreover, high employee turnover necessitated training for new operators lacking prior assembly experience. Consequently, the identified issue revolved around optimizing the training process to reduce time and resource investment.

After consulting technical managers from the final assembly department, considering prevalent production challenges, and assessing available smart technology solutions within the SFL, the decision was made to address the operator training challenge in this case study. The problem statement was tentatively framed as follows: "To expedite operator training while also simplifying the training process, with a focus on enhancing training efficiency." This problem statement served as the foundation for the subsequent stages of the case study within the SFL process.

Subsequently, the outlined problem statement was shared with the Smart Factory Lab team and incorporated into the comprehensive list of business cases maintained by SFL. This list serves as an organized repository for ideas, use cases, and other relevant information. To delve deeper into the identified problem statement, a meeting was arranged involving both the Smart Factory Lab personnel and the representatives from the final assembly staff. This meeting served as a platform to gain a more comprehensive understanding of the nuances and intricacies of the problem at hand. During this session, various technologies were explored, and potential solutions tailored to the specific challenges and scenarios were deliberated upon and documented. The collaborative discussion aimed to identify feasible technological interventions that could effectively address the operator training issue. By leveraging the expertise of
both the Smart Factory Lab and the final assembly staff, a diverse range of perspectives, insights, and potential solutions were amalgamated to pave the way for a more refined problem-solving approach.

The Idea Management phase for this case study yielded the following outcomes:

In terms of resources, the preliminary estimation included the allocation of lab hours within the Smart Factory Lab, the engagement of the Smart Factory Lab working team, project management hours from Smart Factory Operations (SFO), and project lead from the final assembly department. These resource requirements were outlined during the Idea Management Step, serving as an initial outline for resource allocation.

Subsequently, a collaborative effort between the project leader from the final assembly and the Smart Factory Operations led to the formulation of a Project Directive known as the Assignment Directive (AD) within the case company. Further details regarding the AD are available in Chapter 5.2 of the documentation.

In addressing the defined problem statement, the investigation revealed that potential solutions existed within the domain of Virtual Training. By augmenting/simulating the existing physical training process with complementary virtual training methods, the identified problem could be mitigated. Within this context, three primary categories of virtual training for operators were selected for the case study:

1. Quiz Based Training
2. Virtual (Desktop/tablet/mobile-phone) Training
3. Virtual Reality Training

Drawing from these initial discussions, it was determined that the case study derived from the final assembly plant would be presented as a prioritized case during the DP-2 meeting of the SFL council. This Case Study was rephrased from the original problem statement to "Virtual Training." Thus, the solution to address the challenges related to training in the Final Assembly plant involved the adoption and implementation of Virtual Training technologies. Consequently, the available Virtual Training Tools were slated for evaluation during the forthcoming pre-study phase of the SFL process.

5.1.1 Decision Point -2 (DP-2)

Once the case had been thoroughly discussed among various stakeholders, the next step was to present the case before the Smart Factory Lab Council. As the council had not yet been formally established at this juncture, a dedicated meeting was organized for this particular case presentation. The invited attendees for this significant meeting included:

- Technical manager from Final Assembly
- Smart factory Lab Manager
- Smart Factory Operations
- Case lead from the Final assembly plant
- Other parties such as representatives from the Research network, Unions etc

The purpose of this gathering was to present the identified case study, fostering an environment for detailed discussions and deliberations among the key stakeholders. Given the cross-functional nature of the attendees, this meeting served as a platform to comprehensively examine the case, leverage diverse perspectives, and ultimately make informed decisions regarding its progression within the Smart Factory Lab process.
The decision meeting with the Smart Factory Council yielded several crucial discussion points, leading to a decision of the proposed case study:

- **Practicality of the Case:** The meeting began by addressing the core question of whether the proposed case study was feasible to carry out. The attendees assessed the compatibility of the case with the available resources and technologies in the Smart Factory Lab. It was emphasized that the concept of using smart tools to enhance operator learning was not new to the lab, and there were already technologies available that could potentially contribute to solving the training issue. Through thorough evaluation, it was collectively agreed that the proposed case was not only realistic but also aligned with the lab's objectives of exploring and implementing innovative solutions in the production process.

- **Existing Virtual Reality Tools:** The meeting addressed the fact that virtual reality tools were already within the Smart Factory Lab's inventory. Previous attempts to identify viable use cases for these tools were not successful, yet the technology remained accessible within the lab. Despite the lack of documented test results, the decision was made to revisit the technology’s potential by testing it for the new use case within the context of the final assembly plant. This case study aimed to serve as a platform for assessing the effectiveness of Virtual Training through the structured Smart Factory Lab Process.

- **Priority of the Case:** Given the broader goal of testing the newly conceptualized Smart Factory Process, the priority of the case study was deliberated. It was recognized that this case presented a unique opportunity to align the conceptual process with practical implementation. The council acknowledged the importance of having a real-world scenario to apply the new process and identify any gaps, inconsistencies, or improvements. As a result, the case was accorded higher priority, ensuring its advancement within the Smart Factory Lab's initiatives.

- **Sprint Planning Preparation:** The requirements for the sprint planning phase were considered to be fulfilled. The case’s relevance to the Smart Factory Lab's functioning, its deemed feasibility, and the preliminary development of an Assignment Directive and staffing plan all contributed to ensuring the readiness for the sprint planning phase.

With a positive consensus resulting from these deliberations, the Smart Factory Council meeting approved the case study’s progression to the sprint planning phase, marking a significant step. This implies a **GO** decision from the Smart Factory Council meeting and the case study is now moved to the sprint planning phase.

### 5.2 Sprint Planning

During the Sprint Planning phase of the Smart Factory Lab Process, the focus shifts to the practical implementation of the chosen case study. This phase involves breaking down the tasks identified during the earlier phases into actionable steps, allocating necessary resources, and planning for the immediate upcoming sprint.

One of the key components of the Sprint Planning phase is the finalization of the Assignment Directive (AD). The AD, initially outlined during the Idea Management phase, is now refined with more comprehensive and detailed information. It serves as a guiding document for the entire case study project. A detailed AD helps ensure that all stakeholders have a clear understanding of the case’s purpose, objectives, expected benefits, milestones, and resource requirements. The finalized Assignment Directive typically includes the following components:

- **Background:** This section provides context by explaining why the chosen case study is being undertaken. It outlines the challenges, issues, or opportunities that the project aims to address.

- **Objectives:** The objectives section outlines the specific goals of the case study. These objectives serve as benchmarks against which the success of the project will be measured.

- **Expected Benefits:** Here, the potential positive outcomes of successfully implementing the case study are enumerated. This could include improvements in efficiency, cost reduction, increased productivity, or enhanced operator training.
- **Milestones**: Milestones represent crucial checkpoints or achievements within the project timeline. They help in tracking progress and ensuring that the project stays on course.

- **Resource Requirements**: This section details the resources needed to execute the case study successfully. This includes human resources, technical tools, lab hours, and any other necessary inputs.

The Assignment Directive essentially serves as a project plan that provides a comprehensive overview of the case study, its goals, and how it will be executed. It also acts as a communication tool between different stakeholders, ensuring a shared understanding of the project’s scope and objectives.

It’s important to note that during the Sprint Planning phase, the primary focus is on breaking down the Pre-study phase into smaller, manageable tasks. Detailed information about the virtual training solution itself may not be a primary concern at this point. Instead, the goal is to create a structured plan for the practical execution of the case study and to allocate the necessary resources to carry out these tasks effectively within the upcoming sprint.

**Outcome of the Sprint planning phase:**

**Figure 5.1: Assignment Directive**

The objectives outlined for the pre-study phase of the Smart Factory Lab Process are:

- **Evaluate the Suitable Virtual Training Platforms**: The primary objective is to assess and compare the available virtual training platforms to determine which one(s) are the most compatible and effective for addressing the training needs in the Final Assembly plant.

- **Test Expected Benefits**: This objective centres on validating whether the expected benefits of using virtual training technologies are realized in the real-world setting of the Final Assembly plant.

- **Assess Learning Time and Quality Improvement**: This objective aims to determine whether the implementation of virtual training can lead to a reduction in the time required for operators to become proficient in their tasks. Additionally, it seeks to analyse if virtual training contributes to an enhancement in the quality of assembly work, potentially leading to fewer errors or defects.

- **Collect Subjective Opinions**: This objective focuses on gathering the opinions and feedback of the test subjects who undergo virtual training. Their insights, perspectives, and experiences are
valuable in understanding the user perception of the technology, its usability, and its impact on their training and work processes.

The Smart Factory Lab’s Operations (SFO) team will lead the sprint planning and has its crucial role in orchestrating the execution of tasks and activities outlined in the Assignment Directive (AD). The sprint, spanning a duration of four weeks, is a time-bound period during which specific objectives are addressed through a series of targeted actions. The breakdown of the AD into detailed set of activities demonstrates a comprehensive approach to achieving the objectives of the case study, “Virtual Training.”

- **Study the current operator training process.**
  - Detailed study on the current training Methodology.
  - Defining different factors that lead to successful training.
  - Find the measurable Factors. Ex: Training time required for new operator.

- **Theoretical Evaluation of the different Virtual training technologies**
  - Comparative study among the three chosen technologies
  - Clearly define the benefits from each of the technology in terms of the factors defined.

- **Build Proof of Concept**
  - Get license from each of the technology supplier
  - Select the pilot area
  - Build the pilot area in the virtual environment
  - Define the test methodology
    * Choose the candidates for the test
    * Plan the test date and logistical activities needed for the test

- **Test and Evaluate the results**
  - Conduct the test
    * Collect the data as intended
  - Compare the test results from Virtual Training to the current physical training.
  - Report the results
    * Reduced learning time for the operators
    * Improvement in the quality of assembly

Given the limited timeframe of the thesis project, all tasks were consolidated into a single sprint, departing from the conventional agile approach of distributing tasks over multiple sprints. Unlike the standard agile model where the product owner determines sprint priorities, here the Smart Factory Steering Group assumed that role. In contrast to agile product owner, this steering group held the responsibility of selecting sprint activities. While the report doesn’t delve into specific details, resources were assigned to each activity discussed during the sprint planning.

### 5.2.1 Decision Point -1 (DP-1)

The Smart Factory Lab steering group assumes the role of deciding the activities for the upcoming sprint. These meetings encompass not only the presented project but also other concurrent initiatives in the Smart Factory Lab. This necessitates the recurring meeting of the SFL steering group after each sprint planning session. The steering group’s function lies in aligning the sprint’s proposed activities with the overarching vision of the case company as an entity. The steering group meeting convened for the smart factory lab saw the participation of several key stakeholders:

- Management group from Industrial Development department
- Manager from Final Assembly
• Smart factory Lab Manager
• Smart Factory Operations
• Case lead from the Final assembly plant
• Representatives from the Research network
• Union representatives
• Case company’s Purchasing Representative

Given that this case marked a new entry for the pre-study from the Idea Management phase, the Assignment Directive (AD) was presented to the steering group alongside other planned sprint activities.

The Smart Factory Lab steering group meeting yielded the following key discussion points:

• Manning and funds available? Manning was secured for the tasks; the majority of the tasks was assigned to the thesis student. Smart Factory working team also had some tasks assigned to them. Since there was no new investment required in this case study, there was no need for any funding.

• AD (assignment Directive) prepared? AD was presented by the SFO and all parties agreed to the Assignment and its objectives.

With above discussion points it was a GO from the Smart Factory steering group and the case study is now moved to the pre study phase.

5.3 Prestudy

The pre-study phase is the execution stage of the activities outlined in the sprint planning. It’s essential to ensure that tasks are appropriately divided into manageable segments during the sprint planning, allowing the allocated resources to have a clear and attainable focus during the sprint. The primary objective of the pre-study isn’t to arrive at a perfect solution for the virtual training case but to adhere to the Smart Factory Process and verify and refine the process’s effectiveness.

As you delve further into the report, it’s possible to encounter certain uncertainties in reporting the pre-study results. The emphasis lies in the validation and streamlining of the process rather than an exhaustive solution to the virtual training problem.

Following are the outcomes of the sprint for prestudy:

5.3.1 Study the current operator training process

Understanding the production issue in depth is the initial step in this phase, involving gathering input from all relevant parties. It is imperative to attain consensus within the working group concerning the identified issue or problem before proceeding with the solution-finding process. Given the potential for errors or misunderstandings in articulating requirements or problem statements from production units—often due to a lack of familiarity with smart tools and their capabilities. Addressing key questions becomes crucial and this includes clarifying the genuine needs of the customers, where in this case, the customer refers to one of the production unit that is the final assembly plant.

Information was gathered through discussions with Production Managers regarding the training of new employees, particularly focusing on operator training. This training process encompasses several key components:

• Intro Week: New employees undergo a 4-day training at the Case company’s Education Academy immediately after recruitment. This period covers organizational rules and regulations and is termed the “Intro Week.”

• Code of Conduct: Training regarding the company’s code of conduct is provided.
• Mentorship: Each new employee is assigned a dedicated trainer or mentor for the entire training duration.

• Factory Training: This involves a comprehensive process, including:
  – Factory Tour to showcase workplace safety measures.
  – Shadowing the trainer/mentor at the assembly station to observe and learn the assembly process.
  – Learning one position in the assembly line, which takes 2-4 weeks.
  – Considering ergonomic factors, an operator learns 2-3 positions that they will rotate during shift work.
  – Encouraging operators to learn multiple positions for a flexible work environment and production management.
  – Training on using position standards and element sheets, which are essential reference documents. They are defined in Chapter 4.1

• Upon mastering at least 3 positions, basic training is complete, usually taking 6-10 weeks.
  – Enhancing Competence: Ongoing training is provided to operators who have already undergone basic training. This continuous training enables them to handle various assembly positions along the production line. This increased competence fosters flexibility in the production process, allowing operators to seamlessly switch between different positions as needed.
  – Quality Maintenance: Quality is paramount in assembly work. With time, there might be a decline in the quality of assembly output. Regular training sessions are crucial for operators to maintain and enhance their skills. By keeping operators well-trained and up-to-date, potential quality issues can be minimized or eliminated, ensuring that production maintains high standards.
  – These continuous training efforts contribute to maintaining a skilled and adaptable workforce, which directly impacts the efficiency and quality of the assembly process.

Figure 5.2: Element Sheet used by the operator in production. Image Source: Case company’s web
In the context of defining assembly tasks, two essential documents play important role:

- **Element Sheet** (Figure 5.2): Serving as the core reference, the element sheet offers a comprehensive breakdown of each assembly task. This document goes beyond merely outlining the assembly steps; it delves into the very essence of the task. It answers critical questions concerning the "What," "How," and "Why" aspects of the assembly process. The Purpose of the element Sheet is to describe the method to get zero deviation and zero accidents during the assembly process and also to enhance productivity.

- **Position Standard**: This document serves as a comprehensive guide for a specific assembly position. It encompasses various key elements:
  - All the assembly steps involved in the respective position.
  - The sequence in which these assembly steps should be executed.
  - Essential metrics such as tact time, cycle time, and occupancy, which are pivotal for maintaining efficient operations.
  - Information about different variations that might exist for the specific assembly task depending on the product to be assembled.

Both the element sheet and the position standard are integral to establishing a standardized and optimized assembly process. They collectively provide a clear path for operators to follow, ensuring consistent quality, safety, and productivity in the production line.

![Figure 5.3: Training Framework for assembly operations](image)

Examining the table presented in Figure 5.3 allows us to comprehend the distinct phases of knowledge acquisition in operator training. This reveals a clear demarcation between what can be effectively imparted through computer-based training (virtual) and what necessitates hands-on training. Thus, it was evident from the outset of the pre-study that eradicating physical training entirely is unfeasible. Virtual training serves as a supplementary tool to amplify and speed up the established physical training methods.

When we juxtapose this table with the ongoing physical training regimen within the company, it becomes evident that all facets of cognitive training are already addressed. This is achieved through hands-on practice, observation of assembly procedures, and learning from paper-based materials.
5.3.2 Evaluation of different Virtual training technologies

A comprehensive evaluation was conducted on the array of virtual training tools, encompassing the three distinct categories of virtual training technology. These technologies were examined to discern their suitability and effectiveness within the context of operator training.

- **Quiz Based Training**: SeQualia adeptly emulates the existing element sheets within real production and converts them into interactive quiz-style modules. These modules not only furnish information on what, how, and why specific assembly operations are performed, but they also challenge operators to engage with the content. While SeQualia enhances operators’ knowledge of product and assembly sequence, it predominantly targets cognitive aspects, somewhat lacking in imparting the finer intricacies of assembly finesse.

- **Desktop Training**: Vizendo/Siemens, representing Virtual Training Solutions, presents a software option tailored for training operators within a virtual 2D environment, displayed on digital screens. This software allows operators to engage in a sequence of assembly steps, closely replicating authentic assembly scenarios. Vizendo is a comprehensive virtual training tool that originates from the company Vizendo. The proprietary nature of Vizendo’s tools means that the company retains ownership, distributing licenses to clients such as this Case company.

- **Virtual Reality VR**: To develop operator training, a suitable software platform is necessary. The Smart Factory Lab employed the Unity Game engine to construct a virtual reality environment for assembly operations. In this setup, operators don VR headsets, immersing themselves in a virtual assembly environment and following a step-by-step training program designed for enhanced learning. This training closely mirrors the actual work environment, enabling operators to move and navigate as if on the factory floor. Sensors track operators’ movements, providing a realistic experience by offering feedback through tactile sensations, such as handheld device vibrations. Unity VR is one such platform enabling the creation of this virtual environment.

A game engine is essentially a software framework facilitating the integration of elements like 3D models and programmed behaviours. For instance, in a game, you interact with a 3D character that responds to keyboard inputs by moving and performing actions. Unity is a notable game engine that offers advanced features, including real-time rendering. While renowned for gaming, Unity is versatile and applicable in industrial settings, such as manufacturing and digital twin capabilities. The flexibility of a game engine, like Unity, is a major advantage, allowing programming of diverse functionalities required for VR training, including sensor inputs and interactions with real machines in production scenarios.

Developing a virtual reality environment involves several steps:

- **Creating the Soft Story**: This includes scripting the training steps clearly, ensuring understanding by both Virtuality Tool Developers and the Entity Procuring the tool. Production resources involved in the relevant assembly tasks contribute their insights to tool development.

- **Programming**: This encompasses various aspects such as:
  - **3D Models**: These models enable user interaction. For example, in peddle car assembly, each visible component is represented by a model.
  - **Behaviours**: Rules for 3D model movements within the VR environment.
  - **Process**: Instructions and steps displayed on the screen based on the procuring entity’s defined process.

- It’s noteworthy that only the developer needs an understanding of the Unity game engine, while trainees should be able to operate the software without detailed Unity knowledge.

With regards to quiz-based training, it was determined that its benefits were already encompassed by desktop (virtual) training. Thus, it was concluded to further evaluate only Desktop and Virtual Reality training through actual user testing.
5.3.3 Design of experiment and conducting Subjective Evaluation

In this case study on Virtual Training, we formulated a subjective evaluation method for two distinct Virtual Training Tools: Vizendo (a virtual/desktop training tool) and Unity VR (a virtual reality training tool). The evaluation process was designed for participation by a specific group of employees chosen from the case company.

As an integral part of the Pre-study phase, the evaluation process will involve a direct comparison of the training materials developed for the Pedal Car Assembly using the two designated Virtual Training tools. The selection of the pedal car assembly for training material development is strategically beneficial due to its relatively simple assembly steps. Furthermore, the absence of specific permissions required for sharing assembly information with the Virtual Training tool supplier simplifies the process. This approach ensures a comprehensive assessment of the suitability and effectiveness of both Vizendo (virtual/desktop training) and Unity VR (virtual reality training) tools.

5.3.3.1 The process of creating training material (content) and preparing the tools for the evaluation involved several key steps:

- The Smart Factory Lab (SFL) personnel arranged the setup of computers and necessary peripherals for the evaluation test.
- Since software tools often require access to case company’s internet network, IT team support is usually necessary. However, due to the laboratory setting, this test was conducted without IT support, without considering data security implications.
- Acquisition of licenses to utilize the Virtual Training tools under evaluation was a prerequisite.
- The central task was content creation, involving the establishment of a virtual environment and the incorporation of assembly steps within the selected tools. These steps aimed to simulate the physical assembly environment and replicate the assembly sequence for the Pedal Car assembly.
- The content creation process varied for each of the evaluated tools, reflecting their unique methodologies.
- Unity VR:
  - Unity VR is an actively developing tool, signifying that its complete potential hasn’t been fully explored. Consequently, only minimal training material had been generated by the SFL for testing purposes.
  - The evaluation’s required training material was already available, having been produced by SFL personnel as part of their exploration of the VR training tool. This rendered any new content creation unnecessary during the case study.
- Vizendo
  - The tool license was obtained from the supplier, Vizendo Company, at no cost. This advantageous practice entails that supplier companies offer their tools to the Smart Factory Lab for testing purposes.
  - a collaborative effort between SFL and Vizendo had resulted in the creation of content for the Pedal Car assembly. For this particular case study evaluation, the existing content was utilized, obviating the need to generate new animations or materials.

5.3.3.2 Design for the Evaluation

- Criteria’s taken into account while designing the tool evaluation
  - Function: How effectively does the tool meet task requirements?
  - Ergonomics: How ergonomic is the solution?
  - Ease of use
  - Time Criteria: Time savings when using virtual tool vs. traditional methods
Cost of virtual tool
Estimated introduction cost and time for the tool
Tool maintenance
Adaptability of tools to changes

- The target group for the evaluation comprised individuals associated with assembly operations in the final assembly plant, encompassing both blue-collar and white-collar employees.
- Participants were presented with a consent form, which they were requested to sign to indicate agreement with its clauses.
- Participants were invited to the Smart Factory Lab where both the Vizendo and Unity VR tools were set up side by side.
- They first engaged in Vizendo training, followed by the same training in virtual reality.
- Post virtual training, participants physically assembled the pedal car, with safety protocols in place.
- After completion, participants completed a questionnaire. Participants responded to the questions using the Likert scale (as detailed in reference 3.2.2), a commonly employed research scaling technique. The Likert scale prompts respondents to indicate their level of agreement or disagreement on an agree-disagree scale for a series of statements. The five-level Likert item format, for instance, ranges from "strongly disagree" to "strongly agree."

5.3.3.3 The questionnaire prepared for the test:

Questionnaires were carefully formulated to address the primary objectives outlined in the Assignment Directive. These objectives primarily encompassed identifying the optimal Training Tool for implementation in the Final Assembly Plant and gauging the benefits associated with these Virtual Training tools.

1. Is it easy to use the application?
2. Was it difficult to find the options to click and proceed with the training?
3. The following tool is a good tool to get product/part Knowledge (Product shape, features etc)?
4. Following is a good tool to learn assembly sequence?
5. Following is a good tool to learn assembly operation/process. (Functionality of the Tools used, Interface between the parts etc)?
6. Following is a good tool to learn about the ergonomic aspect of the assembly process?
7. Following tool is a good at enhancing current training method, and it will help is decreasing the training time for new operators?
8. Following tool is a good at enhancing current training method, and it will help prepare the operators for low volume variants?
9. Following tool will make it easier to train operators for new position and thereby facilitate job rotation?
10. Following tool has a potential business value and thus should be implemented in Final Assembly Plant?
11. Would the following make the training more fun/interesting?
5.3.3.4 Evaluation Results and analysis

The evaluation results have been presented here. The Evaluation Questionnaire was developed using Google Forms, facilitating the collection of results in a format conducive to straightforward analysis.

![Figure 5.4: Responses Chart](image1)

Figure 5.4 illustrates that the evaluation involved 13 participants, primarily composed of Production Engineers from the Final Assembly Plant. The evaluation further included participation from the Operations segment, including Engineering Managers.

![Figure 5.5: Experience of respondents](image2)

Figure 5.5 indicates that over 80 percent of participants possessed two or more years of experience within the case company. The horizontal axis represents the number of years of experience, while the vertical axis denotes the number of individuals.
In Figure 5.6, it is evident that Vizendo is notably more user-friendly in comparison to Unity VR. The chart displays a higher number of individuals who strongly agree with Vizendo's ease of use. However, this trend might also be attributed to the innovative nature of the user interface for Virtual Reality (VR), involving handheld devices for screen control, as opposed to Vizendo's computer-based training.

Figure 5.7 illustrates that participants encountered challenges in locating options within the training content for both Vizendo and VR. This difficulty might be attributed to the participants’ initial exposure to the tools. It is reasonable to anticipate that with increased usage, this issue could naturally dissipate. Furthermore, the user interface could be enhanced if necessary, offering potential improvements in the future.
Figure 5.8: Question 3.

Figure 5.8 indicates that both Vizendo and VR are effective in imparting product knowledge to trainees, with a particularly strong agreement in the case of VR. This consensus could potentially stem from the fact that in VR, trainees can visualize parts in three dimensions, leading to a heightened comprehension of the shape and characteristics of the assembled components.

Figure 5.9: Question 4.

Figure 5.9 illustrates that Vizendo is notably superior for learning the assembly sequence. This discrepancy could be attributed to Vizendo’s incorporation of multiple training levels, effectively gamifying the learning process. This gamified approach involves four distinct levels of training. The initial level provides comprehensive instructions along with highlighted assembly parts. As the trainee advances, instructions diminish, requiring the trainee to apply knowledge gained from previous levels. Mistaken assembly steps are marked and corrected until proficiency is achieved.

While VR holds promise for teaching assembly sequences and offers endless gamification possibilities, such functionalities demand substantial resources for development. Consequently, the VR evaluation focused on a single-step training scenario, forgoing the multi-level approach.
Figure 5.10 presents the efficacy of the Virtual tools in instructing the assembly process itself. Assembly line complexity greatly varies, encompassing factors operators must consider and tools they employ to complete tasks.

Vizendo allows users to select necessary tools and assembly parts on the screen for each operation. However, the assembly process is displayed in a 2D format and lacking immediate feedback on accuracy.

In contrast, VR employs handheld devices to provide haptic feedback, guiding trainees on correct assembly techniques. Moreover, spatial feedback in VR aids trainees by presenting precise 3D assembly positions and methods, enhancing the immersive training experience.

Figure 5.11 indicates that VR excels as a tool for training assembly operation ergonomics in comparison to Vizendo. VR training is executed within a 3D environment, offering trainees real-time feedback on ergonomic posture during training. The evaluation results strongly support VR’s effectiveness in this aspect.
Figure 5.12: Question 7.

Figure 5.12 illustrates that the majority of participants strongly agree that both Vizendo and VR are tools capable of reducing operator training time. This aligns with a major anticipated advantage of virtual training tools: resource reduction in operator training. While this evaluation showcases the potential Case Study for virtual tools, it also suggests the need for a more comprehensive study to delve into the specifics.

Figure 5.13: Question 8.

Figure 5.13 demonstrates that participants strongly agree that both VR and Vizendo are beneficial in enhancing the current operator training method. This consensus among participants suggests that these tools can effectively complement the existing physical training process.
Figure 5.14: Question 9.

Figure 5.14 indicates that participants are in agreement that these tools can be valuable for training operators in new positions, signifying the potential to enhance operators’ competencies through the use of virtual tools. A significant advantage is that operators can train themselves without the need for mentors/trainers.

Figure 5.15: Question 10.

Figure 5.15 demonstrates that a majority of participants hold the belief that there is business value associated with these tools, while some participants express disagreement with this viewpoint. This indicates the necessity for a comprehensive and detailed study to be conducted to thoroughly evaluate the potential value in the business case.
Figure 5.16 illustrates that both VR and Vizendo training methods are perceived as more enjoyable and engaging for the operators. This aspect of making the training process enjoyable is significant for fostering the adoption of new technologies.

5.3.4 Analysis of the Prestudy

- There is evident business value in adopting virtual training tools, primarily due
  - Time savings in operator training
  - Increased operator competence.
- The tools are user-friendly and can be readily adopted by operators in their training processes, although some initial guidance might be necessary.
- Both Vizendo and Unity VR excel in imparting product knowledge and familiarizing operators with different part variants.
- Gamifying operator training proves to be an effective strategy for enhancing training efficiency.
- Learning the assembly sequence, a critical aspect for operators, is significantly facilitated by these virtual tools. This leads to reduced production deviations and improved customer satisfaction.
- Unity VR receives a higher rating for learning the assembly process, while Vizendo also boasts features beneficial for learning the assembly sequence.
- Virtual tools, especially VR, offer training in maintaining proper ergonomics during assembly tasks, contributing to operator well-being.
- These findings suggest that the adoption of virtual training tools can greatly enhance operator training efficiency and performance in the final assembly plant.

5.3.4.1 Vizendo (Virtual/Desktop) Training:

- The training analysis can delve into specific assembly steps that posed the most difficulty for operators to learn. By aligning this data with production deviation records, a clear picture emerges regarding areas that require operator training.
- The correlation between training data and production deviations can guide targeted operator training using virtual tools. Virtual training proves particularly valuable in addressing the specific assembly operations.
• Process Update: Given the constant addition of new assembly operations in the production facility, it’s crucial to integrate these into the virtual environment. However, this updating process is manual and potentially time-intensive. Vizendo operates on a unique ID system for each assembly operation, which diverges from case company’s lack of assigned unique IDs to its operations.

5.3.4.2 VR (Virtual reality) Training:
• Complex assemblies can pose significant challenges when developing training content for the VR environment.
• Process Update: Consistent addition of new operations to the production facility requires substantial effort for their incorporation into the virtual environment.
• Efficient development of training content is crucial, aligning with the frequent changes in assembly procedures. Flexibility in training content adaptation is paramount.
• The ergonomics of the VR tool need to be assessed, including its long-duration wearability.

5.3.4.3 Delimitations in the Case Study:
• Operator Training Methodology: The existing operator training approach lacks exhaustive definition, including crucial aspects like success parameters and their statistical analysis.
• Limited Tool Evaluation: The assessment covered only few available virtual training tools, potentially omitting other tools in the market.
• Absence of Technical Benchmarking: The study lacks technical benchmarking against alternative technologies.
• Content Creation Omission: The prestudy did not involve content creation, thus precluding evaluation of experience in creating content for Vizendo and Unity VR.
• Maintenance Evaluation Gap: Maintenance aspects of the evaluated virtual training tools were not scrutinized.
• Network Integration Unaddressed: The study did not assess seamless integration of these tools into case company’s network system.
• Skewed Participant Representation: Predominantly involving engineers and white-collar employees could introduce bias due to their greater familiarity with technology.
• Test Method Documentation Challenge: The absence of standardized testing method documentation led to a dearth of explanatory detail in some instances.
• Financial Evaluation Omission: The study lacks financial evaluation, crucial for case company’s decision-making in implementing these technologies. Justifying investments through tangible customer value remains paramount.

After the sprint, the results from the pre-study were evaluated within the working group. In addition, the results have to be presented in the steering group.

5.3.5 Decision Point 0 (DP 0)
After transitioning from the idea management phase to sprint planning and pre-study, the findings and conclusions of the case are shared with the steering group. This critical step involves the steering group making determinations about the subsequent course of action for the case. This pivotal decision-making session aligns with the recurring steering group meetings that follow each sprint planning meeting. During these meetings, various cases are presented, representing different stages of the Smart Factory Lab (SFL) process.

The decision meeting with the Steering Group encompassed several key discussion points:
• Evaluation of Pre-study Results: The steering group evaluated the outcomes of the pre-study. However, it was noted that the results provided an incomplete understanding of the tools under investigation in this particular case study. Additionally, essential elements such as the exploration of business value and a comprehensive consideration of all delimitations were missing.

• Demonstration of Pre-study Results: The pre-study results were demonstrated to the steering group members, allowing them to witness the actual solution in action. Demonstrations hold significance in the Smart Factory Lab’s process, particularly during the pre-study phase where tool development is involved.

• Case Readiness for SPS Process: After careful consideration, it was concluded that the case was not prepared to transition to the SPS (Case company’s Production System) process. The decision was influenced by the absence of sufficient evidence to confirm the potential benefits of the tool for Case company.

Based on the outlined points, the decision rendered was a “NOGO” for the Virtual Training case. It’s worth highlighting that this study was intentionally limited to the Pre-Study Phase. The primary purpose of this case study was to serve as a base for evaluating the efficacy of the SFL process, rather than aiming to implement the technology itself.

5.4 SPS, the process to implement the technology in production after the Pre-study

The report highlights that the SPS (Smart Production System) process discussed within the context of this thesis remains conceptual and has not been subject to testing in the course of this study. It’s important to note that while the SPS process is actively employed by the case company across its Production Resource Units (PRUs), its current application primarily involves the implementation of new ways of working, such as changes in leadership structures, rather than the introduction of new technologies.

Given this distinction, there arises a necessity for a comprehensive and thorough investigation to assess the applicability and effectiveness of the SPS process in the context of technology introduction. If the assessment indicates that the SPS process is either insignificant or ineffective for the purpose of integrating new technologies, it would be prudent to consider the development of a new process tailored specifically for the successful introduction of technology.
Chapter 6

Results and Analysis

In the preceding chapter, a case study was undertaken to evaluate the theoretical Smart Factory Lab (SFL) process. As the SFL process was a conceptual framework devised by Senior Employees at Case company, specific step-by-step guidelines were not available. During the case study, “Virtual Training” was subjected to this concept process, leading to the identification of inconsistencies and opportunities for process improvement.

This section documents inconsistencies, improvements, and lessons learned about the SFL process based on the case study. An improved SFL process is suggested, and research questions are thoroughly answered.

6.1 Smart Factory Lab (SFL)

An overall description of the Smart Factory Lab can be found in section 4.2

Advantages of Smart factory Lab:

- The production and logistics departments face challenges that demand smart solutions. The market offers diverse technologies and concepts, requiring precise alignment with relevant problems or use cases. The Smart Factory Lab serves as a vital platform, facilitating the convergence of solutions with real-world issues. Its collaborative and research-oriented approach enables rigorous evaluation and experimentation to identify the best-fit technologies, promoting productivity and innovation.

- Incorporating “Business Cases” within the Smart Factory Lab serves as a valuable avenue for exploring and understanding new technologies. Even if these cases do not lead to the implementation of smart solutions in production, they still yield invaluable knowledge. Through systematic documentation, the insights gleaned from these instances contribute to the collective learning and advancement of the organization’s capabilities in adopting innovative technologies. The SFL also leverages the reuse of previous business cases and internal innovation, maximizing its potential to address diverse production-related issues.

- Test licenses and tools from technology suppliers offer a cost-effective way for the case company to explore new technologies. Encouraging more “Business Cases” allows thorough assessment before committing to full-scale implementation. Utilizing test licenses and tools from technology suppliers offers an economical method to explore new technologies and assess their applicability.

- The practice of reusing previous business cases can be advantageous. For instance, the Vizendo tool underwent testing in the Smart Factory Lab a year before this thesis work but wasn’t implemented in production. However, in the current Case Study of Virtual Training, Vizendo was among three tools compared and subsequently reintroduced in the SFL process.

- In addition to testing and adapting external tools and technologies, the Smart Factory Lab (SFL) also engages in in-house development of new technologies. This internal innovation allows the SFL to explore and create bespoke solutions that cater to specific needs and challenges within the organization. By combining both approaches, the SFL maximizes its potential to address a wide range of production-related issues and fosters a culture of continuous improvement and innovation.
Limitation of the Smart factory Lab:

- The Smart Factory Lab (SFL) at Case company operates as a dedicated laboratory with a specific group of individuals focused on testing and evaluating smart tools and technologies aligned with the smart factory vision. However, the lab may have limited resources, preventing it from engaging in large-scale implementation of these smart technologies in production units (PRUs). Instead, the SFL primarily conducts pre-studies and provides partial involvement in the implementation process within the PRUs, facilitating a more focused and strategic approach to incorporating smart technologies into Case company’s production landscape.

- A notable limitation of the Smart Factory Lab (SFL) is that the tests conducted on a pedal car may not fully replicate the complexities found in the actual truck assembly process. The pedal car assembly process is inherently less intricate and less representative of the challenges faced in real-world truck production. As a result, the findings and results obtained from the SFL’s testing may not be directly transferable or fully indicative of the outcomes that would be encountered in the larger-scale truck manufacturing environment. While the SFL serves as a valuable testing ground, its simulations may need to be interpreted with caution when applying the insights to real truck assembly scenarios.

6.2 Smart Factory Lab Process (SFL Process)

As a result of this thesis work, several important outcomes were achieved:

- Discovery of Inconsistencies in the Theoretical SFL Process: During the course of the thesis, inconsistencies within the theoretical Smart Factory Lab (SFL) process were identified.

- Creation of a Structured Table for Each Process Step: To address the inconsistencies and improve the SFL process, a structured table was developed for each step of the process. These tables offer a systematic and organized approach in the lab’s activities.

- Documentation of Additional Process Explanation: As part of the thesis work, further elaboration and documentation of the SFL process were undertaken. This documentation provides a comprehensive understanding of the various stages and intricacies involved in the lab’s operations.

- Suggestion of Further Process Improvements: The thesis work also resulted in the proposal of additional enhancements to the SFL process. These suggestions aim to optimize the lab’s operations and increase its ability to effectively contribute to the adoption of smart technologies within the organization.

Overall, this thesis work has contributed valuable insights and improvements to the Smart Factory Lab’s approach, promoting a more systematic and structured methodology for testing and implementing smart technologies.

General inconsistencies in the Process:

- Role Clarity/Definitions: One major inconsistency lies in the lack of clearly defined roles within the Smart Factory Lab (SFL) Process. Each “Business case” is treated as a separate project, necessitating a standardized process with well-defined roles. For instance, the Smart Factory Operations role, which primarily focuses on project management and liaising with other production units (PRUs), is an example of a role that requires clarification and alignment within the SFL.

- Lack of Structured Knowledge Management: Currently, there is no structured approach to save and manage the information and knowledge generated during each phase of the SFL process. Proper knowledge management is crucial to ensure that valuable insights and findings are well-preserved and accessible for future reference and continuous improvement.
Combination of Waterfall and Agile Project Management: The SFL process requires a balanced combination of both waterfall and agile project management methodologies. Software changes, for example, are often best managed through agile project management, while hardware changes are better suited for waterfall project management. A hybrid approach is necessary to accommodate the varying nature of tasks and activities involved.

- Agile Approach for SFL Tasks/Activities: The tasks and activities conducted within the Smart Factory Lab can benefit from an agile project management approach. The iterative and flexible nature of agile project management aligns well with the dynamic testing and exploration of technologies in the lab setting.

- Waterfall Implementation in Production: On the other hand, the implementation of “Business Cases” (referring to a smart solution to a business problem) in the production environment necessitates a waterfall method. This more structured and sequential approach ensures a thorough and controlled implementation process within the larger production setting.

- The SFL team prefers to operate in sprints, which involves allocating all available resources to execute tasks according to the sprint time plan. However, projects are marked by distinct milestones, and decisions related to these milestones are contingent upon predetermined decision points. This arrangement might introduce delays in project progression as the project has to wait for these decision points to be reached.

Addressing these general inconsistencies will be essential for optimizing the Smart Factory Lab Process, enhancing role clarity, knowledge management, and project management methodologies, leading to more efficient and effective adoption of smart technologies in production.

Further, The Case study contributed to structuring each SFL process step Idea Management, Sprint Planning, Pre-study with (Input-Process step-Output) blocks. Explanation of the process, identified inconsistencies, and suggested improvements are documented.

6.2.1 IDEA Management

<table>
<thead>
<tr>
<th>Input</th>
<th>Process/Activities</th>
<th>Output</th>
</tr>
</thead>
</table>
| "Wishlist" of ideas/areas/areas cases from the different stakeholders  
  - Background/Purpose, Value/Benefits, Resources (a rough AD for each ideas/areas/areas cases)  
  - Strategic goals e.g. digital ambition  
  - New manufacturing methods  
  - New products  
  - New Technologies  
  - Deviations  
  - TRM gaps  
  - Research results from partner universities  
  - Etc. | Collect ideas, use cases, focus areas and infrastructure needs from stakeholders  
  - Group and coordinate ideas/areas/areas cases into Pre-studies/Activities  
  - Estimate the business value (current or potential) of the grouped pre-studies/activities, ideas/areas/areas cases  
  - Make a gross list of the Pre-studies/activities, ideas/areas/areas cases and make a prioritization in the list.  
  - Propose items from the gross list to the next sprint at Smart Factory Council Meeting | • A prioritized gross list of all the Pre-studies/initiatives.  
  - AD of the pre-studies/initiatives etc. shortlisted for the sprint plan. |

Figure 6.1: Table for steps involved in idea management
Additional Explanations of the process:

- "Business Cases" in the Smart Factory Lab (SFL) are not limited to originating from the production unit itself. Ideas can emerge from various points along the value chain, including external suppliers or other departments within the organization. For instance, if a technology with high potential is brought to SFL by an external supplier, the SFL can proactively explore its applicability and identify use cases within production, illustrating a technology push rather than a pull approach.

- "Business Cases" that are run through the SFL process but are not implemented at or adopted by any production unit are not discarded. Instead, they are archived within the Smart Factory Lab, creating a repository of knowledge and experience. Future endeavours in the lab can benefit from this accumulated knowledge, eliminating the need to start from scratch and promoting continuous learning.

- In the “Business case” used in the case study of this thesis work, there were solutions (Virtual training tools) already available in the SFL and the available tools were evaluated. But there will be cases when the SFL will not have the solutions readily available and in those instances SFL Process starts with a problem statement in the Idea Management phase and may be rough concept solution is developed in the pre-study phase also SFL may look for solution from the suppliers/outside of Case company.

- While some "Business Cases," like the one in this thesis work (Virtual training tools), may involve available solutions within the SFL, but there will be instances where solutions are not readily available to implement. In such situations, the SFL initiates the process by formulating a problem statement during the Idea Management phase. The Pre-study phase may involve the development of rough concept solutions, and the SFL may explore potential solutions from external suppliers or sources outside the Case company. This adaptive approach allows the SFL to tackle a diverse range of challenges and tap into external expertise when required, ensuring comprehensive problem-solving for the organization.

Inconsistencies:

- The prioritization process lacked clarity and transparency, leading to uncertainty in determining the order of importance for various projects.

- Despite a considerable interest in smart technologies within the final assembly, there was no well-defined road map for Digitalisation. Additionally, there was a lack of a comprehensive list of issues targeted to be addressed through the implementation of smart technologies.

- The absence of a standardized method to evaluate and determine the business value when prioritizing projects in the gross list created challenges in making informed decisions regarding resource allocation and project sequencing.

Further Improvements:

- Implement a transparent prioritization process based on Case company’s Priorities, such as the Technology Road map. This will ensure that projects are ranked and selected based on their alignment with the company’s strategic goals and objectives.

- Enhance the production process by establishing a comprehensive list of issues identified by production units (PRUs) that can potentially be solved using smart technologies. To enable PRU personnel to better understand available smart technologies, encourage attendance at demo events hosted by the Smart Factory Lab. By deeply studying and approaching production issues from a Smart Factory perspective, solutions can be identified within the smart factory landscape, promoting innovative problem-solving across the organization.

- Introduce a Smart Solution for idea collection, where problem statements can be submitted to the Smart Factory Lab through an online form. Setting up this platform within the company will facilitate a seamless and efficient management of ideas, streamlining the process of idea generation and evaluation.
6.2.2 Project Planning

Additional Explanations of the process:

- When new cases are generated from the Idea Management phase, Sprint planning encompasses defining the Assignment directive (AD) and presenting it to the Steering group to secure a "GO/NOGO" decision for the pre-study. In the SFL process, Sprint planning is synonymous with Project Planning, wherein the entire Case Study is meticulously planned, ensuring a well-structured approach to managing the project from inception to execution.

- The SFL is in the process of getting established, and its structure of working is gradually taking shape. Despite this ongoing development, the adoption of the sprint system is evident in the SFL. It is imperative for each of the Business cases to adhere to the sprint time plan system, ensuring streamlined and efficient project management within the SFL framework.

- In terms of Smart Factory Lab working, sprint planning serves as an activity where tasks are meticulously broken down and planned in detail for the next upcoming sprint. Notably, this planning encompasses multiple business cases running in parallel in the lab, leveraging shared team and resources efficiently.

  - In ongoing cases with a prior GO decision, the Sprint planning phase involves selecting activities from the sprint backlog. The sprint backlog comprises a prioritized list of tasks, user stories, and features that the development team intends to address during the sprint, following Agile project management principles.

### Figure 6.2: Table for steps involved in sprint planning

<table>
<thead>
<tr>
<th>Input</th>
<th>Process/Activities</th>
<th>Output</th>
</tr>
</thead>
</table>
| • List of approved initiatives/pre-studies for the sprint.  
  - Description from AD  
  - Draft Manning and funds          | • Plan the ideas that were selected from the gross list in DP-2  
  • Break down Initiatives/ Pre-studies > Epic/Cases > User Stories > Tasks | • Plan for the sprint; what pre-studies to focus on  
  • A plan for each pre-study  
    • What to achieve (US)  
    • Task (how to fulfill it)  
    • Resources etc.  
    • Propose Manning and Funds available for individual projects |
• In addition to adhering to the overall sprint system, each Case Study in the SFL necessitates developing its specific time plan, divided into sprints. This approach ensures tailored project management, accommodating unique milestones and requirements for effective execution.

• The decision meetings in the SFL are standardized and pre-planned, with a predetermined organization attending based on the scheduled frequency. This approach ensures consistency and allows for efficient decision-making processes within the Smart Factory Lab.

• During the project planning phase, breaking down tasks can be challenging due to the dynamic nature of discovering new insights during the pre-study. In certain instances, when the Case Study concept is not fully developed, project planning becomes difficult as envisioning project steps and milestones becomes complex. To address this complexity, multiple sprints may be designated solely for Project Planning, allowing for a more comprehensive and structured approach to handle the project’s uncertainties effectively.

Inconsistencies:

• In the SFL process, the term "Sprint planning" exhibits inconsistency. It involves preparing the Assignment directive (AD) and presenting the project plan, which are time-consuming activities unique to each business case. On the other hand, sprint planning refers to the planning of activities for the upcoming sprint, adhering to agile methodology and taking place before the start of each sprint. The term’s ambiguity stems from the varying tasks depending on the case’s stage within the SFL process.

Further Improvements:

• In the SFL process, the "Sprint Planning" activities combine both the agile step of sprint planning and project planning. To enhance clarity and efficiency, these tasks should be separated. Project Planning is a distinct activity, while sprint planning should be integrated into the pre-study process, spanning multiple sprints for comprehensive and focused execution. By delineating these tasks, the SFL process can be streamlined and more effectively managed.

• Finalizing the AD is a time-consuming process that cannot be accomplished in a single meeting, necessitating a dedicated activity for each case. Additionally, a project plan must accompany the AD and be presented to the Decision forum. To alleviate confusion, this process step could be aptly renamed as "Project Planning" encompassing the comprehensive preparation of the Assignment directive and the associated project plan.
6.2.3 Pre-Study

Additional Explanations of the process:

- If the results of the pre-study are deemed satisfactory, the case can progress to the SPS process (implementation phase of the smart technology). Before this, it must be presented to the steering group and aligned with the respective Production units. Once approved, a dedicated project manager is assigned to lead the project, superseding the role of SFO (Smart Factory Operations).

- If the pre-study results are not satisfactory, the sprint activities are reintegrated into the Smart Factory Lab’s sprint backlog for further refinement.

- In cases where the results suggest the solution is not suitable for Case company, the steering group may decide to shelf or pause the project.

- The pre-study’s type and approach depend on the specific case and the developmental phase of the technology/tool/solution being considered.

- Supplier involvement in tests, evaluations, and experiments is a possibility.

- Generalized criteria were established from the conducted pre-studies to evaluate and select among different solutions for implementation at various production units of the case company:
  - Functionality of the tool: To what extent it helps solve problems or support tasks.
  - Ease of tool development: Custom tools may be required, and development time is critical.
  - Adaptability for the case company.
  - Ease of content creation on the tool.
  - User-friendliness.
  - Ease of tool maintenance.

<table>
<thead>
<tr>
<th>Input</th>
<th>Process/Activities</th>
<th>Output</th>
</tr>
</thead>
</table>
| • Plan for the sprint; what pre-studies to focus on  
• A plan for each pre-study  
  • What to achieve (User Story)  
  • Task (how to fulfill it)  
  • Resources etc. | • Man and execute the pre-studies planned in the sprint  
• Testing within Smart Factory  
• Check Scania safety regulation and data security  
• Involve necessary stakeholders  
• Maturity Assessment  
• Agile proof of concept development process  
• Demonstrate the technology and its expected benefits | • Test Protocols from Pre-Study  
• Documentation and Evaluation from Pre-Study  
• Results from Maturity Assessment  
• Major part of proof of concept activities carried out.  
• Feedback from the Stakeholders.  
• Method /concept /POC demonstrated |
Value addition in terms of time, cost, resources, safety, health, and environment.

**Inconsistencies:**

- The pre-study should include the Sprint planning, which involves the actual process of planning activities for the upcoming sprint.
- The agile capability of this process was not thoroughly tested, as it was only evaluated for one sprint. Assessing a process for agile capability requires an extended period and multiple projects to gather feedback after each sprint.
- There is no clear definition for Proof of Concept (POC), Prototype testing, and Pilot from the Smart Factory Lab perspective, leading to potential misunderstandings. It is essential to establish precise definitions for these terms within the context of the Smart Factory Lab.

**Further Improvements:**

- Lack of a reference template for the design of experiments in subjective evaluation is a limitation. Such evaluations are common for technologies like Virtual Training, which heavily rely on the User Interface (UI). Introducing reference templates for different pre-study types, including POC, Prototype, and Pilot, would enhance productivity.
- The SFL process should be adaptable to both Hardware and Software solutions, considering the diverse nature of technologies.
- Defining general steps in the pre-study can expedite the process:
  - Specify the level of analysis for the product/technology/idea, including statistical analysis levels.
  - Determine the appropriate pre-study method (POC, subjective evaluation, prototype, pilot) for specific problems.
  - Define the required participation count in statistical analysis to ensure test/experiment/evaluation validity.
  - Identify the relevant KPIs to be considered for the test/experiment/evaluation.
  - Providing references for all upcoming studies in the Smart Factory Lab would streamline the SFL process.

### 6.3 Suggested SFL process

*As a result from this thesis work a Modified SFL process is suggested.*

![Smart Factory Lab Process along with Case company’s Production System process](image)

This process is iterative and requires adherence, with multiple iterations planned to continually enhance its effectiveness. As ideas, use-cases, and technologies are tested using this process, improvements will be made based on the learning experience and outcomes to ensure its ongoing refinement.
6.4 Research Questions Answered

How to enable effective transfer of Smart Technologies into the production/ Final Assembly Plant from Smart Factory Lab where the technology is tested and adapted/developed for Case company?

- What are the major constraints for the technology transfer?
- What is the strategy to overcome the constraints and effectively transfer the technology?

6.4.1 What are the major constraints for the technology transfer?

The main goal of establishing the Smart Factory Lab (SFL) at Case company is to enable the company’s production to advance towards becoming a smart factory. As an independent organization within Production Logistics, SFL is relatively new in Case company and is in the process of integrating with other production departments. In contrast, the production units are well-established factories with their established processes. However, it is evident that there has been limited technology transfer from SFL to the production units, particularly the Final Assembly Plant. This research aims to identify the constraints that hinder the smooth transfer of technologies from SFL to production units. The internal constraints within the case company regarding technology transfer from the Smart Factory Lab (SFL) are as follows:

- Limited Communication: The Final Assembly unit, a production unit, has not established effective communication with the newly established SFL.
- Technology Maturity: Some technologies are not mature enough for direct implementation in production, requiring further development.
- Resource Intensive: Implementing certain technologies in production would require substantial resources and investments.
- Digitalization Direction: For successful digitalization, a balanced approach of pushing and pulling tools and technologies from SFL to production is essential.
- Knowledge and Competence Gap: Lack of knowledge and expertise related to Industry 4.0 within the production units.
- Existing Processes: The processes in production departments do not incorporate support for digitalization in their process steps, making it challenging to introduce new digital technologies. Modifying the established processes to accommodate digitalization poses difficulties due to potential disruptions and resistance to change within the production environment.
- Brownfield Challenges: Adapting to new ways of working in established production units (brownfield factories) can be complex.
- IT System Interface Concerns: Different IT systems and interfaces pose challenges during the implementation of new technologies in production units.

6.4.2 What is the strategy to overcome the constraints and effectively transfer the technology?

Adapting the Smart Factory Lab (SFL) process is indeed the crucial first step to overcome the constraints in technology transfer. The SFL process can function as a facilitator for the efficient implementation of all the aforementioned strategies

- Communication and Collaboration: Establish regular communication channels and collaboration between the SFL and the production units, especially the Final Assembly unit. Encouraging open dialogues and knowledge sharing will help build trust and understanding between the teams.
- Technology Maturity Assessment: Conduct a thorough assessment of the maturity level of the technologies being developed in the SFL. This assessment will help identify the readiness of these technologies for real production and provide insights into the necessary improvements needed for successful implementation.
• Resource Allocation: Allocate sufficient resources, including time, finances, and expertise, to bridge the gap between the technology developed in the SFL and its practical implementation in production. Adequate investment in resources will ensure that the technologies are made production-ready.

• Push and Pull Approach: Foster a two-way approach to technology transfer, involving both the push of new technologies from SFL and the pull of interest and acceptance from production units. This balanced approach will facilitate the adoption of smart technologies.

• Upskilling and Training: Offer training programs to enhance the knowledge and competence of production unit employees in Industry 4.0 technologies. Upskilling the workforce will create a receptive environment for technology transfer.

• Pilot Projects: Implement pilot projects in selected areas of production to demonstrate the effectiveness and benefits of the new technologies. Successful pilot projects can build confidence and encourage wider adoption.

• Change Management: Implement effective change management practices to address the challenges of modifying existing processes and workflows. Engage employees and stakeholders in the change process to minimize resistance and ensure smooth implementation.

• Integration with IT Systems: Address the concerns regarding different interfaces between IT systems by developing standardized protocols and ensuring compatibility between SFL technologies and production unit systems.

• Long-Term Planning: Develop a long-term strategy for technology transfer and integration with production units. This strategy should include phased implementation and continuous evaluation and improvement of the SFL process.

The process adaptation should involve incorporating feedback from stakeholders, aligning with production unit requirements, and ensuring clear and efficient communication channels. With an improved SFL process, the organization can enhance collaboration, prioritize technology transfer, and create a conducive environment for successful implementation of smart technologies in the production departments.
Chapter 7

Discussion and Conclusion

7.1 Discussion

The findings of the study centered on the challenges and opportunities associated with transferring smart technologies from the Smart Factory Lab (SFL) to production units, particularly focusing on the Final Assembly Plant in a brownfield factory context. Through a case study approach, several key insights were unearthed, contributing to a comprehensive understanding of the technology transfer process.

This thesis work has illuminated several critical aspects of technology transfer and implementation in the context of a smart factory. The findings underscore the importance of effective communication and collaboration between innovation-focused entities like the Smart Factory Lab and established production units. Clear communication channels facilitate the exchange of knowledge and enable the smooth transition of technologies.

Furthermore, the challenges posed by technology maturity and resource allocation emphasize the need for a measured and strategic approach to implementation. Not all technologies developed in the SFL may be immediately suitable for large-scale production. A comprehensive assessment of technology maturity and allocation of adequate resources are vital steps in ensuring successful implementation and avoiding disruptions.

The push-pull strategy advocated here recognizes the symbiotic relationship between innovation and production. While the Smart Factory Lab pushes innovative technologies, production units should pull these technologies based on their practical needs. This dual approach fosters mutual collaboration and ensures that the technologies developed align with the actual requirements of the production environment.

This thesis provides a comprehensive exploration of the Smart Factory Lab process, its inconsistencies, improvements, and the challenges and strategies involved in technology transfer. The refined SFL process presented here offers a practical framework for organizations aiming to bridge the gap between innovation and production, facilitating the realization of the smart factory vision.

The study presented several limitations that should be acknowledged when interpreting its findings. These limitations could have influenced the results and the generalizability of the conclusions drawn.

- Single Case Study: The research focused on a single brownfield factory as the case study. While this approach provided in-depth insights into the specific context, it limits the generalizability of the findings to other industrial settings. The unique circumstances and dynamics of this factory may not fully represent the challenges faced by other brownfield factories or different industries.

- Limited Sample Size: The study involved interviews with a relatively small number of engineers and managers within the case company. This limited sample size might not capture the diverse range of perspectives and experiences related to technology transfer. A broader participant pool could provide a more comprehensive understanding of the challenges and potential solutions.

- Technology-Specific Focus: The investigation concentrated on the technology of “Virtual Training for Assembly Operators.” While this choice allowed for a detailed examination of a specific
technology, it may not encompass all possible smart technologies relevant to the industry. Other technologies with distinct characteristics and challenges might yield different transfer dynamics.

- **Short-Term Perspective:** The study’s time frame was relatively short for the type of research work with regards to organisational effectiveness. The limitation was the researcher’s outsider status, which necessitated considerable time to grasp the complexities of organizational change, efficiency, and mindset within the case company. This limitation may have influenced the depth of understanding regarding the long-term effects of technology transfer. Some challenges might only become apparent after a prolonged period of implementation and utilization.

- **Limited External Context:** The research primarily centered on internal dynamics within the case company. External factors, such as market trends, regulatory changes, and advancements in technology standards, could significantly impact the technology transfer process but were not extensively explored.

- **Absence of Quantitative Analysis:** The study relied predominantly on qualitative data gathered from interviews and case study analysis. While this approach offered rich insights, the absence of quantitative analysis limits the ability to generalize findings and establish statistical relationships. Recognizing these limitations enables a balanced assessment of the research’s scope and findings while providing directions for future research endeavors in this domain.

### 7.2 Conclusion

In this thesis, the primary focus was on addressing the challenge of effectively transferring smart technologies from the Smart Factory Lab (SFL) to the Final Assembly Plant of the case company (problem is formulated in chapter 1.2). This challenge stemmed from the necessity to bridge the gap between innovative technological solutions and their integration into the established production processes within brownfield factories. By delving into the existing Smart Factory Lab process (Documented in chapter 4.3 and conducting an extensive case study in chapter 5, this thesis sought to identify inconsistencies within the initial SFL process and develop systematic solutions to overcome these issues.

As a result of this thesis work, The SFL process, now enhanced and refined (can be read in detail in chapter 6.2), serves as a bridge between innovative smart technologies and practical production implementation. The focus was on enhancing role clarity, improving knowledge management, and optimizing project management methodologies within the SFL. It recognized the need for a balanced push-pull strategy, enabling the production units to both benefit from and contribute to the smart technology landscape. By refining the SFL process, the goal was to establish a standardized and structured pathway for technology transfer, facilitating seamless integration into existing production units.

The research was conducted within the specific the Case company, which has its own unique organizational structure where the Smart factory lab is already established. It also has many of the processes defined and has a culture of following the process for achieving the results, and the case company has its own set of challenges. The findings and solutions proposed may not directly translate to other companies with different contexts and operational environments, but leveraging the insights and recommendations from this study can enable companies to optimize their technology transfer efforts, facilitate smoother integration of smart technologies, and ultimately achieve greater operational efficiency and competitiveness.

Looking forward, several avenues for future work emerge from this thesis. One potential direction is the continued refinement and iteration of the enhanced SFL process. Incorporating feedback from stakeholders and staying abreast of technological advancements will be crucial in ensuring the ongoing effectiveness of the process. Longitudinal studies could also be conducted to assess the long-term sustainability and impact of the implemented changes.

Furthermore, exploring strategies to scale up the successful integration of smart technologies beyond the Final Assembly Plant to other areas of the production ecosystem presents an exciting opportunity. Understanding the broader implications of digitization on operational efficiency, quality, and workforce
dynamics within brownfield factories is essential for maximizing the benefits of technology adoption in industrial settings.

In the context of future work, expanding the Smart Factory Lab (SFL) process to integrate with the Case company’s Product Development (PD) process holds immense potential. Traditionally, product development and factory upgrades have been often sequential processes within manufacturing organizations. However, by incorporating the SFL process into the PD process, the Case company can realize synergies and streamline the transition from product design to production implementation. This entails embedding smart technology testing, validation, and refinement into the early stages of product development, ensuring that new products are designed with compatibility and readiness for smart manufacturing systems.

The integration of SFL into the PD process enables a holistic approach to innovation, where technological advancements are seamlessly integrated into product design and manufacturing strategies from the outset. This proactive approach minimizes the need for costly retrofits and facilitates smoother transitions to mass production, ultimately reducing time-to-market and enhancing competitiveness.

In conclusion, this thesis has contributed valuable insights into the challenges and opportunities associated with technology transfer in brownfield factories. By refining the Smart Factory Lab process and establishing a structured approach to technology integration, this work lays the foundation for continued progress towards achieving effective digitization in industrial settings.
Chapter 8

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