CHALMERS
UNIVERSITY OF TECHNOLOGY

Smart Maintenance implementation in a TPM based manufacturing company

Developing a strategy for the combination of Smart Maintenance and TPM

Master's thesis in Production Engineering

Dennis Fariabi-Hamadani
Filip Bergom

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2025
www.chalmers.se

Master's thesis 2025

Smart Maintenance implementation in a TPM based manufacturing company

Developing a strategy for the combination of Smart Maintenance and TPM

Dennis Fariabi-Hamadani
Filip Bergom

Department of Industrial and Materials Science
Chalmers University of Technology
Gothenburg, Sweden 2025

Smart Maintenance implementation in a TPM based manufacturing company
Developing a strategy for the combination of Smart Maintenance and TPM
Dennis Fariabi-Hamadani
Filip Bergom

Supervisor: Jon Bokrantz, Department of Industrial and Materials Science
Industrial supervisor: Andreas Månsson, Volvo Trucks
Examiner: Jon Bokrantz, Department of Industrial and Materials Science

Master's Thesis 2025
Department of Industrial and Materials Science
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Printed by Chalmers Reproservice
Gothenburg, Sweden 2025

Smart maintenance implementation in a TPM-based manufacturing company
Developing a strategy for the combination of Smart Maintenance and TPM
Dennis Fariabi-Hamadani
Filip Bergom
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

This study investigates the possibility and implications of combining Smart Maintenance and Total Productive Maintenance (TPM) in a factory that works with TPM. The study is conducted at the Volvo Trucks factory in Tuve. The main objective is to create two roadmaps that combine both strategies. The first roadmap will be tailored to academia with the precondition of maturity in TPM. The second road map will be tailored to the needs of Volvo Tuve.

Through rigorous work with interviews and thematic coding, a current state analysis is presented. This shows the level of maturity Volvo has reached in TPM. Combined with the investigation of the two concepts, which gave the gap between TPM and Smart maintenance. The investigation gave the necessary information to create the roadmaps that have the potential to raise equipment reliability, reduce costs, and strengthen the competitive advantage.

Declaration of the use of AI technologies in this Master's Thesis

ChatGPT: Has been used to refine the structure of sentences to improve the clarity of the text.
Grammarly: Has been used as a tool for spellchecking and grammar correction.

All content and analysis presented remain the original work of the authors. ChatGPT and Grammarly have only been used to improve the writing process.

Keywords: TPM, Smart Maintenance, Thematic coding, Implementation, Roadmap, Industry 4.0, Strategy

Acknowledgements

We would like to begin this statement by thanking our supervisor and examiner at Chalmers, Jon Bokrantz. He has been a major contributing pillar to this project, with questions and valuable feedback. Jon is also highly relevant for this topic, as well, since the Smart maintenance concept has been part of his research.

The next person we would like to thank is our supervisor at Volvo, Andreas Månsson. He has provided us with a lot of practical support, from arranging offices to guidance on where and whom to interview. Life would be difficult without the support from Andreas. Kondwani Kalimanjira is also in the acknowledgements list. He is the maintenance manager who spent his time doing the survey, which gave us valuable information. We would also like to thank Mikael Granbom for giving us the opportunity to write this thesis and for the support in the administrative area to get us going with the Volvo systems and accesses. Last but not least would like to thank the interviewees who participated in this study. The result would not match the real-world situation without their transparency.

Dennis Fariabi-Hamadani, Gothenburg, May 2025

Filip Bergom, Gothenburg, May 2025

List of Acronyms

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

API	Application Programming Interface
AM	Autonomous Maintenance
AI	Artificial Intelligence
CBM	Condition Based Maintenance
CMMS	Computerized Maintenance Management System
ERP	Enterprise Resource Planning
EWO	Emergency Work Order
FMEA	Failure Modes and Effects Analysis
HCR	Human Capitol Resource
I4.0	Industry 4.0
IIoT	Industrial Internet of Things
IoT	Internet of Things
KPI	Key Performance Indicator
KSAO	Knowledge, Skills, Abilities, and Other characteristics
ML	Machine Learning
MTBF	Mean Time Before Failure
MTTR	Mean Time To Repair
OEE	Overall equipment Effectiveness
OLE	Overall Line Effectiveness
OTPM	Offire TPM
PdM	Predictive Maintenance
PM	Planned Maintenance
QRQC	Quick Response Quality Control
R&D	Research and Development
RQ	Research Question
SDT	Self Determination Theory
SHE	Safety, Health & Environment
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TBM	Time Based Maintenance
TPM	Total Productive Maintenance
3M	Man, Machine, Material
5S	Sort, Sweep, Straighten, Schedule, and Sustain
VMMS	Volvo Maintenance Management System

Contents

List of Figures

List of Tables

1
Introduction

This chapter introduces the study by presenting its background, aim, and objectives. It also formulates the research question that guides the investigation. To define the scope of the work, the chapter concludes with a description of the delimitations.

1.1 Background

Everyone is familiar with the first industrial revolution, where the use of coal and steam machines transformed our way of working forever. The first revolution was in the 18th century, and since then, we have had three more [1]. At the time when this report is written, we stand on the edge of a fifth revolution, often referred to as “Industry 5.0”. This fifth revolution has, like the first one, an enabler, but it is not coal, instead, it is driven by technology. It comes in the form of digitization, Internet of Things (IoT), AI, big data, and a human-centric view [2]

With these technologies, there are more options available for engineers and operators to save costs and increase the useful life of their equipment. This can be done through real-time monitoring of machines using algorithms to predict breakdowns and repair machines before a production-stopping breakdown occurs [3].

The drive for digitization will be necessary for competitiveness and will affect the organization’s maintenance departments in different ways. The seven most probable areas would be data analytics, interoperable information systems, big data management, enhanced education and training, fact-based maintenance planning, new smart work procedures, and system perspective in maintenance planning. These are the areas that maintenance managers need to incorporate in their long-term maintenance strategy to achieve digitalized manufacturing [4].

TPM is at the center of modern production, and it serves as a complete maintenance strategy. The purpose of TPM is to maximize the effectiveness, reliability, and lifespan of equipment [5]. When implemented correctly, positive results like productivity and efficiency could be increased 1.5-2 times in the production facility, production costs reduced by 30%, and improved product quality could be gained [6].

It has been shown that industry 4.0 technologies like IoT and cloud computing, integrated into TPM, improve the management performance in the maintenance department. However, this comes with a couple of challenges, like compatibility due to a diverse set of machines and systems. Additional complexity could be a barrier where the workforce is ill-equipped with the skills needed for I4.0 [7]. The research on practical guidance to integrating I4.0 technologies to support the development of the maintenance department is limited [8].

The unit of the Volvo group that designs and manufactures trucks is called “Volvo Trucks”, and they have their main office in Gothenburg, Sweden. They also have factories in 12 different countries and produce 16 different models of their trucks [9]. This thesis will be written with a focus on their Tuve plant, with a special focus on their maintenance department and their strategy. The Volvo Tuve plant supposedly uses an adapted version of total productive maintenance (TPM) as its main maintenance strategy for the production facility.

The main task of the maintenance organization is to supply the plant with the highest technical availability and to be cost-efficient. Today, this can be a challenge with equipment being of different technical levels and ages. The maintenance team relies heavily on their own experience and historical events to sustain the availability of the production line; their current prioritization today does not rely on data-driven decision-making. One issue the company faces is the lack of real-time data with high accuracy. To increase the data-driven decision making, the concept of smart maintenance becomes relevant [10].

Smart maintenance is an organizational design for managing maintenance in a digitalized production era. It involves four dimensions: external integration, internal integration, human capital resource, and data-driven decision making [11]. It has been shown that smart maintenance is crucial for competitiveness in the market [12]. Therefore, the maintenance department in Volvo Tuve wants to investigate how to move towards smart maintenance in combination with the current practices. These steps are taken as a way to move closer to the strategic vision of the Volvo Group.

1.2 Aim

This thesis aims to develop two sustainable roadmaps that can be followed by a manufacturing company that wants to combine its TPM-based maintenance strategy with smart maintenance. The first roadmap will be based on the research conducted during this project, and it will be aimed at generic manufacturing companies to combine the two concepts. This will be done as a contribution to the scientific community.

The second one will be based on the first generic roadmap. However, this one will be tailored to the Volvo Trucks maintenance department with specific deliverables to achieve. By combining these two concepts, Volvo Trucks should be able to reach a higher equipment reliability, reduce its costs, and strengthen its competitive advantage.

1.3 Objectives and research questions

To specify the subject that will be the core of this thesis, one research question has been specified:

RQ: How can TPM be combined with smart maintenance to improve technical availability in a TPM-based production facility?

1.4 Delimitations

- The project will be limited to the time allocated to the master thesis by Chalmers, which is between the dates 13-01-2025 and 30-05-2025. There is also a limited budget for this thesis of zero kr.
- The study will have a primary focus on the Volvo Trucks Tuve plant, which means that other plants may be included as research, but the results of the study will focus on the Tuve plant.
- There will be no implementation into the organization of any results from the roadmap.
- The study will not present highly detailed steps of Volvo's roadmap.

2
Theory

This chapter describes the theoretical backbone of the study by introducing key concepts related to Maintenance, Total Productive Maintenance (TPM), and Smart Maintenance. It also covers relevant literature on strategy formulation and change management to provide organizational context. These theories form the basis for the analysis and support the development of the roadmap.

2.1 Maintenance

Maintenance is a collection of activities to keep a product at a functioning state or restore it, from a non-functioning to a functioning state according to European standard EN 13306: 2001. Two main types of maintenance have been defined, one is corrective maintenance, which is done after a failure has occurred. The other type is preventive maintenance, which is done in advance on equipment with the purpose of maintaining the intended function of the equipment. Preventive maintenance has two subcategories, which are predetermined and condition-based maintenance (CBM). A subcategory of predetermined maintenance is time-based maintenance (TBM), where maintenance is done on equipment with predefined intervals in a schedule. This schedule could, for example, be provided by a supplier or created based on experience. CBM is maintenance done on equipment with the help of performance metrics that are being measured by, for example, sensors. The performance metrics could be monitored on request or continuously [13]. A more advanced type of maintenance is predictive maintenance (PdM), where monitoring is done on the equipment with the addition of machine learning on historical data that can forecast failures[14].

In a plant setting, the main role of maintenance is to keep the plant assets in a reliable operating state. The activities needed to achieve this could be equipment inspection/lubrication, new installations, and maintenance of the plant building [15]. To manage all this, a computerized maintenance management system (CMMS) is a key tool. CMMS enables better monitoring of assets and activities related to maintenance. Other task like work order and inventory management is also part of this system[13].

Many top executives have historically described maintenance as “necessary evil” and as a component that does not add value to the company. Not many see maintenance as essential to the plant; instead, just a repair team. However, this is not true since properly managed maintenance is an investment [15]. Maintenance plays a crucial role in a company's profitability, which affects the competitiveness in the market. There is an initial cost of maintenance installation, but this could be neglected in the long run due to the increase in business efficiency and profitability. Recently, the maintenance view has shifted to a core contributor for achieving organizational targets rather than being an expense. When the equipment does not have a proper management strategy, the reliability will be suboptimal and create direct/indirect expenses. This could be overcome with a maintenance strategy that optimizes the life cycle of each section in the production facility [16].

The impact of maintenance affects quality, capacity (output), costs, safety, and the environment. This could be, for example, energy waste by machines standing idle and spare parts that are not used to their intended lifespan due to incorrect calibration. If a critical machine causes a stoppage the production, then this would impact the output as well. The inaccuracy in calibration could also lead to quality issues that result in rework and possibly customer dissatisfaction due to warranty claims. The cost per unit can also be reduced by spreading fixed costs like salaries and equipment depreciation across more produced units [17]. Safety is also a factor that impacts where failures in machines could lead to personal injuries [18]

2.2 TPM

This chapter covers the history of TPM, its main pillars, and the use of Overall Equipment Effectiveness (OEE) to measure performance.

2.2.1 History

TPM originates from Japan in the 1970s, with the concept first introduced at a supplier for Toyota Motor Company [6]. The idea emerged when the supplier Nippondenso wanted to introduce preventive maintenance on automated processes. The management realized that the program would lead to an overload of work tasks. Therefore, they decided to utilize the operators who used the machines to perform tasks like lubrication. As a side effect, the operators got more skilled with their machines and were able to detect issues. At the same time, maintenance personnel shifted their focus to more complex problems and long-term strategies for the machines. This led to increased quality of the product and the machines [19]. The main pioneer of the concept is Seiichi Nakajima, who is part of the Japan Institute of Plant Maintenance (JIPM) [20]. JIPM later visualized the concept with the famous eight pillar house representing all aspects where the TPM concept is involved [6].

2.2.2 Pillars

The TPM strategy is built upon a foundation that is called “5S”, this is also a part of the “Lean” philosophy, and it is short for: Sort, Sweep, Straighten, Schedule, and Sustain. In short, it means that the employees should remove unnecessary things from their workplace, organize tools for easy access, clean their workplace, establish routines, and maintain the discipline to do so [19].

Autonomous Maintenance
The maintenance personnel are often very busy keeping the factory in top shape by performing different kinds of maintenance tasks. Some of these tasks include inspecting, lubricating, and cleaning the tools and machines used by operators in the production. This takes a lot of time, which means that the maintenance personnel have less time for preventive maintenance and other more technical tasks.

This is where the Autonomous maintenance (AM) pillar comes in, by teaching the production operators to care for their equipment and giving them a sense of ownership for the tools. The maintenance personnel would have more time for other tasks as the “easier” things would be done by the people using the equipment [19]. An analogy can be made with the operator’s cars as an example, they look for punctures, change their oil, and wash their cars. This is because it is their cars and they want them to run as long and efficiently as possible, this is the sense of ownership the AM pillar aims to develop for the equipment used by the production operators. Another important part of AM is the creation of standards, which is necessary for correct cleaning, maintenance, and the following of inspection schedules. This enables a correct and structured maintenance of equipment. [21].

Focused Maintenance
“Focused Maintenance” is also called focused improvement, this is what this pillar is about, improvements. The overall goal of the improvements is to improve the “Overall Equipment Effectiveness” (OEE). This should engage the whole company and be done through small improvements rather than one big one. The small ongoing improvements are like the concept of continuous improvement. The original name for focused maintenance in Japanese is kobetsu kaizen, and kaizen means continuous improvement [19]. This could be done through tools like FMEA, the 5-why method, or root cause analysis. Once the root cause has been identified, solutions are needed to solve the issues [20].

Planned Maintenance
Most factories want to have trouble-free equipment, high reliability, and zero defects. This is where the pillar “Planned Maintenance” (PM) is needed. Included here is preventive, time-based, and condition-based maintenance. The pillar also aims to stabilize the “Mean time before failure” (MTBF), which is a measure of how long equipment works before a breakdown occurs, and “Mean time to repair” (MTTR) which measures the time it takes to repair equipment [20].

Quality Maintenance

Delivering good-quality products to the customer is important for every manufacturing company. The quality maintenance pillar aims to keep the equipment that is used in production in the best working conditions so that the company can produce products in a faultless manufacturing process. To achieve this, it is essential to identify equipment conditions that may lead to quality issues, so they can be prevented in advance [20]. This could be done by tracking equipment that causes quality issues and addressing them with a root cause analysis. Another way of securing high-quality products is by mistake proofing or error proofing. This could be done with the help of sensors that detect faults or a preventive mechanism that does not allow the operator to make a mistake [20].

Education & Training

This pillar aims to create multi-skilled employees by improving knowledge and skills. The company needs to create a culture where employees want to learn new skills by self-improving based on the needs that exist. This should improve employee morale and make the employees more prone to perform all the functions required. This pillar is also important for the focused maintenance pillar, as training and education are the base for continuous improvement [20]. Training and evaluation of training is also a very important step, which also relates to autonomous maintenance. This is because maintenance duties can only be transferred to operators who have the required knowledge and training for it, which is why the training must be evaluated and verified [21]

Safety, Health, and Environment

Factories can be a dangerous place to work, with heavy machinery, forklifts, heat, and other dangerous factors. Companies following the TPM strategy should aim for zero accidents, as it is important to protect their workforce. As operators' main task isn't maintenance, they won't have the knowledge of the maintenance department. As such, performing maintenance on their machines could be a risk. To mitigate the risk, assessments, hazard maps, and education are necessary to keep operators safe on the job [21].

Office TPM

Office TPM (OTPM) aims to identify losses in the administrative functions, while at the same time improving flow and collaboration between departments. This could be in areas such as cost, procurement, communication, or even customer complaints due to logistics breakdowns [19].

Development Management

When designing or buying new equipment for the factory, it is important to remember lessons learned from maintaining the already existing equipment. This means involving the maintenance team and operators in this process, as they are the ones who work with the equipment and know it best. Aspects to consider are minimization of problems, maintainability, and implementation on time [20].

2.2.3 Overall Equipment effectiveness

Overall Equipment Effectiveness (OEE) is a measure that can be used to measure the success of TPM strategies. The measure aims to show how efficient the machines in a factory are [20], and the equations for OEE is shown in 2.2.3, 2.2, 2.3, and 2.4.

$$OEE = Availability \times Performance \times Quality \tag{2.1}$$

where:

$$Availability = \frac{\text{Required availability - Downtime}}{\text{Required availability}} \times 100 \tag{2.2}$$

$$Performance = \frac{\text{Theoretical cycle time} \times \text{units output}}{\text{Actual cycle time}} \times 100 \tag{2.3}$$

$$Quality = \frac{\text{Production output - defects}}{\text{Production output}} \times 100 \tag{2.4}$$

Availability is the measure of the relationship between the programmed production and the actual production. The difference here can be breakdowns or material that does not reach the machine in time. Performance is a measure of cycle time, it shows how the machine performs compared to how it should perform. Quality is a measure of how many parts from the machine are in good condition, which is important to know as manufacturing defects are a loss in terms of revenue and environment [20]. In a study done in the manufacturing industry in Sweden between 2006 and 2012, the average OEE turned out to be 51.5 %. The two main factors that contribute to the low OEE are availability and performance. The study also indicated that the manufacturing industry is not using its full capacity, with maintenance being primarily reactive rather than preventive [22].

2.3 Smart Maintenance

Smart maintenance is a concept for organizations to manage maintenance in manufacturing plants with widespread digital technologies. The concept consists of 4 dimensions: data-driven decision making, human capital resource, internal integration, and external integration. The dimensions are connected and therefore, achieving maturity in one dimension is not enough for achieving full potential, making it necessary to ensure all dimensions. The main performance objective of smart maintenance is maintenance performance. This is, for example, lowering MTTR, increasing MTBF, and being cost-effective. The outcome of maintenance performance is, for example, equipment availability, which also impacts the financial performance and competitive advantage. This would occur if higher equipment availability led to reduced lead times while maintaining the same unit cost. As a result, the increased productivity could generate higher profits [11].

Data-driven decision making
This dimension is defined by the level to which decisions are based on data. There are two types of decision-making: automation and augmentation. The first alternative refers to the technology making the decision for the humans, and the second one is when technology assists the human with information that decisions can be based on. The decision-making process could be aided with technologies like AI and ML [23]. The message of this dimension is that decisions based only on experiences are not as accurate as those based on data [11].

Human capital resource
The knowledge, skills, abilities, and other characteristics (KSAOs) of employees are a central part of this dimension. The dimension means that the KSAOs of employees are necessary to accomplish the goals of the maintenance department. Interactions and the relationship among employees are also important. This dimension puts the emphasis on the need for new skills due to emerging technology in industry [11]. Some of the necessary skills in this dimension are analytical skills, which are necessary for understanding and working with the data. Social skills to collaborate and advocate for the maintenance department. Business skills to link, for example, the revenue and cost of projects to accountants. Technical and adaptability to have hands-on knowledge with the ability to learn new skills. Lastly, to be proficient in digital tools [23].

Internal integration
The collaboration between maintenance and other departments, like production and R&D is the idea conveyed by the dimension. When there is good collaboration between different departments, knowledge, information, and data flow across the organization. This also includes, for example, integrating CMMS with other internal systems and synchronizing planned stops with production [11]. Besides data sharing, creating discussion groups across departments to share specialized knowledge is one way of increasing internal integration. Through the forums, maintenance personnel should raise the status of their department [23]. This could increase the influence of maintenance in key decisions like equipment design.

External integration
The external integration concerns the collaboration with the external stakeholders, like the suppliers. The strategic partnership with suppliers is necessary to grow in technological areas and gain knowledge, which is done faster in specialized, smaller firms. The collaboration includes, for example, system integration with suppliers and communication with suppliers regarding buying processes [11]. Other ways to increase the external integration could be to join networks of factories and suppliers to foster organizational learning. If the partnership with a supplier is close, then considering co-investing in technologies like digital tools is possible. In this way, both could benefit from the learnings and results [23].

2.3.1 Technologies used in Smart Maintenance

Sensors:
To collect data such as vibrations, heat, current usage, or acoustic emissions, sensors must be used. These sensors are the backbone of the infrastructure enabled by IoT technologies that allows organizations to do advanced data analytics on their equipment [24].

Internet of Things (IoT):
The network that consists of hardware such as sensors, data analysis software, and connectivity that allows organizations to real-time monitor their equipment is called Internet of Things (IoT) [25].

Artificial intelligence and Machine learning algorithms:
Artificial intelligence (AI) is the concept where machines (computers) can simulate human intelligence, which can be in fields like reasoning or problem-solving.

Machine learning is a subset of AI where algorithms learn patterns from historical data and improve "themselves" from it. This can be used for things like predicting failures of machines or forecasting demands [26].

2.4 TPM and Smart Maintenance

The Industry 4.0 concept, also called the fourth industrial revolution, has overlapping dimensions with Smart maintenance. The common technologies that are mentioned in the literature are, for example, big data and cloud computing. The technologies that are used in digitalized production systems will also impact the maintenance departments. Smart maintenance is an organizational design to manage these technologies. With the addition of integrating soft values like human capital resource [11].

Integrating TPM and Industry 4.0 concepts has been proven to be beneficial. The TPM practices that work well when integration with I4.0 is setting 3m conditions (machine, man, and material, operator ownership) and standards for AM checks. The I4.0 that integrates well with TPM is IoT and Big Data, which enables data-driven decision making and machine inter-connectivity with employees. A recommendation from research is that managers should focus on these technologies first in the digital transformation. Consequently, focus on TPM pillars Education and training, and Autonomous maintenance [27].

Some benefits of adopting I4.0 technologies are reduced maintenance costs, increased equipment availability, reduced waste, and improved decision making [28][29][7]. However, to achieve full integration, several important barriers need to be addressed. With the most influential being top management support, followed by I4.0 adoption program, mid management involvement, solid TPM baseline knowledge, and engagement from production teams [29]. Additionally, a shift in management thinking with the adoption of statistical reliability as a central part in maintenance management. One of the most common issues in industry maintenance is that employees make decisions based on their experience. That is why managers are encouraged to focus on data so that they can gain a competitive advantage [30].

2.5 Strategy formulation

Formulating a strategy could be done in numerous ways. One way is by first understanding the market and then defining operational objectives. This method is called the outside-in strategy and requires a continuous investigation of the market and customers' needs, which will guide the strategy. Another way is to start with understanding the resources and core capabilities, also called an inside-out strategy. Based on the capabilities, define the performance strengths to make strategic decisions that enhance market position [31].

The maintenance strategies have historically been more focused on mathematical calculations for equipment plans rather than comprehensive department strategies. Additionally, the guidance on how to develop organizations during the digitalized manufacturing era has been low. From a maintenance perspective, it is vital to include internal factors like processes within the maintenance department and leadership. Including the external factors like suppliers and production environment [8].

To sustain alignment and employee engagement, it is important to communicate the overall goals and progress. Visualizing the progress is traditionally done with maintenance KPIs like OEE and MTBF. However, to succeed with a smart maintenance strategy, more KPIs like job satisfaction and financial performance should be included [8].

[8] developed a strategy with a cyclic process for implementing smart maintenance. Table 2.1 summarizes their framework, which is based on empirical findings and theoretical interpretations. The authors recommend that future research provide more detailed insights into each step to prepare the maintenance organization for digitalized manufacturing.

Roadmaps are also an approach to formulate a strategy and have been adopted in many industries worldwide. This flexible approach can handle challenges like ambiguity, uncertainty, and the complexity of industrial systems. However, there is a lack of simple graphical illustrations that are crucial for easy communication with stakeholders. Instead, the common roadmaps in industry are practical with many technical steps, which makes it complicated for senior management to understand [32]. Although a roadmap is essential for strategy implementation, there is no universal approach, and each company must create its own based on its budgets. priorities, goals, intent, capabilities, motivation, and competencies [33].

1. Benchmarking	Benchmarking with the smart maintenance tool to assess the current state of the four dimensions in smart maintenance.
2. Setting goals	The organization should set goals that are more than traditional KPIs (OEE), like job satisfaction, financial performance, and employee individual goals. Additionally, linking these with company goals ensures strategic alignment.
3. Prioritization	Based on the result from the tool in step one, the company should prioritize the sequence in which activities for the dimensions of smart maintenance should be done.
4. Planning	Define what type of activities are needed to reach the goals. This could be done with the help of employee workshops and best practices from the industry. The scheduling of activities could be communicated with a roadmap.
5. Implementation	Implementing the activities defined would be the next step. Some obstacles in this phase could be leadership, culture, and investments.
6. Follow-up	The last step of the cycle involves a follow-up on the impact of the roadmap and linking this to the company's and the goal of individual employees. The KPIs could be revisited and evaluated, including the traditional ones. Since the strategy is iterative, the process starts over with step one when completed.

Table 2.1: Smart maintenance implementation strategy

While trying to explore new opportunities and innovate, still improving the existing process continues to be a challenge. There are two common ways of approaching this issue: either by structural ambidexterity or contextual ambidexterity. Structural ambidexterity is when the organization has separate units for innovation and improving existing processes, whereas contextual ambidexterity is when a balance is created between both activities in the company. Achieving contextual ambidexterity is necessary for a competitive advantage, and achieving contextual ambidexterity gives the biggest potential for innovation; however, it is the most challenging [31]. Research has shown that when ownership of organizational changes is transferred from employees to specialists or other units, the program is more likely to fail. Additionally, resistance to change increases when the change initiative is not communicated [34].

2.6 Change management

Implementing a new strategy is not always successful; a study from 2011 showed that 26,9 percent of the organizational change failed [35]. Some barriers for strategy implementation are a lack of purpose and commitment, resistance to change, ineffective resource allocation, lack of honest feedback, and communication [36] [37] [38].

The strategic fitness approach is one method used to bridge the gaps between goals and results. One key aspect of this approach is the gathering of employee input. This is done to break mental models and comfort zones at all levels. A special task force is created within the company to gather employee data, which could then be used in open discussions with management. Honest communication fosters a culture where leadership becomes aware of employees' perspectives and vice versa. By creating a comfortable space for honest feedback, employees feel heard, and top management can focus on growth rather than fear of losing authority. This has been used in organizations like Hewlett-Packard with positive results, including gaining knowledge on both sides, strengthening organizational alignment, and responsiveness to strategic challenges [36]. This also shows the importance of motivated employees who engage with organizational change; however, it is easier said than done.

Self-determination theory (SDT) is a proven theory in many different sectors, from health care to work management. The theory suggests that different types of motivation affect the employee's wellbeing and performance [39].

Motivation has a range of different categories, from amotivation to intrinsic motivation. However, the two main categories of motivation are controlled motivation and autonomous motivation. Autonomous motivation is when employees engage in their activities with willingness and free choice. This kind of motivation often leads to better performance. Controlled motivation is when the employee only works under the influence of contingent rewards or power dynamics. This could be beneficial in the short term, but negative effects on work engagement and performance long term [39].

The SDT has another dimension that acts like a mediator for work behaviors and well-being, which are the basic psychological needs of humans. The three basic needs are autonomy, competence, and relatedness. Autonomy is a feeling of having control and being the source of our actions. The practical implications of this could be that leaders encourage employees to take ownership of their tasks rather than enforcing rigid control. The absence of autonomy will eventually lead to resistance. Competence is the feeling of being able to carry out the daily tasks and challenges, including the development of skills over time. The sense of fulfillment and self-worth could be affected if competence is ignored. One example is if the organization decides to cancel developmental and training due to economic reasons [40].

Relatedness is the feeling of being supported and cared about. This feeling should be authentic without other motives and go both ways among employees. Traditional beliefs could be that the work is just work, even though we spend a large portion of our time at work. The desire for connection and meaningful relationships is natural human behavior and key to employee engagement. Research has shown that engaged employees are also more ready for change [41]. Another point in relatedness is to contribute to something meaningful that makes a real difference in the world and is bigger than us. Leaders cannot force relatedness, but it can be encouraged [40].

Leaders and management are the key source of impact in many areas of an organization. The lack of strong leadership and clear communication of vision is one of the hindering factors in smart maintenance implementation. Management commitment, among others, is crucial in smart maintenance implementation. Table 2.2 summarizes the hindering factors in smart maintenance implementation in a study done by [8].

Leadership clarity	When many different ongoing initiatives are implemented in an organization, a lack of clarity from management could arise. This makes employees confused and disengaged.
Culture	The combination of old habits with employees who simply resist change and lack of collaboration between other departments creates a stagnated environment.
Systems perspective	Lack of standards and knowledge sharing could lead to a narrowed view where on functions or factories are prioritized instead of seeing the whole company as a system towards a goal.
Time and resources	Lack of availability for strategic development and resources.
Goals and follow-up	Setting goals that are not just technical availability is necessary in a smart maintenance implementation. There should be a combination of goals to reach the dimension of smart maintenance, including the technical availability.
Setting activities	Creating the specific activities to reach the goals of each dimension could be difficult. Brainstorming workshops with employees are a solution to form and prioritize activities.

Table 2.2: Hindering factors in smart maintenance implantation

3
Methods

This chapter describes the methods used during the thesis. These include literature studies, interviews, current state analysis, benchmarking, analysis of results, and the creation of a roadmap that will help companies to implement smart maintenance.

3.1 Methodological Framework

Figure 3.1 shows all the methods used in this thesis project, and how they are connected and where every part leads. The project starts with a formulation of the problem, which is done primarily with stakeholders from industry. This is further validated by the supervisor from academia to ensure compliance with academic needs. A method was then formulated and validated in an iterative way, primarily with an academic supervisor. Once the method was selected, a literature review on TPM was done to gain more knowledge for the thematic coding. The interviews were held with maintenance technicians, engineers, operators, and team leaders to gain insight into the current way of working. The data from the literature study and interviews were the ingredients to create a framework for the thematic coding. However, the thematic coding was modified with a lite version of SWOT. The SWOT was divided into strengths and weaknesses only, and laid the foundation for a gap analysis.

The gap analysis was then used in the roadmap to know the starting point and the amount of focus in different areas of TPM and smart maintenance. Benchmarking and interviews with other Volvo sites were done in sequence. The benchmarking gave a quantitative result of how far the company has reached the dimensions of smart maintenance. The interviews gave inspiration from other Volvo sites that have come far in areas in which Volvo Tuve was lacking. The literature study on smart maintenance and TPM-smart maintenance was necessary to realize the gap between the concepts, which was key in both roadmaps.

This study was conducted for the maintenance department in Tuve, which supports the whole factory with maintenance-related issues. The study was therefore done on the whole factory, and data were gathered from other departments, like production.

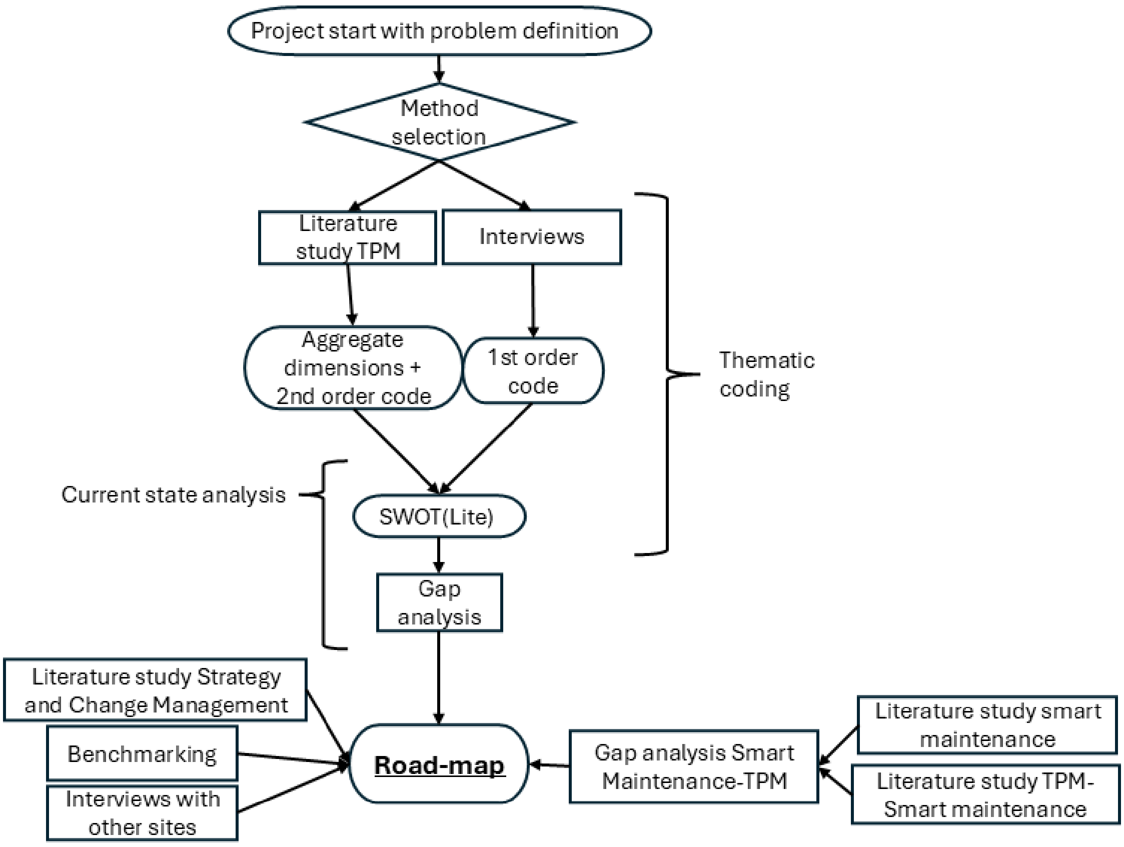

Figure 3.1: Methodological Framework

3.1.1 Method outcome

By following the methodological framework, the data collection created both qualitative and quantitative results. The qualitative part consisted of 25 interviews, 25 scientific papers, and 5 books. This generated the thematic coding data with the 8 aggregate dimensions down to 424 quotations. The quantitative part generated 4 graphs out of a tool called SMASh. Figure 3.2 describes how much data has been processed and the outcome of it.

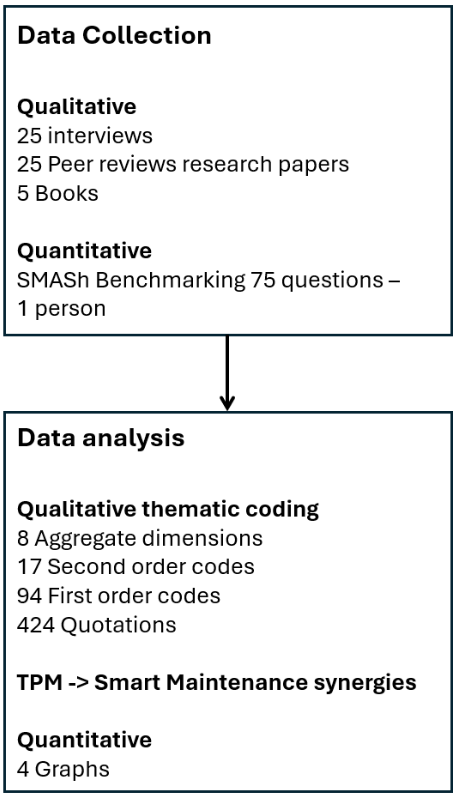

Figure 3.2: Outputs of the methodology

3.2 Current State Analysis

This section will analyze the current state of the Volvo Trucks Tuve plant with interviews, thematic coding, benchmarking, and a gap analysis.

3.2.1 Literature study TPM

To get a better understanding of the TPM strategy that Volvo Tuve claims to use today, a literature study was conducted. This was necessary as a current state analysis of the factory was to be done, and a knowledge base for TPM had to be developed. To do this, databases like "Scopus" were used to find peer-reviewed articles that cover the TPM strategy. The information gathered from the literature served as a filter to identify relevant data from interviews [42]. This was later used to develop the coding framework discussed in section 3.2.4.

The search string that was used in Scopus was "total-productive-maintenance" and sorted by highest citation. The reason for sorting by the most cited articles was due to the large number of publications available, making it more effective to focus on the most accepted understanding of the concept. The articles were selected primarily for their relevance to the objectives of the project. The articles were looked through to find specific information needed, for example, the practices of TPM, which were key in the project.

3.2.2 Interviews

The interviews in the current state analysis mainly consisted of two types, semi-structured interviews and unstructured interviews. The semi-structured interviews are performed with a list of questions to be addressed. These questions are based on TPM theory and the constructs created from the theory. The questions aimed to extract information on how they work with different pillars. The questions can be seen in the appendix A. These were structured with a main question and probes to guide the topic. However, the format and order are quite flexible with open-ended questions to expand the ideas [43]. These types of interviews were conducted to gather data for the SWOT analysis. The interviews ranged from 15-45 minutes. The widespread interview times were mainly due to the open-ended questions, where some had a lot to say. The unstructured interviews aimed to extract the ideas of the interviewee without the structure of the interviewer [43]. This was useful in situations when gathering initial data to understand Volvo maintenance practices and improvement areas.

The current state analysis was made with the data from these interviews, which means that the interview subjects were in different parts of the factory. Assembly operators, maintenance and assembly team leaders, and maintenance engineers were an important part of this process. Each interview was recorded and transcribed. The transcription is then divided by section and labeled as supporting or contradicting to TPM theory. The interview processes were concluded once a saturation point was reached. This means that during the last interview, there were no new information discovered.

3.2.3 Benchmarking

The end goal of the project is to create a roadmap that the organization can use to implement smart maintenance. To start this roadmap, an investigation on how far they have come needs to be done. It will be done by using a benchmarking tool called "SMASh". Which evaluates the four dimensions of smart maintenance presented in the introduction of this report [12].

The questions for the SMASh tool were developed by researchers at Chalmers in a research project that, among other offers strategic guidance for managers [44]. The tool acts like a self-assessment tool for benchmarking smart maintenance achievement. Additionally, it provides a discussion basis for managers to take the next step towards smart maintenance.

The maintenance manager answered a survey with questions where they graded the organization on a scale from one to five. To get deeper discussions in the analysis part of the project, the maintenance manager should have some basic knowledge of smart maintenance. To ensure this, a small discussion was held about smart maintenance, and after this, it was deemed that the manager had enough knowledge to perform the analysis. The results from the survey were then compared to a database of 150 other organizations [12]. This showed how far Volvo Trucks Tuve has come regarding smart maintenance.

3.2.4 Thematic Coding

Thematic coding is a qualitative method where data from, for example, interviews is labeled (coded), which is then matched with either existing theories (deductive) or the development of new theories (inductive) [42]. Deductive coding was used in this project due to the characteristics of the method, which matched with needs of the problem. Table 3.1 describes the process of deductive coding.

Stage	**Description**
Creating a research question and selecting guiding theory	The research question was selected during the problem definition with the guided theory being TPM.
Applying theory	In this stage, core components of the TPM concept are gathered in the format of descriptions, which are also called aggregate dimensions and 2nd order code. The stage is described in more detail in section 3.2.1
Collecting targeted data	Data was gathered in this stage, and this was done through interviews, which are explained in section 3.2.2.
Coding and analyzing data	The data from interviews is then extracted and matched with theory. This is where the keywords (1st order code) are created, described in section 3.2.4.
Creating a framework	A framework is created in the last step to visualize the current state of TPM in Volvo Tuve.

Table 3.1: Process of deductive coding

Since the current maintenance strategy at Volvo Tuve is an adaptation of TPM, the first step was to evaluate if they have reached the foundational aspects of TPM and by how much. The deductive coding was therefore done with TPM as the theoretical base. A common illustration of TPM is the famous house with eight pillars, seen in figure 3.3, representing the key aspects for the strategy [6].

The deductive coding approach began with the constructs created with the theory. These constructs are also called aggregate dimension and 2nd order codes, which are purely theoretical and build the framework for the analysis [42]. One example of this could be autonomous maintenance as an aggregate dimension and fostering ownership as a 2nd order code.

The results deviated from traditional TPM theory. However, it served as a foundation for the current state analysis. Therefore, the outcomes reflect the factory's actual operations. Most of the data should be related to TPM, as it is the strategy employed by the maintenance managers; the other answer was used for the smart maintenance implementation.

This was then combined with the data from interviews to create value. The citations/statements from the interviews were labeled in a Word file to categorize against the correct pillar. These then fell under a keyword and were matched with second-order codes, which represent a part of the pillars. The data either support or contradict the theory that builds the second-order code.

To structure and visualize the data, a SWOT analysis was used. SWOT analysis has been widely used in industry as a tool for strategic decision making and is ranked among the best methods for strategic planning. The SWOT is commonly conducted with a matrix consisting of 2x2 cells with the following areas: strengths, weaknesses, opportunities, and threats [45]. The common application in general management is to create strategies by evaluating the areas of the matrix [45]. This makes SWOT a clear choice to assess the current state of Volvo Tuve in TPM.

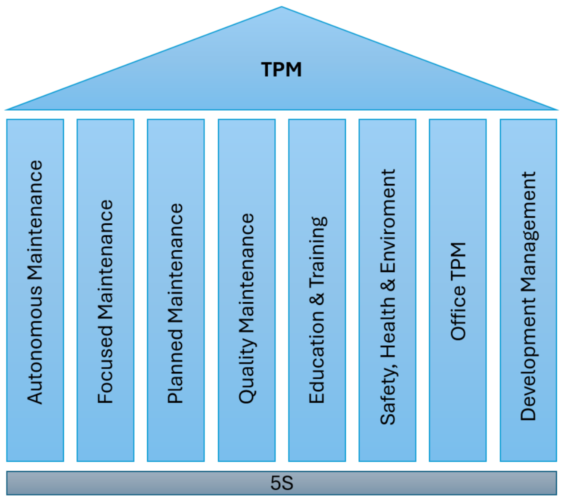

Figure 3.3: The pillars of TPM

When it comes to the SWOT analysis, threats and opportunities are focused on external factors. Things that aren't under the organization's control. With this in mind, and the time pressure from the project deadline, the focus of the analysis was only on the strengths and weaknesses as these are internal factors [46]. Each analysis was done with data from the interviews and more specifically, 1st order code, which is citations from the interviews. As seen in Figure 3.4, these citations were divided into the strength and weaknesses categories based on their contribution to the TPM strategy. The strengths act as supporting, and the weaknesses as contradicting the TPM theory.

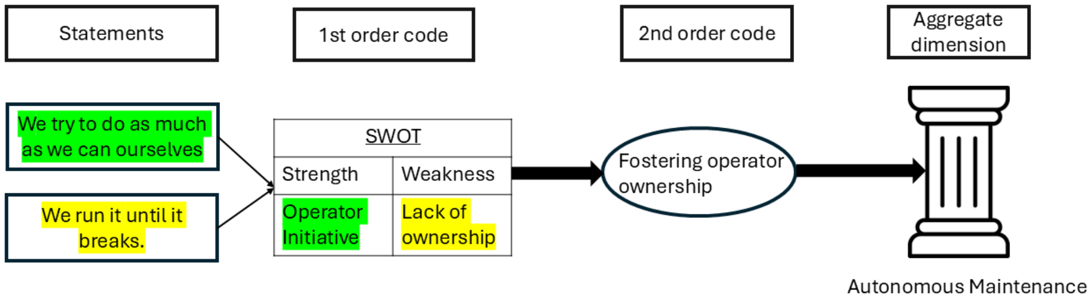

Figure 3.4: Coding method

3.2.5 Gap analysis

In this stage of the current state analysis, the data were examined to assess how they relate to the original theory. The data was also compared against the theory. However, rather than challenging it, the comparison highlights a gap. The difference from the original deductive coding method is that the theory will not be challenged and refined [42]. Based on these strengths and weaknesses from the SWOT analysis, a gap analysis was made where an ideal state is created. This ideal state is each pillar of TPM, based on the literature study for TPM. This was then compared with the current state of each pillar in the factory. The comparison created a gap that highlights the difference between the ideal and current state.

The identified gaps will indicate areas where Volvo Tuve needs to work and where the roadmap will have the most focus. The second roadmap that is made for academia and other manufacturing companies will start with the roadmap with the assumption of maturity in the TPM pillars.

3.3 TPM Smart Maintenance synergies

This section will analyze the gap that needs to be filled between TPM and Smart Maintenance to use a combination of both in a factory.

3.3.1 Literature study on Smart Maintenance and connection with TPM

The purpose of the literature study on smart maintenance was to have the theoretical knowledge necessary when recommending specific actions in the roadmap. Additionally, the literature study gave the necessary knowledge to see patterns and combine both TPM and Smart maintenance. The primary database used was Scopus with the search string "Smart-maintenance" and "Smart AND Maintenance" combined with the year filter of 2016-2025, which generated 343 documents. The most relevant documents were selected based on relevance. The information extracted from these papers was mainly on the four dimensions and their impact.

A literature study was also done on the connection between TPM and smart maintenance. The purpose of this literature study was to see if previous work has been done to merge the two concepts. The database Scopus was used with the following keywords ("smart maintenance" OR "Maintenance 4.0") AND ("total productive maintenance" OR "TPM").

3.3.2 Gap analysis between Smart Maintenance and connection with TPM

Understanding the gap between smart maintenance and TPM is important when developing a balanced and effective roadmap. Therefore, a gap analysis was made to understand the connection between the concepts and the differences between them.

Additionally, understanding the connection between TPM and smart maintenance would make the roadmap less comprehensive. This is due to fewer steps overlapping pillars, and the dimension could be jointly implemented. This gap analysis is an important component in making the generic roadmap for academia and manufacturing companies.

The gap analysis was done in brainstorming sessions where ideas about where the gap lies were tested a redefined. The ideas were cross-examined by the researchers with the literature on the concepts as a guide. The two concepts were finally classified as either fully aligned, partially aligned, or not aligned.

3.4 Literature study Strategy and Change Management

The literature study on change management and strategy was done to gain inspiration from academia when creating our roadmap. Details like what should be included and how roadmaps are constructed were used. The main database used was Scopus, with different search strings for the two topics. For change management, the search string “change-management” was used, and for “Strategy-formulation” and “Strategy AND Roadmap”. The articles were sorted by relevance and cherry-picked with search words in the papers like “roadmap” and “contributing factors” for change management.

3.5 Interviews with other sites

When the result from the SMASh tool had been analyzed, an understanding of where Volvo Tuve is related to smart maintenance was acquired. Depending on which dimensions of Smart Maintenance are identified as weakest, an interview was conducted with another site that demonstrates strong performance in those specific areas. This is because insights and learning from other Volvo sites are easier to implement, as they have already been shown to work in a similar context. Additionally, these interviews were used as inspiration for the roadmaps.

3.6 Roadmap

The decision to create a roadmap was due to its flexible approach and ability to handle the complexity of industrial systems. The thesis generated two roadmaps, where one was specific and provided the necessary steps for Volvo trucks Tuve, and one was more general for academia. The roadmap for academia will also serve as a framework for other companies in a similar situation.

The layout of the roadmap for the case company was discussed with stakeholders to ensure a layout and format that suits their approach to strategic decisions. The basic format of the roadmap was the activities to reach the milestones with a relevant timeline. The sequence of the activities was also sorted in a logical order.

The sequence and content of the two roadmaps were brainstormed in session to generate ideas. The academic roadmap was, however, mostly influenced by the synergies between the TPM and SM. Meaning that the suggested activities were based on closing the gap between the concepts. The Volvo roadmap needed was generated similarly, however, with additional influence from the gap towards TPM. Meaning that recommendations were also made to close the gap between their current state practices and the TPM ideal state. One example would be recommendations on specific weaknesses discovered in the swot analysis.

4
Results

This chapter presents the key findings of the study. It begins with a current state analysis based on a literature study, thematic coding of interviews, and benchmarking. The analysis identifies the maturity level of TPM at Volov Trucks Tuve with a gap analysis. The chapter then explores synergies between TPM and Smart Maintenance, structured around the four dimensions. Insights from interviews with another site are also presented. The chapter concludes with the presentation of two roadmaps.

4.1 Current state analysis

This chapter presents the results from the current state analysis, synergies between Total Productive Maintenance (TPM) and Smart Maintenance, benchmarking of smart maintenance maturity, and the roadmaps.

4.1.1 Literature study on TPM

From the literature study on TPM, the pillars that are presented in 2.2.2 were extracted. The literature study also contributed to the coding process by providing the "second order code". These codes are presented in Table 4.1.

Fostering operator ownership is the first code in AM, and as the title says, this code indicates whether the operator takes care of their equipment and maintains it. Standards for cleaning, inspection, and maintenance code indicate if the company has different standards for operators and other personnel, which can be followed to perform the maintenance.

PM (CBM, TBM, PdM) code stands for planned maintenance practices like condition-based maintenance, time-based maintenance, and predictive maintenance as a strategy for equipment. MTBF and MTTR essentially mean that they are measured.

The code "Get to the root cause of the problem" is about the use of root cause analysis, and one example of how you could get to the root cause of a problem is by using methods like 5-whys. Continuous improvement code means that they have an ongoing effort to enhance equipment performance and reduce waste.

The training code indicates if the employees have received formal training in, for example, equipment handling. “Knowledge of equipment” is a result of received training and means that they actually have the competence. “Periodic skill evaluation and updating” indicates if the company has skill evaluation and updating that is done systematically in given time frames.

The code “Establishing and addressing equipment conditions that can cause product quality defects” is about the methods and tools used to find out which tools and why they damage the product. The code “Error proofing” means that there are sensors or automatic switches that act as a barrier for quality errors.

The code “Utilization of previous knowledge/data in design and purchasing” explores if the operators/engineers are involved in design and purchasing.

The code “Identify and eliminate risks/hazards” represents the way employees work with risks and how the risks are mitigated or eliminated. “Safety standards” are if they have documents for risk together with risk reporting and safety culture. “Environment” indicates if, for example, the indoor climate is pleasant.

The code “Cross collaboration between departments” represents the important part of TPM where different departments in the organization collaborate to improve the OEE. “Improving administrative processes” could be, for example, shortening decision times on different matters.

TPM Practices as Second-Order Codes			
Autonomous Maintenance	Fostering operator ownership		Standards for cleaning, inspection, and maintenance
Planned Maintenance	PM (CBM, TBM, PdM)		MTBF and MTTR
Focused Maintenance	Get to the root cause of the problem		Continuous improvement
Quality Maintenance	Establishing and addressing equipment conditions that can cause product defects		Error proofing
Education and Training	Training	Knowledge of equipment	Periodic skill evaluation and updating
Development Management	Utilization of previous knowledge/data in design and purchasing		-
Safety, Health, and Environment	Identify and eliminate risks/hazards	Safety standards	Environment
Office TPM	Cross collaboration between departments		Improving administrative processes

Table 4.1: TPM Practices and Their Second-Order Codes

4.1.2 Thematic coding

There were in total 25 interviews, and all these have been compiled in a "deductive coding document". Important quotes from the interviews that relate to the 8 pillars of TPM or important information about their way of working. These were divided into "Strength" and "Weaknesses", and similar quotes were filed under the same keyword. To highlight the "importance" of the keywords. They are arranged in descending order based on the number of occurrences, with the most frequently quoted keyword at the top and the least frequently quoted keyword at the bottom of the table. Examples of the quotations given in the text will be one of the actual quotations from the interview; every quotation will not be covered, but the chosen ones will reflect similar characteristics as the rest of them for every keyword.

The pillar "Autonomous Maintenance" was divided into 2 different second-order code sections, which were chosen based on the literature study that was performed on the topic of TPM. These sections were chosen for the pillar Autonomous Maintenance. 4.2 shows the first section, "Fostering Ownership", and the strengths/weaknesses that were found during the interviews.

Starting with the first strength shown in 4.2. Citations that were addressed under this keyword suggest that the assembly operators take responsibility for inspections and give their best effort for the repairs of their equipment. Exemplified by the

Fostering Ownership	
Strengths	**Weaknesses**
Operator Initiative	Lack of ownership
Maintenance Initiative	No active initiative
Ongoing development	Miss use of equipment

Table 4.2: SW- table: Fostering ownership

following quotation "*But we try to do as much as we can ourselves, but it comes down to lifting tools, and when it's like that. Yeah, but when it comes to electricity or air or things like that, we often leave it alone.*". The next highest keyword is "Maintenance initiative", this means that the maintenance personnel, technicians and engineers, try to create an environment where the assembly operators can and want to take ownership of the equipment used in production. "*I'm a little bit pushing for more of what you're talking about here, ownership that you feel committed to in the machine.*" is a good example of a quotation used when creating this keyword. The last keyword in the strength column is "Ongoing development" and a quotation from the interviews for this word is "*A process is underway there to get the cell operator more involved in the maintenance part*" and this suggests that there are an ongoing initiative that aims to develop the sense of ownership in more operators.

Moving on to the weaknesses of the fostering ownership category. Highest is "Lack of ownership", this is contradictory to the strength, but it is important to remember that this analysis is of the whole plant, and this means that there are a lot of operators. Some feel the sense of ownership and some do not, all the interviews are equally worth, and every opinion has been considered in this analysis, as it is important that every opinion is heard. The first keyword in weaknesses means that there are a lot of employees that does not have the ownership feeling, this can be operators, technicians, or engineers. Some know that problems exist and do nothing, "*And that is until it breaks, that is absolutely the case.*" is a good example. It means that machines are used until they break down, even if a fault is found before the breakdown, stated in "*The problem we've had, I've had a few of those, is that the ownership in the machine hasn't been passed on.*". It can also be that the ownership feeling isn't passed down from experienced employees to new ones.

Next keyword is "No active initiative" and this means that the initiative to create ownership is not being driven by the employees who are required to engage in it for its successful implementation, this keyword comes from quotations like this "*No upcoming initiative, but when you say it out loud, it's something absolute. Which isn't stupid to have*". The last keyword in the weakness section is "misuse of equipment", which covers the fact that some equipment is being used to do things it wasn't designed to do. This can be for example using electric screwdrivers as hammers, which significantly shortens the useful life of the electric screwdriver which contains sensitive parts and this is supported by "*Yes, some machines are being used as a hammers and what they use as a hammer will affect the working inside the machine. The impact before you put it inside the machine will affect how the* *machine behaves.*".

4.3 shows the second category (second order code) for the Autonomous maintenance pillar, and it will be explained in the same order as the first category. "Standards" houses all the citations that describe that there exist standards for cleaning, inspection, and maintenance supported by "*And there it is, clear standards. You have to lubricate and follow and give daily attention to.*". These standards are specifically for the production operators, assembly operators, or process operators. These are the standards that, together with the sense of ownership, build up the autonomous maintenance pillar. AM Calendar and AM responsible go hand in hand, the calendar is a document that shows when and where the operators should do the cleaning, inspections and maintenance. "*We work with operator maintenance and on a daily basis. We have an am calendar.*" and "*All groups have an AM responsible.*" supports these last two keywords. The AM responsible is one person who is responsible for the completion and logging of the AM tasks. The existence of these things can be seen as a strength for the company and the maintenance strategy TPM.

Moving on to the weaknesses for this category, starting with "information gap". This keyword is related to the AM calendar and the standards that were deemed strengths. Some interviews suggested that the standards, AM calendar and other related documents were either missing, not updated in years or other important information were missing supported by "*Eh I we have an AM schedule is a little outdated.*" and "*And then we don't have an exact schedule for that either.*". Again, it is important to remember that this does not mean that the whole factory has these problems, but they do exist. The next weakness is "Lack of involvement", this is describing that the maintenance department has nothing to do with the standards after the first implementation, as stated in "*Maintaining it is nothing we do. Without it. It is more the preparatory work for their maintenance*". This means that there is no control of updated documents or instructions from the maintenance department. It is up to the assembly operators to keep them updated; these operators are very skilled at their job of running the lines and building trucks, but it is the maintenance department that knows when and what needs to be done to the equipment. Last keyword is "Not prioritized" and this means that there sometimes is no time to perform autonomous maintenance, supported by "*Do they have operators who are willing to do the things. So it's not always that it has time to do things.*"

Standards for cleaning, inspection, and maintenance	
Strengths	**Weaknesses**
Standards	Information Gap
AM Calender	Lack of involvement
AM Responsible	Not prioritized

Table 4.3: SW- table: Standards for cleaning, inspection, and maintenance

Moving on to the "Planned maintenance" pillar and the first category, which is "PM (CBM, TBM, PdM)", and the keywords for this can be seen in 4.4. The first strength is "Experience utilization", which means that the maintenance teams have a lot of knowledge about the equipment that they work on. This knowledge is used to modify maintenance schedules to make a more effective planned maintenance, "*but in hindsight you might see that you don't need to check this so often or you might take your experience with you to the slopes instead.*" supports the keyword. Next strength is "Data availability". This keyword says that there are a lot of data available, with this data one can see the number of times a connected electric screw-driver has been used, maintenance records that could be used to calculate MTBF, there is even data that could be categorized as condition based such as vibrations and current usage for some equipment. Quotations under this keyword include "*All equipment is logged in vmms.*", "*If there was an electric machine connected to tool-snet*", and "*Yes, exactly, there are sensors and such in all drive stations that see a lot of things with buckles and such.*"

"TBM/Strategy" stands for the fact that there are different time-based strategies for different types of equipment, which aligns with the TPM strategy, supported by "*Every machine has its own plan.*" and "*For example, if you are going to do maintenance on one of the punching machines, you will get a list of what you should do and what you should check, how often the points should be checked, and what should be done physically.*". "*We always want to move away from firefighting and towards prevention when trying.*" describes that there is ongoing work with the aim of moving from a corrective approach to a preventive one, using tools like condition monitoring. This is how it should be done according to TPM, Volvo isn't there yet, but the work to get there is underway, and that can be seen as a strength. The keyword for this is "Initiative". Next is the "Maintenance coordinator", this is a newly created position in the maintenance department, "*Where we have now got a new position that will work on it full-time.*", with the responsibility of coordinating the preventive maintenance in the factory. The creation of this role is a good step in the direction of preventive maintenance and, therefore, deemed a strength for Volvo. The last strength in this category is "Planned stops", this is an opportunity for larger maintenance projects to be scheduled. As some things are very difficult to do during the production hours, these stops makes it easier to plan the preventive maintenance, supported by "*We have a stop every Friday now, so we go to a specific location, so if there was a problem with the dimensions or something like that, we try to solve it urgently or plan it in and make a statement about the stoppages all weekend.*".

There is a lot of strength in the planned maintenance pillar, but there are also a lot of weaknesses that might have a big impact on the strengths. To begin, there is the keyword "Reactive Thinking". This means that there exists a reactive mindset among the maintenance teams. This is a weakness as the people who are supposed to work preventively see obstacles with this way of working and focus more on reactive maintenance as stated here "*Generally speaking, I work. That, no, that's because we don't have time for that, but we have to take it when things happen a little bit.*" and here "*almost only on an emergency basis for me.*". The next thing is "Lack of data usage", examples from the interviews is "*We're not good at extracting and*

PM (CBM, TBM, PdM)	
Strengths	**Weaknesses**
Experience utilization	Reactive thinking
Data availability	Lack of data usage
TBM/strategy	Inconsistent Logging
Imitative	Supplier-driven Maintenance
Maintenance coordinator	Replacement machines
Planned stops	Reactive managers
-	Selective Maintenance

Table 4.4: SW- table: PM (CBM, TBM, PdM

analyzing that data today." and "*Then I actually don't know what we do with that data today.*". Some employees say that the collected data isn't used for anything, and others did not know what the data is used for. Continuing on the theme of data, "Inconsistent Logging", data such as time for a maintenance task is reported at the end of the day with no notes of the actual times. This makes the reported times more of an estimation and does not reflect the actual times for the task. Supported by quotations such as "*but I'm afraid we don't input that data so that the analysis is uh fair.*" and "*Where we can get the logs from. Area for improvement.*"

"Supplier-driven maintenance" refers specifically to the pneumatic and electrical screwdrivers used in production. What is meant by this is that preventive maintenance is only done on the electrical ones, as the supplier is bound to do so as per the contract between Volvo and the supplier. This means that there is no preventive maintenance done on some of the pneumatic screwdrivers; these ones are used until they break down. There is also knowledge about this, but no one does anything about it. Quotes that built this keyword include "*Eh, if you're going to do it like that, they're going to pick up the machines and sort of check them and all that, but that's not done. The only thing that is subject to PM is electrical machines. But that's because Atlas is contractually bound to do PM on*". This is also related to the "reactive mindset" mentioned previously.

This next keyword needs some motivation on why it is a weakness, as it can be unclear without an explanation. "Replacement machines" means that if a machine breaks down, there are backups, things like another screwdriver and a torque wrench can be used until the machine is repaired. As stated in "*Oh, if your machine breaks down, machine A, then we'll have machine B that they can switch between while we have machine A and fix it, that's the plan and that.*". This can be seen as a good thing at first glance, but in this case, it is an enabler for reactive thinking. As the maintenance teams know that there is a plan B when the machines break down, it is an easier decision to neglect the preventive maintenance. There is also the case on extra work for the production operators who have to do more manual work until the original equipment is repaired.

The next weakness has to do with management,“*It’s not our managers who are driving. Maybe always, but it’s the production managers who are interested in the downtime. And then question it.*”, “Reactive managers”. Some employees feel that the push for preventive maintenance comes from the managers in production, and that there is a lack of interest in this field from the maintenance managers. Next is the “Selective maintenance” keyword, this is to show that there is only preventive maintenance for selected equipment, “*For some machines we have our PM*”, so there is equipment that does not qualify for preventive maintenance.

4.5 shows the MTBF and MTTR related to planned maintenance. The first strength of this category is “External MTTR”. This means that there is knowledge of the MTTR if the equipment is sent for repair externally. Then there is information if it will take, 1 day, 2 days, 1 week, or one month. It is not more exact than on the day, but there is knowledge about this, which is a strength. This is supported by “*If we send the machine externally for repair, we have a better idea of how long it will take before we get it back. For example, if it takes a month, it takes a week, if it takes a day, it takes a week.*” Next is “MTTR balk”, this is related to the first part of the factory, which isn’t assembly but a process operation. In this part of the factory, there is a very good knowledge of MTTR, which is very good and a strength. As stated in “*Yes. It is followed up all the time.*”

MTBF and MTTR	
Strengths	**Weaknesses**
External MTTR	Internal MTTR
MTTR Balk	Experience based MTBF

Table 4.5: SW- table: MTBF and MTTR

Moving on to the weaknesses in this category, “Internal MTTR”. This one is short and simple, MTTR isn’t measured in-house, “*But not much attention is paid to MTTR here at home.*”. However, as previously written the times is logged in VMMS, which is Volvos CMMS, but it is usually not the correct times which comes from the quotation “*But I usually write down most of the jobs before going home in the afternoon, sit down at the computer and write them all down together, because otherwise if you had started the job and finished it in the morning, you would have had a more accurate time.*”. Last is “Experience based MTBF”, which means that it is not measured. But if the technician knows that some equipment has broken down before, it’s possible to go back in VMMS and see when that was and what was done if it was logged correctly which is supported by “*But that, you have to gain more experience from experience, yes, then you have to check. But there’s nothing that pops up, that’s just it.*”.

In 4.6, the next category can be seen, which is the first category of the focused maintenance pillar. Starting with quotations like “*It’s this EWO that we use then.*” and “*Yes, we have something called in EWO where it’s 5 whys. Then go in there. And then use it, it’s kind of a fishbone diagram really.*”. Represented by the keyword

"Methods", this is related to tools for root cause analysis. In this case, it is a tool called "Emergency Work Order" or "EWO" in short. This is a tool that involves the collection of data, possible issues, verifying issues, 5-why, and countermeasures. This is a strength that Volvo can apply when issues arise. Next strength is "Equipment failure logging" with the quotation "*then we log it in their system, should we say there is a request*". This means that when issues occur, they will be logged. The production team leader calls an emergency number, and the phone operator creates a work order and sends out maintenance technicians. These work orders are saved, and the maintenance operators should log the problem and the solution for future work. "Collaboration 2" is the last strength here, and just as it sounds, it is about collaboration. It means that the maintenance and production personnel work together to keep the factory producing, supported by the quotation "*And engineers, really, construction, production technicians, we have to gather everyone to help.*"

Get to the root cause of the problem	
Strengths	**Weaknesses**
Methods	No Standards 1
Equipment failure logging	Incident-Driven Troubleshooting
Collaboration 2	Recurring Failure
-	Traceability

Table 4.6: SW- table: Get to the root cause of the problem

Moving on to the weaknesses in 4.6. The first one is "No Standards 1" with a supporting quotation "*There may be or is about to be nothing I have actually seen anything of. But historically it has only been solving the problem*", which means that there are no standards in the way problems are solved. It is all up to the technicians to solve problems however they see fit. Next, "Incident-Driven troubleshooting". This is about the mentioned "EWO" process that is the only tool used for root cause analysis. It is only for issues that stop the production line for a predetermined amount of time, "*We are bigger stop in over, I think that if we have stopped for more than 10 minutes, more than ewo*". This means that the cause of smaller issues, issues on a pre-station, or similar, is never investigated. Which means that the likelihood that it will happen again is rather large.

This next keyword is a consequence of the previous one, "Recurring failure", and it is from assembly operator interviews. The citations here says "*I have carts in there and things that we build on and the fixtures we can actually take as we use them. They are very loose and we have to call them extremely often.*" and "*fixtures that have broken time after time after time and then all just like this*". There are a lot of recurring failures that happen to carts, fixtures, and other equipment that isn't directly line-stopping. This could be seen as related to the lack of root cause analysis and validation of the previous keyword. Last weakness of this category is "Traceability", and it means that there is an issue to find information about previous failures, quotations here include "*If it happens again in six months, how do you know what we did then? Where do we find the information about what we* *did.*". It indicates that the failure logging is flawed, or that the operators do not know where to find the information. In that case, it would indicate a lack of training.

4.7 shows the second category under the Focused maintenance pillar, this one is called "Continuous Improvement". "Collaboration 1" and "*Yes, either way, you get to solve it together often. It's the one who stands by the machine that knows the machines, and if they have a problem, then you have to come. See what you say??*" is the first strength, and this suggests that it seems to be a good collaboration between the maintenance and production departments when it comes to issues and breakdowns. It means that problems will be solved faster and smoothly, which is a clear strength. There is also "Ongoing development", maintenance teams have dedicated times for improvement work as stated "*We also have something we call improvement work, we even have time set aside for improvements.*". There are also projects to improve equipment and change to tools that need less maintenance, this comes from "*We are working on it. It is always very small, because we are trying to find tractors that we can replace slowly but surely. There is a major effort underway to change all the machines to electric.*". Continuing on this subject, the next keyword is "Walk the line" and it originates from quotes like "*So you can 'walk the line'. We find various things about the new around so much where it's like high noise levels, maybe a lot of vibrations. So, just awkwardness like we find places. We're already checking what they have, already checking what alternatives are there*". This is when maintenance and production operators walk alongside the production line and look for issues or areas that can be improved. The last strength is "Tools", this means that Volvo supplies tools for continuous improvements, such as an app that makes it easier to document and collaborate with others, supported by "*We have such an app. Okay, we can go in and improve in the app.*"

Continuous Improvement	
Strengths	**Weaknesses**
Collaboration 1	Passive Approach
Ongoing development	No standards 2
Walk the line(GEMBA)	Personnel shortage
Tools	No Time

Table 4.7: SW- table: Continuous Improvement

Moving on to the weaknesses in 4.7, the first one is "Passive approach". This represents the fact that some employees do not work with improvements and some only do it if they see something that can't be ignored during work with maintenance. Quotes that built this keyword are among others "*Eh, I think it's very rarely used and applied, proactively.*" and "*On the upswing I would say. Are you sure you can work and find something*". Moving on to "No Standards 2", it seems that the improvement work lacks standards, "*No, not really.*" was the answer to the question of standards. What is meant by this is that there is no clear structure on how to work with and document improvements. This means that improvements done can't be applied in a similar situation somewhere else, as there is no record, or limited records of what has been done before. “Personnel shortage” refers to the production side of the factory, where it is hard to do improvement work as there rarely are people that aren’t in production which comes from “*If you take our department’s point of view, we usually have very poor staffing.*”. “No time” and the quotation “*So it has to happen, we can’t keep doing lengthy investigations. It has to happen quickly right now.*” is on the same track, there is no time for lengthy investigations in the production, everything needs to be done fast.

Table 4.13 shows the results of the first category in the Quality maintenance pillar. To make sure that the machines deliver a continuous stream of high-quality products, there are different types of controls done. These range from torque checks to tightening of drive belts, to visual checks on critical equipment, quotes covering this is “*So we work with what was said and how safe how safe do we make sure everything works as we should we do our checks on the machines*” and “*so we do tests we tighten belts and feel the cracks with torque wrenches and a little bit like that. Eh then it’s a visual check*”. “Standards” is the next strength and contains two different tools, the first one is QRQC and stands for “Quick Response Quality Control” and is used to counter quality issues in a structured way, which leaves a paper trail to follow in the future. The second is EWO, and it has already been explained, but it is also used in quality control situations, which is why it is a strength in this pillar as well, and quotes include “*quality deviation eh then there are five whys because just like you are talking about. QRQC and stuff like that I am actively working with eh to find root causes*”. Last strength here is “Traceability”, this means that all the trucks built has it’s own ID and can be traced back to the operator who built it, the electric screwdriver used, and different controls during the production. This means that when an issue is discovered, it can be traced to the cause of the issue, which is said in “*It’s analyzed back. So, for example, every beam we make is unique, it has its own. We know exactly when and who made each beam as well. So everything can be traced that way.*”.

Establishing and Addressing Equipment Conditions That Can Cause Product Quality Defects	
Strengths	**Weaknesses**
Control	Material conditions
Standards	No standards
Traceability	-

Table 4.8: SW- table: Establishing and Addressing Equipment Conditions That Can Cause Product Quality Defects

Weaknesses in this category start with “Material conditions”, which means that there have to be the right conditions to be able to do the job right. There has been issues with damaged threads, where the electric screwdriver gets tricked to think that the screw is all the way in. But in reality, it stopped in the damaged section. This makes it hard to detect as the computer system thinks that the screw is correctly torqued when it is not. This keyword originates from quotes like "*That's always been the harder part. It's getting good material here.*". Next is "No Standards", this means that some employees work with no standard when repairing equipment and it is supported by quotes like "*But I can't say that I have any standard in that work, it's just a matter of solving it on the spot.*".

The next category in the quality maintenance pillar is seen in 4.9, and "Connected tools" is the first strength. In error proofing, this means that tools are connected to a computer system. It can be electric screwdrivers, poka yoke. "*He has been an electric machine received that was connected to toolsnet among possible*" is one of the quotations here. It is also possible for the maintenance operators to connect their phones to some equipment to troubleshoot it. Next keyword is "Controls 2", it is related to the processes at the beginning of the factory. In these parts, there are sensors that monitor the product and detect if something is wrong; this can then be related to the machine that made the error, and then it can be repaired. which is supported by "*Is it a hole that we don't have. Example. Eh, it can go out online and wanted and there and today's daily equipment to make that hole.*"

Error Proofing	
Strengths	**Weaknesses**
Connected tools	Lack of data
Controls 2	Initiative

Table 4.9: SW- table: Error Proofing

The first weakness is "Lack of data", here some of the parts that need to be fastened with bolts lack the correct data, such as torque, which makes it difficult to calibrate the tools. This keyword also covers the issue where maintenance personnel have difficulties finding information about previous quality issues caused by equipment, this originates from quotations like "*Not that I can find it off the bat.*" and "*It doesn't exist. Or it does exist but not on everything. No, but it should exist on everything*". Next word is "initiative", there seems to be an initiative to error proof operations, but no effort or time is being put towards it supported by "*No, there is a hope if you want to do it, but if there is constant work going on for it, it doesn't.*".

Table 4.10 shows the first category in the Education and Training pillar of the TPM strategy. The first strength is "Equipment Training", which refers to training of the operators who use the equipment that the maintenance teams are responsible for. When a new assembly operator is hired, they will be trained in equipment safety and how to use it, which originates from quotes like "*You always take the machine training before you start here and then you learn how to use angle machines.*". The maintenance teams also receive training on equipment that they are supposed to work with, supported by "*I would probably still say that I get enough training on the existing stuff or have taught myself afterwards so explain my work.*". Next strength is related to autonomous maintenance and is "AM Training". The operators that is responsible for the AM should get training on how the AM calendar works and how to perform the different tasks included in the calendar. This keyword comes from quotes like "*I received AM training when I was an AM as an assembly operator.*" and "*We call it the same am training. Then we get a guide and training on how to do things*".

Training	
Strengths	**Weaknesses**
Equipment training	No training in AM
AM Training	Maintenance
-	Management support
-	Team-leader Assembly

Table 4.10: SW- table: Training

Moving on to the weaknesses, the first one is contradictory to the last strength. But again, this study was performed in a big factory, and there are different conditions in different areas. In some places of the factory, the AM responsible did not get any training and had to figure out how to perform the AM. This is seen as a weakness as there are no guarantees that the AM is performed correctly in these parts of the factory. This statement is supported by "*No training at all actually. Instead, we just become responsible for these areas*". Continuing on this theme, there seems to be a similar issue in the maintenance department with new employees not getting the proper initial training for the work tasks. This is represented by "Maintenance" and quotes like "*I didn't get a ** when I started. I'm really unhappy about it.*" and "*But in the beginning there was a lot of uncertainty and so*", there has also been situations where new machines have been introduced, and the training on how to maintain it comes when the machine has been operational for two years.

Next weakness in the training category is "Management support". Training and education are provided only upon explicit request from employees, and in some cases, employees must actively advocate for the necessary training to be granted. Quotes like "*I have demanded training on the various parts and hydraulics and electricity.*" and "*Frozen, yes, but there is a possibility. It does. Although it doesn't happen that way, there isn't that much education.*" stand behind this keyword. This is seen as a weakness, as learning is a significant part of TPM. Last weakness is "Team-leader Assembly", some team leaders in production did not get the initial training. Which created confusion for them when equipment breakdowns occur "*uh, as a team leader. I didn't get any training, if you put it that way.*" is the base for this keyword.

The second category of the education and training pillar can be seen in 4.11. The first strength here is "Five Senses", and it refers to the five senses that the operators have: sight, hearing, taste, smell, and touch. Using this, a type of condition monitoring of the machines exists. The operators can sense when some equipment is about to break by the way it feels, this applies to the maintenance personnel as well. Quotes like "*but when I go around and check each machine, I can hear if it sounds different*" are the base for this keyword. Moving on to "Prioritization" and quotes like "*So it's a little different depending on what they're having trouble with.*". This is the employee's ability to determine how serious an issue with equipment is. They know if it is an emergency or if the repair can wait, which suggests that the operators have good knowledge about the equipment that they work with. "Competence awareness" is continuing on the theme of operators and equipment. They also have good knowledge of which issues they are capable of handling themselves and when they have to call maintenance. This keyword originates from quotes like "*But we try to do as much as we can ourselves, but it comes down to lifting tools and when it's like that. Yeah, but when it comes to electricity or air or things like that, we often leave it alone.*"

When it comes to the maintenance teams, they are responsible for a vast amount of equipment, and this makes it hard to have knowledge of everything. But there is always someone who has that knowledge, and the teams are good at sharing that knowledge between themselves, and this is seen as a strength for the maintenance department. Which is represented by "Competence spreading" and quotes like "*to walk around together with others in a team and learn.*". The last strength in this category is "Equipment Specialization", and this is aimed at the process part of the factory. Where the operators have a very good knowledge of their equipment and can perform more advanced maintenance tasks. This is stated in quotes like "*Balk does more advanced stuff.*".

Knowledge of Equipment	
Strengths	**Weaknesses**
Five senses	Lack of Standards
Prioritization	Instruction availability
Competence awareness	Hands on training
Competence Spreading	-
Equipment Specialization	-

Table 4.11: SW- table: Knowledge of Equipment

The weaknesses of 4.11 start with "Lack of Standards", which means that there seems to be no clear line of what an operator is allowed to do on their equipment. Sure, the competence awareness strength tells us that they can make their own assessment. But this does not ensure that everyone can make this assessment. "*So, not that I know of that there is any clear limit for me. You think that certain things you shouldn't tinker with and keep trying to solve.*" stands behind this keyword. Moving on to "Instruction Availability", this keyword relates to both the maintenance teams and the production operators. Starting with the maintenance teams, they do not work with all machines daily, and they have very little contact with some equipment. This means that when they have to work on that equipment, they might not know exactly how it works, and it might be a very complex thing to perform maintenance on. This is where easily available instructions are needed to refresh their knowledge. As stated, it also applies to the production operators. There are some instructions for some complex operations, but it is not available everywhere. One of the quotations behind this keyword is "*So when I pick up a ball screw that is quite complex, I want a little instruction because there will be younger guys coming in and in the future so they get the conditions to do a job when we are no longer with it because what has been bad with it is here, if you will, work descriptions that we will get better at getting it into a system.*". Last weakness for this category is "Hands on Training", and it has to do with the equipment training received by the operators. It seems like they get a more theoretical training than a practical one, and according to the interviews, it is hard to learn how to use some equipment without hands-on training. This comes from "*a little more practical. It won't help you much to read through a power point.*".

4.12 shows the last category in the Education and Training pillar, and the strength starts with "Skill Updating/ development". This means that there are opportunities for training and education within the organization, supported by quotations like "*If you want to learn something, there's really no problem here.*".

Periodic skill evaluation and updating	
Strengths	**Weaknesses**
Skill updating/ development	No skill evaluation
-	Lack of time

Table 4.12: SW- table: Periodic skill evaluation and updating

Moving on to weaknesses, there is no evaluation of the knowledge that the employees have. This means that there is no formal record of who knows what, or controls that the employees know what they should know. This could create problems for new managers or scheduling. This is represented by the keyword "No skill evaluation" and quotations like "*Ehm, not directly I wouldn't say*" and "*I've never been involved in doing that.*". Next weakness is "Lack of time", this means that all the opportunities that exist for learning within the organization are limited by the employee's ability to free up time for the training. This is supported by "*Yes, everything except time.*" and "*It's about doing it yourself a little bit and taking a little initiative of your own and then taking the time to do it. Because there's no ready-made template, it would work and it works and it's about what you get, you get enough.*".

Moving on to the pillar called Development Management, and the first strength "Operator involvement", this means that some project managers involve the operators in the process of purchasing new equipment. This is seen as a strength as the operators have a lot of knowledge about the assembly process and will have valuable insights, this is originating from quotes like "*Yes, I think so, that. There are many things that have suddenly changed direction because an operator says, like, useful thought about this, like, I would say.*". There is also the "Maintenance Involvement", which also means that sometimes the maintenance department gets to come up with their opinions on new equipment. This will be on the subject of maintainability, spare parts, or other information based on their experience. This comes from "*Yes, absolutely, absolutely, that's how it is on some projects.*".

Utilization of previous knowledge/data in design and purchasing	
Strengths	**Weaknesses**
Operator involvement	Lack of follow up
Maintenance involvement	No involvement
-	Staff Limitations

Table 4.13: SW- table: Utilization of previous knowledge/data in design and purchasing

The weaknesses here are related to the strengths, "Lack of follow up" represents the issue where the departments responsible for new equipment rarely circle back to the production teams with their decisions. This is built up with quotes like "*Yes, but it takes time. It takes quite a long time. I know they have a lot to do, but it usually feels like you give feedback and then you get nothing back.*". Continuing on this theme, "No Involvement" means that the decision to involve maintenance teams in the process of buying or developing new equipment often depends on which project manager is responsible. More often than not, they will not reach out to maintenance for information. Behind this keyword are quotes like "*We, we have no say in it. But it's tooling that takes care of it. Production places an order with Tooling, and Tooling takes care of the rest. They come to us. That's it, hey. We've bought this. Good luck, have fun.*" and "*Yes, it depends a bit on who the project manager is.*". Last weakness is "Staff limitations", this means that historically when the question for input has come there has been hard to free up personnel that can go to the supplier and evaluate the equipment, supported by "*but it has been, it's difficult to get staff*". The next pillar is Safety, Health, and Environment, and the first category can be seen in 4.14. Starting off, the strength is "Risk elimination", "*But it's usually not a problem and you can get it fixed.*", and "*So I think it's good. The things that have been pointed out have been fixed.*". This keyword means that when a risk is found, it is a fast and easy process to counter or mitigate it. Continuing on this theme, "Initial risk assessment". The meaning of this is that there is an assessment done before new equipment is brought into the factory, supported by "*A risk assessment is always carried out by the project manager.*"

Identify and eliminate risks/hazards	
Strengths	**Weaknesses**
Risk elimination	Reactive thinking
Initial risk assessment	Unsafe tools

Table 4.14: SW- table: Identify and eliminate risk/hazards

Moving on to the weaknesses, "Reactive thinking" represents a way of working with safety that can have e negative effect on the safety. There are some trainings on how to work with equipment that might be dangerous. However, there isn't usually preventive training but reactive. This means that the training is developed after an accident has already uncured and the quotes that stands behind this include "*Unfortunately, there has actually been an accident in connection with what we are actually doing.*" and "*Unfortunately, sometimes you don't develop an activity or training until something has happened.*". Next is "Unsafe tools", this relates to both production and maintenance. For production, there are tools that injure operators over time, and for maintenance, there is equipment that might be dangerous to maintain. Examples are equipment containing energy, for example, air, heat, or oil. It can be dangerous even if the machine is turned off, and hard to control if the energy is still there. Quotes here include "*Because it's a knock-off machine. That's it, it's actually something we shouldn't have.*" and "*We have compressed air which, for example, can also be oil, so there can be a lot of energy left in a system even if the system is not running. Which remains*".

4.15 shows the next category for the SHE pillar. "Standardized risk reporting" is the first strength and this means that the employees seem to have very good knowledge of what do to when they come across a new risk, one quote is "*Then I will contact technical maintenance, and we will review the process.*". "Safety document" is the second strength and it means that there are documents at some dangerous equipment describing risks, and reminding employees to wear necessary safety equipment, quotes for this include "*So there is a very clear instruction on how to hold the pull and to remember that the sleeve gets hot, think about that as well when handling the drill.*". Certain equipment includes safeguards, such as components designed to absorb the force from high-torque screwdrivers, preventing damage and ensuring safe operation. This is represented by "Machine safety" and "*resistance takes all the strength,*". "Culture" is meant to describe just the culture in the factory, there is a high priority for safety, and most employees work together to make sure that everyone can come home without injuries, quotes behind this keyword include "*there is a big focus on safety anyway. Ehm, but just that I take runes every morning*". Last strength is "Risk judgment" represents the maintenance personnel's ability to look at equipment and see potential risks. Here they can say that they will not work on the equipment until a specific risk mitigation task is done, supported by "*Yes, we have it in many places. So then and is it that we judge that when we can't do it risk-free*".

Safety standards	
Strengths	**Weaknesses**
Standardized risk reporting	Risk awareness
Safety document	Initial ergonomic training
Machine safety	-
Culture	-
Risk judgment	-

Table 4.15: SW- table: Safety standards

The first weakness of this category is “Risk awareness”, this means that maintenance personnel are aware of most risks and that they know that there is safety equipment. But it is sometimes not used. It can be hearing protection or safety glasses that aren’t being used when they should be. Or if it is an emergency with some equipment, the lockout that stops the machine might be worked around to get the machine up faster. This weakness is about unnecessary risks and the knowledge that there is a risk, but ignoring that knowledge. Quotes behind this keyword are “*We, we’re usually pretty good at breaking and locking. Well, it depends a bit on whether it’s an emergency job or a planned assignment.*” and “*safety glasses and it’s just laziness if you don’t actually use them*”. Last weakness is “Initial ergonomic training”, this is related to the production personnel. Here, the opinion is that the initial training isn’t good enough to prevent injuries related to ergonomics. This comes from quotes like “*I think it might be good that maybe in the beginning when you start here you get to learn about ergonomics right away so that you don’t get distracted right now.*”.

The last category of the SHE pillar is seen in 4.16, and the first strength is “Pleasant environment”. Most employees seem to think that the working environment is good, while some think that it is good for a factory, which could also be seen as a positive thing. Quotes in that are the base for this keyword include “*we are doing very well*” and “*I don’t see anything strange about my work environment.*”.

Environment	
Strengths	**Weaknesses**
Pleasant environment	Climate
-	Forklift

Table 4.16: SW- table: Environment

Moving on to the weaknesses, “Climate” is the most mentioned. Things mentioned in the interviews include that it is too warm in the summer and too cold in the winter, high noise, and lots of dangerous equipment. “*If it’s 27 degrees outside, it’s almost 30 in here. It’s terrible.*” and “*So there’s noise and stuff,*” supports this. Continuing this, some maintenance personnel mentioned careless driving by the forklift driver. This means that they feel like the forklifts are driven too fast and too close to the maintenance personnel while they work on equipment. This is, however, the weakness at the bottom of the table, which means that it is the one mentioned the least amount of times. It does, however, not make it any less important, and it is supported by “*a little. Nonchalant from the truck staff, they push past the barriers a little too fast*”.

The last pillar that was investigated during the interviews is Office TPM, and the first strength is “Standardized processes”. This means that there seems to be standardized processes for maintenance reporting, and it is clear how the process flows from issue detection to repair. This makes the maintenance process smoother and faster, and it comes from quotes like “*But the principle is that the operator detects the correct fault. The operator calls a line at the central station, where we have an alarm operator who receives the call.*”. “Collaboration” and “*it usually goes very* *well*” means that there is a good collaboration between the production operators and the maintenance teams, everyone pitches in to make the line run as good as possible.

Collaboration between departments	
Strengths	**Weaknesses**
Standardized processes	Lack of standard
Collaboration	Information flow

Table 4.17: SW- table: Collaboration between departments

Moving on to the weaknesses and “Lack of standards”. Some equipment issues aren’t reported to the maintenance department, production operators report the issue to the right places, but not all places. This creates issues as maintenance teams are out of the information loop when it comes to the equipment that they are responsible for, and quotes include “*Without them, it goes to the right authorities, but they don’t go to all authorities,*”. Last weakness is “Information flow”. There are problems between the different maintenance teams when it comes to information. The maintenance technicians on the different shifts often go to repair the same issues that the shift before had already fixed. There is a lack of data informing to next shift of what has been done, and it creates unnecessary work. The base for this is quotes like “*Share all four shifts get the information so I thought they go to the same error multiple times*”.

The last category can be seen in 4.18 and the only keyword here is “Time”. This refers to the fact that this is a big organization. Requests and decisions need to pass many desks to be approved or considered, which creates delays and long waiting times for production and maintenance. The base for this is quotes like “*Everything takes time in here and unfortunately, as they say, before it is fixed.*”.

Improving administrative processes	
Strengths	**Weaknesses**
-	Time

Table 4.18: SW- table: Improving administrative processes

4.1.3 Benchmarking

The analysis done using the “SMASh” tool gave results that could be used as a base for interviews with other sites. The analysis is divided into the 4 different categories that build up smart maintenance: Data-driven decisions, human capital resource, internal integration, and external integration. Two of these categories were above the mean for the Swedish industry, and two were below the mean for the Swedish industry. The results are given in a scale from 1 to 5, and the scores can be seen in Table 4.19. A visual example of the data-driven decisions graph can be seen in

Appendix B.

Smart Maintenance Category	Description or Reference	Score
Data-driven decision-making	Decisions based on data analysis rather than intuition	3.1
Human Capital Resource	Skills, knowledge, and competence of the workforce	3.2
Internal Integration	Collaboration across departments within the organization	2.7
External Integration	Integration with suppliers, customers, and networks	2.8

Table 4.19: SMASh score

4.1.4 Analysis of result

The results from the current state analysis have been compiled into gaps for each pillar of TPM. The following sections will explain all the gaps.

Autonomous maintenance
The gap to the autonomous maintenance pillar is that there seems to be a lack of ownership of the equipment in the factory. This can be from engineers and operators. Some places also lack standards for how autonomous maintenance should be carried out, and some places lack training for AM.

Planned maintenance
For planned maintenance, the biggest gap is the absence of MTBF and MTTR tracking, these two are key in the planned maintenance pillar. The next is the reliance on reactive approaches and the lack of data-driven maintenance, such as condition monitoring. Inconsistent logging is also a big gap since this impacts correct repair times, which is connected to MTTR.

Focused maintenance
Identifying and effectively addressing the root causes of problems is an important part of focused maintenance. As this is only done on problems that stop the production line for more than 10 minutes, which means that there is no analysis on smaller problems. There also seems to be a passive approach to improvements and time allocation for it.

Quality maintenance
In the quality maintenance pillar, there isn't a big gap, however, there are things that need to be addressed. This is related to the data collected on the equipment. There is no data on which equipment is related to quality issues, which can make it harder to make improvements.

Education and training
There are some things in the plant that fit in the gap between the ideal and the current state. These things are insufficient training for new employees, systematic skill evaluation, accessible instructions, support from the management when it comes to training, and a lack of time for training. Some have also expressed that more "hands-on" training is needed.

Development management
When it comes to the design, development, and purchasing of new equipment for production, there are inconsistencies in the way the production and maintenance departments are involved. Sometimes they are involved, sometimes they are involved but won't get their needs met, but the most common situation is that they aren't involved at all.

Safety, Health and Environment
The gap in this pillar lies in the inconsistencies between the company's strong safety culture and the actual implementation. While protocols and a safety culture exist, reactive thinking, limited risk awareness, and insufficient ergonomics training hinder proactive risk management. Additionally, unsafe tools, noise, summer heat, and forklift safety concerns indicate that workplace hazards still need to be fully addressed to achieve a zero-harm environment.

Office TPM
The primary gap for Office TPM is that there are no standard procedures for collaboration between departments. There is also an issue of information sharing between the different shifts on the same department.

4.2 TPM Smart Maintenance synergies

The litterateur study resulted in more insights into the two concepts of TPM and Smart Maintenance. This is where patterns of similarity between the two concepts could be seen. The synergies between the concepts would create a better flow, and in creating a roadmap, by not introducing completely new dimensions. Figure 4.1 describes the connection between the pillars of TPM and smart maintenance with the categories strong alignment, partial alignment, and weak alignment. Strong alignment is characterized by a high degree of similarity across the key components of the concepts. Partial alignment indicates a few similar components. Weak alignment means that the two concepts significantly deviate from each other.

	Data-driven decision making	Human capital resource	Internal integration	External integration
Autonomous maintenance	○	◐	◐	○
Planned maintenance	●	◐	◐	◐
Focused maintenance	●	○	◐	○
Quality maintenance	◐	○	○	○
Education and training	○	●	○	○
Safety, Helath & Environment	◐	◐	○	○
Development management	◐	◐	◐	●
Office TPM	○	○	●	◐

● Strong alignment ◐ Partial alignment ○ Weak alignment

Figure 4.1: TPM - SM Synergies

4.2.1 Data-driven decision making

There is a gap that needs to be filled between data-driven decision-making and TPM. Where this part of smart maintenance focuses on data collection, quality, analysis, and the actual decision-making can be either fully automated or augmented by data-driven systems. This is aimed at increasing the use of data in decision-making. While the company that uses a TPM-based strategy should use some data like MTBF or condition monitoring, the use of data isn't the main objective. With this, the identified gap is that the TPM strategy focuses on **what** should be measured, like MTBF and MTTR. While smart maintenance focuses on **how** data should be used for decision making. The following points describe the connection between this dimension and the pillars.

- ***Planned maintenance***: Mainly involves decision making based on data like MTBF, MTTR, and sensors from equipment. This makes a strong alignment with smart maintenance.
- ***Focused maintenance***: Mainly involves operators logging failures, FMEA, and monitoring of MTTR/MTBF. Decisions based on these data can then be made for continuous improvement. This makes it a strong alignment.
- ***Quality Maintenance***: Includes monitoring of equipment conditions that could lead to product defects. Decisions can be made based on this, and therefore, the partial alignment.
- ***Safety, Health and Environment***: Includes identification and elimination of risks, and this could be done based on previous knowledge or other data. This makes it a partial alignment.
- ***Development Management***: Includes utilization of previous knowledge/-data in design and purchasing. This creates a partial alignment to DDDM.

4.2.2 Human capital resource

Human capital resource (HCR) has many similarities with the pillar of education and training where both focused on skill and technical knowledge, and competence development. However, human capital resources include another component, which is social and business skills. Another component that is included in HCR is the focus on gaining knowledge in digital tools and analytical abilities. Where TPM is more focused on specific skills like technical knowledge of equipment and machine safety, to increase ownership by operators. The following points describe the connection between this dimension and the pillars.

- ***Autonomous maintenance***: To reach maturity in AM, you need knowledge about processes and equipment. This makes a partial alignment to HCR since it indirectly connects to the dimension.
- ***Planned maintenance***: Needs basic education in digital tools and some interpretation of numerical values. This makes an indirect connection to HCR and is therefore classified as partial alignment.
- ***Education and Training***: Focuses on education, skill development, and periodic skill evaluation/updating. These areas a directly connected to HCR, therefore classified as strong alignment.
- ***Safety, Health and Environment***: While SHE focuses on safety, it's not just about policies. It is also about building a culture and developing employee awareness. This indirectly links to how people learn, which is part of HCR. The classification is therefore strong alignment.
- ***Development management***: Includes that operators and maintainers are involved in design. Their feedback leads to continuous skill development and knowledge transfer. This makes an indirect connection to HCR and, therefore, partial alignment.

4.2.3 Internal integration

There is also a gap between internal integration and TPM. Looking at internal integration, the focus is on integrating information systems that enable departments to share information and build closer relationships between the departments. TPM focuses more on improving administrative processes and promotes relationships between departments in a more general way. The following points describe the connection between this dimension and the pillars.

- ***Autonomous maintenance***: Needs some collaboration with the maintenance department when attaining standards for maintenance procedures. This makes internal collaboration align with IE and, therefore, is classified as partial alignment.
- ***Planned maintenance***: Needs some collaboration with production to plan production stops for maintenance and logistics for spare parts flow. This internal collaboration links with IE, making it partially aligned.

- ***Focused maintenance***: Requires collaboration with, for example, production when making improvements that affect both departments. This makes an indirect connection with IE and, therefore, partial alignment.
- ***Development Management***: Needs the collaboration with departments like design and production when purchasing new equipment. This creates an indirect connection with IE and, therefore, partial alignment.
- ***Office TPM***: Is about the cross collaboration between departments and improving administrative processes, which directly links to IE, making it a strong alignment.

4.2.4 External integration

The gap between external integration (EI) and TPM is the fact that EI focuses on the importance of long-term collaboration with suppliers, both when it comes to spare parts and ERP systems. TPM does not explicitly mention this, but similarly, the pillars mention collaboration. The biggest difference between the concepts is that TPM focuses on what kind of collaboration is needed. This could, for example, be collaboration in the design phase to increase maintainability or sorting maintenance contracts for long-term spare part availability. External integration pushes for integrating the CMMS, ERP, or IoT systems with suppliers. The following points describe the connection between this dimension and the pillars.

- ***Planned maintenance***: Needs some collaboration with the supplier for spare parts management or with external maintenance contracts, and therefore creating an indirect link to EI. This creates the classification of partial alignment.
- ***Development Management***: Requires collaboration with suppliers in the purchasing and design phase of new equipment. This is directly connected to EI, which classifies it as strong alignment.
- ***Office TPM***: Is indirectly connected with EI since external collaboration could be between other parts of the company group to share learnings. This is therefore classified as partial alignment.

4.3 Interview with other site

These interviews gave a really good insight into what the concept of smart maintenance means to the industry and how they work with it today, and they even gave some good insight into how it can be implemented. The most valuable information that was gathered during the interviews was regarding human capital resource, and data-driven decisions, as these are the areas where the interviewees had the most knowledge and had made the most progress at the time of the interview.

Regarding HCR, there was a lot of focus on combining skills in maintenance with new skills that are related to digitization. This can be done through training of maintenance staff, or for the more complex tasks, there could be a project group of data scientists and maintenance experts. They were not just developing generic IT skills, but they analyzed which new skills were needed for each project and focused on those. As more projects are started, the competence base will grow naturally.

At this time, there were no fully automated decisions, but they did have augmentation for a lot of their decisions. There was also a lot of focus on visualizing the data in a way that is easy to understand and to access. Here, tools like Power BI, ThingWorx, and Python Power Automate were attractive tools. When a problem is noticed, there are meetings to establish what kind of data we need to monitor this problem in the future, and what data we need to fix it.

4.4 Roadmap

This section contains the roadmap that has been created for academia and manufacturing companies trying to combine the concepts. The general assumption is that the companies following this roadmap have already achieved reasonable maturity in the TPM concept. This implies that the guidance given in each phase will be focused on filling the gap to reach smart maintenance. A visual representation of the roadmap could be seen in Appendix C.1.

4.4.1 Phase 1

In the first phase of the roadmap, there needs to be a preparation for change management. The higher management, including middle management, needs to communicate the initiation of the smart maintenance project. All employees in the maintenance department should know what the vision is and, more importantly, why. This is crucial since leadership clarity is an important part in smart maintenance implementation [34]. The vision should also be communicated with top management and resources departments to allocate the appropriate resources for the maintenance department [8].

The culture in the maintenance department could be an issue where resistance to change is likely to appear. To mitigate this, workshops could be carried out where the maintenance personnel could brainstorm ideas for activities and milestones in each phase of this roadmap. These sessions should be in a comfortable environment where honest feedback from employees is possible. This should create a feeling of autonomy where the employees could have their say and impact the development. At the same time, making the management focus on growth and responsiveness to strategic challenges [36]. It is important to mention that the competence and relatedness dimensions in SDT theory should not be neglected. This is due the risk of employees losing motivation [40]. It is also important that organizational change is driven internally by employees rather than specialists, since this impacts the resistance to change [34]. Success stories should also be shared among employees. This would drive change and remove the lack of trust in, for example, data usage [23].

The last step in this phase is to do an initial benchmarking with the SMASh tool to be used as a discussion basis for the dimensions of smart maintenance that need the most attention. This should be combined with different KPIs that would measure the success of the implementation. The traditional KPIs like OEE, MTTR, and MTBF should still be measured as they are important metrics for maintenance. However, with the addition of the following KPIs: job satisfaction, financial performance, and employee individual goal metric. These metrics should be aligned with the company's strategic vision to increase the compatibility [8]. These metrics should also align with SDT on motivation, which could have a big impact on the success of the implementation.

4.4.2 Phase 2

The first step in phase 2 is to ensure that employees have enough knowledge of the current required skills. This implies that the current employee base is skilled enough to carry out their daily tasks. To do this, a competence matrix could be created for each employee where their knowledge and skills are mapped.

The next step is to look at the future competences that are needed. The competence could be identified with brainstorming workshops, together with maintenance departments. Some of the common competencies that are needed for the next phase are data analytics, information and computational technology, social and business skills [23]. These skills are especially important since they are not mentioned in TPM and therefore require attention to close the gap between the concepts. TPM has a lot of focus on gaining knowledge in the mechanical/practical parts of equipment and processes. This strong foundational knowledge could make it less comprehensive to gain additional knowledge in technology related to mechanics.

The technological skills that are required could be gained by allocating time for education. Since TPM has some analytical practice through condition-based monitoring, the education should focus on more advanced analytics for prognostic purposes. Some literacy in other specific skills, like machine learning, is also beneficial when communicating with, for example, data engineers. The social and business skills could be acquired through workshops on communication and collaboration. These skills are especially useful when sharing best practices and advocating for maintenance importance/needs to other departments. The last step would be to enable employees to seek new skills to keep up with emerging technologies like AI and IoT [23].

4.4.3 Phase 3

The company should start to implement technologies that will help them to start taking data-driven decisions. Technologies such as sensors, Industrial Internet of Things (IIoT), and AI/ML projects. Sensors should be able to measure things like vibrations, heat, noise, current usage, or autistic emissions from machines [47]. An investigation needs to be done to examine which sensors are best in which areas of the factory. As condition monitoring can be used in TPM, there might already be some sensors in the factory. If there is, it is a great start, and it makes the step easier as there already is an existing knowledge base for this kind of technology.

To start the journey to actually taking data-driven decisions, projects with the aim of augmentation and automation of decisions should be started. This could be done through an initial workshop where employees involved in the projects can brainstorm which kinds of decisions are appropriate to start with [8]. There are a lot of decisions that should be taken regularly in the TPM strategy, and as such, these are o good starting point. It can be things like spare parts stock, task delegation, or maintenance schedule.

Some more important and complex problems could use data to complement the human decision-making process, i.e., combining data with human knowledge and experience. This is known as augmentation. When it comes to better-defined decisions, automation can be applied, where human decision-making is substituted by technology [48]. As TBM and PM are a big part of TPM, there is potential to automate many maintenance-related decisions or use augmentation as a base when updating maintenance schedules. When these concepts have been fully integrated, there should be no need for TBM as the algorithms will determine when maintenance is needed, and thus, that part of the TPM strategy should be phased out as the company gets more advanced in Smart Maintenance.

The AI/ML projects should be aimed at automating data collection, converting the raw data into useful information, and predictive analysis that focuses on early failure detection [49] [50]. As using sensors and other I4.0 technologies could be new to the organization, one should start some pilot projects, the aim of which is to learn how the technologies work and it's potential. Later on, when new problems arise, meetings are held to evaluate which data is needed, how it should be collected, and how it should be used to solve the problem. This way, the infrastructure for the condition monitoring grows naturally and only where it is needed [51]. This is why it is important to find the root causes of the problems to know which data is needed, this is a part of "focused maintenance" and an important reason why there should be a system for this. If one has the wrong cause of a problem, there will be problems analyzing the data from the symptoms, instead of analyzing the data of the cause of the symptoms.

The data from the sensors, together with the AI/ML algorithms, should enhance TPM's planned maintenance pillar and evolve it to predictive or even prescriptive maintenance. One should also be able to prevent defects in the production caused by faulty equipment, as the predictive algorithms should be able to detect machine errors before they become critical. One should also be able to use this data as a base for continuous improvements; data on breakdowns, excessive heat, vibrations, etc, should be a good sign of needed improvements. This is where some of the existing TPM tools are impacted by the SM implementation.

Measurements are an important part of smart maintenance, one needs to be able to measure the success of the new implementations, and to do this, KPIs are needed. The amount of decisions that are made with data is a good place to start [10]. There are already many KPIs that come with the total productive maintenance, such as MTBF, MTTR, OEE [52]. To make these more available and visualize them, tools like PowerBI or Grafana can be used [51].

To reach further in smart maintenance, the company needs to start implementing internal integration alongside the data-driven decision-making process. A good starting point is to break down silos between maintenance, production, logistics, and planning. To do this, there needs to be development of systems and routines for data/knowledge sharing. This can be done by integrating maintenance and production systems so all information is available and easy to find, which will enable faster decision making and collaboration [48] [10]. All this data can be a complement to TPMs' planned maintenance with the extension of data-driven decisions. For example, if production stops due to a material shortage in the near future, this would be a good time to perform maintenance. There is also a parallel to TPMs' focus on improving administrative processes, these accessible systems will enable the administrative processes to achieve even higher effectiveness when SM is combined with the existing TPM strategy.

To enable further collaboration and foster a sense of teamwork between the departments, regular meetings/workshops should be held where plant health is the subject. This is a good opportunity to review and discuss combined data usage, make maintenance plans, and follow up on KPIs that measure the collaboration across departments. The KPIs will be important to identify areas where improvements can be made regarding internal integration. It will also be useful if data regarding stop-times, sensor data, and every relevant KPI is shared in a dashboard [23] [53]. These meetings will also be useful to enhance TPMs' sense of ownership of equipment. If every department is involved, there will most likely be more knowledge about the importance of this.

4.4.4 Phase 4

Phase 4 starts with a workshop where employees identify key suppliers that have valuable resources, such as machine suppliers. This step is easy since TPM fosters supplier collaboration to a certain level with development management. The next step is to make sure they have the capability to securely share data, for example, through an API. For a machine supplier, data such as performance logs, failure modes, or external condition monitoring is a good start. This is a good start for contracts that are based on the machine performance [8] [23]. These contracts could also enhance development management from TPM, as suppliers will have an incentive to involve more operators to make the machine as good as possible, and thus, cost them less money in downtime.

Other options for external integration include faster training of ML models, such as predictive models, if more data is available, the training time for the models will be shorter [23].

4.4.5 Phase 5

In the last phase, managers and others responsible for the strategy should do a recap on the results of the KPIs compared to the past. Both the traditional and new KPIS should be revisited to compare and make an overall evaluation of the progress. If certain areas still need improvements, then a new plan should be crafted for those KPIs. A new SMASh could also be conducted and compared to the first one to see the overall progress in the different dimensions [8]. Some key points here are to document the lessons learned and the practices that led to success. But also, the things that went wrong, like resource utilization and how well to department adapted to the changes. Those responsible for the strategy should now plan for the next step to close the remaining gaps.

4.5 Roadmap Volvo

The current state and gap- analysis showed that there are some shortcomings in the way that Volvo uses TPM. This Volvo-specific roadmap will focus on reaching a higher maturity in TPM while also implementing Smart Maintenance. By following the roadmap that is made for academia in 4.4, and complementing it with the steps in the following sections, Volvo Tuve should be able to combine TPM and Smart Maintenance. A visual representation of the roadmap could be seen in Appendix C.1.

4.5.1 Phase 1

As mentioned in 4.4.1, the first step is to communicate the vision for all employees in the maintenance department. This includes all employees of the different shifts. The sessions should be divided into smaller groups where the management and employees can discuss more freely. A suggestion is to have "strategy days" where groups of, for example, 20 employees gather to discuss the future and brainstorm possible pitfalls. An example of the session format would be that the management starts with explaining the journey from TPM to Smart maintenance. Most importantly, explaining why this journey is initiated. The group of 20 should be divided into smaller groups of 5 to give all a chance to speak. The topics that could be discussed during this “How will Smart Maintenance affect our daily work routines?”, “What are biggest concerns?” and “What we need from our management?”. The groups should then reform back to 20 and discuss their topics and ideas with the management. By doing this, both management and employees would move closer to a strategic alignment.

The last step in this phase is to create/follow up on some KPIs that measure job satisfaction, financial performance, and employee individual goal metrics. To measure job satisfaction, one method is to send out a survey. This measurement is already done on a company level at Volvo Tuve. However, a separate one only for the maintenance department would be preferable. The survey questions could, for example, be based on the SDT on motivation. This is due to its higher relevance and focus on specific needs. The individual goal metric could be measured with the individual competence matrix by keeping track of the number of new skills acquired per employee. The financial part is also already measured every month. These KPIs should then be noted and compared to those in phase 5.

4.5.2 Phase 2

The first step in this phase is different from the academic roadmap since the Volvo Tuve needs to bridge the gap to TPM as well. Since MTBF, MTTR, and OEE are not currently being measured. The first step for the maintenance department is to understand the KPIs MTBF, MTTR, and OEE, as these are fundamental KPIs for a maintenance department. The implementation part of these KPIs is described in phase 3. This is also connected to the lack of maintenance training for new employees. Newly employed maintenance engineers and technicians should receive basic maintenance training where the KPIs are included. The managers should support this matter to allocate the time and resources necessary for education.

Moving on to safety, this is both connected to education and a cultural shift in the department. The result indicated that safety measures were on site but neglected. An education in safety with a focus on its consequences should be given to all employees. Connected to this, a new standard should be in place where employees report risks and apply countermeasures. Instead of waiting for an accident to occur. Another example is to investigate tools that are dangerous to work with. These tools could be the ones that contain energy, like air or heat. These points will focus on reaching a higher maturity state in TPM.

The skills required to increase maturity in smart maintenance for Volvo Tuve are mentioned in 4.4.2. These could be acquired with a combination of workshops and education. With the addition of logging, the newly acquired skills are in the competence matrix. An important note here is to continue to innovate and improve existing processes while exploring new opportunities. This should preferably be done with a balance between daily processes to reach contextual ambidexterity, which gives the highest innovation potential.

4.5.3 Phase 3

To reach a higher maturity in TPM, there should also be more use of root cause analysis. Volvo only uses these methods on problems that stop the line for more than a set amount of time. This means that there is a lot of work to fix the symptoms of the problems. Therefore, doing root cause analysis called EWO on production stops more than 10 minutes is insufficient. All line stops should be investigated. The current format standard of the EWO might be too comprehensive, with many steps. To mitigate this, a lite version with fewer steps could be created for smaller stops. Finding the root cause of problems will be an important step in the meetings for sensor choice in 4.4.3 as well.

The change process that was started in 4.5.2 also needs to be implemented, and this is the step to do so. These are very basic KPIs for a maintenance department to monitor. These should, along with the other KPIs, be visualized in a dashboard in the same way described in 4.4.3. It could be done in the same time frame as the rest of the KPIs, but the data collection should be addressed in an earlier phase such as 4.5.2 as the collection method already exist in the VMMS system, but the data needs to be accurate so the times that gets registered cannot be estimations.

When the measurements are visualized and accurate, it is time to start using them. As these KPIs are new to the department, historical data is inaccurate due to the way the maintenance teams are told to input it. It will take some time before these KPIs are useful, as machines need to break down to get the MTBF and be repaired to get the MTTR times, but better late than never.

Areas where these KPIs can be useful are, for example, in maintenance planning. If the data is accurate, it can be used to forecast failures and schedule maintenance before the actual failure, which can reduce downtime [54]. One has to remember that this approach is based on historical data and that it cannot predict the future exactly, but that is also on the way as the department is working towards Smart Maintenance. Down the line, sensors and algorithms should do the heavy lifting in this department as described in 4.4.3.

Other areas where these KPIs are important are related to the improvement work that comes with "Focused maintenance" [55]. Improvements on machines should improve the MTTR, MTBF, or the function of the machine. If this isn't measured, there is no way of knowing if the work actually improved the equipment or if it was unnecessary work.

The product quality is a very important part not only for Volvo but also for the TPM strategy. Which is why data on the machines that cause quality problems is important. One needs to know how often it happens, which machines that are the cause, and why it happened. This comes back as the root cause analysis, but for quality problems. Another reason this is important is to measure the success of the work done on machines. If it happens a lot after the improvement work, it did not work, and other improvements need to be done. The implementation process for this is rather simple; there needs to be logging of these problems, easy access to it, and visualizations in, for example, Power BI could be done. Graphs showing the cost, time spent, and the interval for product damages could be a good place to start.

From the theory on TPM, we know that ownership of equipment is important, and from the gap analysis, we know that the Tuve plant can do better in this area. To reach a higher maturity in TPM improvements needs to be made. Like many of the other stages, these can start with a workshop on how to convey this information in the best way and how to make sure that all the maintenance is done correctly. Examples here can be to make sure that the operators involved get the proper training for it, evaluate their knowledge, make or control standards related to autonomous maintenance, or inform operators that they are using very expensive equipment and that they should only use it as it is meant to be used. One could also focus on countermeasures to the unsafe equipment and the initial ergonomic training for the operators. All these steps can be done at the suggested "plant health" meetings in 4.4.3

The result of the gap analysis says that there are inconsistencies in the way the maintenance departments are involved in the design and purchasing phase of new equipment. There needs to be a more process-based approach to this, rather than a personnel-based approach where it depends on who the project manager is. As mentioned in 4.4.3 the silos between the department needs to be torn down to make way for better collaboration. Some kind of standard operating method that describes the process of purchasing or designing new equipment could be the way to go here. It could be as easy as a checklist where each step of the development phase needs to be done to move on in the project, where gathering feedback from maintenance and production should be one of the steps.

From the gap analysis we also know that there are a problem with information flow in the company, this will be solved by following the steps from 4.4.3 were dashboards should be implemented and silos torn down to improve the flow of information between the departments.

4.5.4 Phase 4

For Volvo Trucks Tuve, there is a great opportunity to share data with other factories in the Volvo Group; this could lower the risk of data leaks and make sharing easier, as a lot of internal systems are the same in the different factories. As stated in 4.4.4, this could shorten the training process for algorithms if more data were available. Otherwise, Volvo could follow the steps for a generic manufacturing company seen in 4.4.4.

4.5.5 Phase 5

Volvo should do phase 5 in the same way as a generic manufacturing company, which can be seen in 4.4.5. The addition for Volvo would be to have an additional strategy day where the focus is on explaining the results from the benchmarking and KPIs. The results should be discussed with the maintenance employees to get their input on how to improve, for example, MTTR. Additionally, a recap should be done from the first strategy day. During the first strategy day, questions like "What do we need from our management?" were discussed. These should be revisited to see if the needs were met. Similarly to phase 1, the groups should be of a smaller size 20, with subgroups of 5.

5 Discussion

This chapter answers the research question and highlights the study's contributions to both academia and industry. It includes a broader discussion of the findings, ethical considerations, and suggestions for future research.

5.1 Answer to RQ

Through the project, we have discovered a lot of things that can be related to the implementation of Smart Maintenance in a TPM-based factory. The first thing that we noticed during the interviews is that maintenance departments are usually quite "old-fashioned", which means that these changes will require quite a lot of change management. There was not much data usage, and there is much trust in experience, which isn't necessarily bad, but it does mean that the journey towards smart maintenance will be quite long, and there will be a lot of work to get there. But we do think that we have managed to make a roadmap that could get the job done.

We think that the best way to implement smart maintenance could be to have another maintenance strategy as a base, which one that is should differ depending on the kind of production the factory has. In Tuve, the TPM strategy fits well, and we do not think that Smart Maintenance can replace TPM but rather enhance it. This is because the research on both strategies has shown that there are a lot of differences between the strategies, and the focus differs in some areas. For a large assembly plant, we think that some TPM-like strategy is a good base, for example, the "Autonomous Maintenance" pillar describes the operator ownership and maintenance, which enables the maintenance operators to focus their work on more advanced things. As Smart Maintenance is missing these kinds of dimensions and focuses more on data-driven decision making and data sharing, there are, as we see it, many advantages to combining these two strategies. TPM contains some KPIs, TBM, CBM, etc., which require a lot of decisions. By implementing Smart Maintenance, there is a lot of potential to enhance the efficiency and effectiveness.

When it comes to the two roadmaps, they are based on a literature study on the two strategies there were a gap analysis was made between TPM and SM, which showed where the two can enhance each other. So it is these gaps that the roadmap aims to fill. The roadmap designed for academia assumes that TPM has already reached a reasonable level of maturity and therefore does not require significant further changes in that area. So the focus there is to implement Smart Maintenance in a way that enhances TPM and fills the gaps in the areas where TPM is lacking. For example, augmentation or automating decisions in TPM practices, or evolving the maintenance team's skills from just knowledge about their day-to-day operations, into more knowledge about data analysis, etc. The sequence of activities was also brainstormed and based on a logical order for the researchers. One example of this would be that a thorough understanding of a topic is essential before attempting to implement it. Therefore, implementing the dimension of human capital resource before data-driven decision making made sense.

The second roadmap that is made for Volvo has an additional focus on reaching maturity in TPM. The roadmap, therefore, contains different areas of improvement to close the gap from the current state to TPM. This is important since some maturity in TPM should be reached before combining the two strategies. One example of this could be that Volvo was lacking some basic TPM practices, such as MTBF and MTTR. These are essential to measure before starting, for example, AI/ML projects.

By implementing Smart Maintenance in a TPM-based factory, we do think that there will be an increase in technical availability, as the focus on data-driven decisions isn't there in TPM. There should be a decrease in spare parts stock as the need for them should be predicted, there should also be a decrease in unnecessary TBM, and there should be fewer breakdowns as failures should be predicted. All this should save the company money, be better for the environment, and the employees who will do less unplanned work. This should reduce stress and enhance safety, as most work can be planned.

5.2 Contribution to academia

We do think that some contributions to academia have been made; there are the TPM- Smart Maintenance synergies, which are where the two strategies overlap. We could not find any research that has made these comparisons before. The same goes for the roadmap, with the aim of combining the two strategies. Hopefully, the academia roadmap can be a base for other companies or other studies that could be done on the subject. Additionally, by understanding the two concepts, our recommendation is that having a maintenance strategy as a base, like TPM, is beneficial. This is because TPM concepts contain a lot of details about what should be measured and involve many different areas. This quite complete maintenance strategy can be enhanced for the needs future industry with Smart maintenance.

There are many different views on TPM and its core practices, making it confusing to know what to implement. The summary of TPM practices is presented in Table 4.1 and complements this need. This is therefore the contribution to other manufacturing industries working with TPM and academia. The practices could be used as inspiration to reach a higher level of maturity by comparing them to current state practices.

5.3 Contribution to industry

One of the more valuable things for Volvo could be the current state analysis, as it shows them how their work deviates from the strategy, and in following phases, where "instructions" for how to reach a higher maturity in TPM are given. We do think that they have quite a good understanding of their current state. As the interviews came with a guarantee of anonymity for the interviewee, we did get some information that we think could be useful for the development of the department's strategy. This information will give the managers some insights into what their employees think and give them areas where improvements are needed. Furthermore, this project gives them a direction to follow that is based on research. We do not expect them to follow every step exactly as we have written, as there are more things to consider, such as budget and other directions from higher management. But it is a valuable base for the organization. This gives them the ability to prove that the direction they want to move toward is based on research, which can prove to be useful in meetings with higher management.

5.4 General discussion

The method contained literature studies, interviews, thematic coding, gap analysis, benchmarking, and interpretation of the results. This is a lot of focus on qualitative methods, which might have limited the sample size when it came to interviewees and data obtained. Even if we reached a saturation point in the answers to the interview questions, there might be more information that we did not get. This information, with the assumption that there are more, could potentially be reached with a quantitative method like a questionnaire or a similar method. However, as most operators had knowledge about the maintenance that they were supposed to do on their equipment, and there were interviews done in almost every part of the factory, one could assume that the new information would be an outlier. The data collection also involves most of the maintenance engineers, team leaders for the maintenance operators, some maintenance operators, assembly operators, and team leaders for the assembly operators. The authors think that this was a good sample size as a saturation point was reached, and there were a lot of different departments involved. There were some issues gaining access to the production operators as they had to work; interviews could only be held if they had a spare operator, which did not happen often. This made the last few interviews a bit stressful as we had to do 6 in the same day. This also meant that the analysis had to be done quite fast, so as not to break the time schedule for the project. It is difficult to say if this had any impact on the study, but we think that if there were an impact, it would have been negligible.

When it comes to the thematic coding and gap analysis, other researchers could potentially have other opinions about the interpretations of some citations, however, most of the answers are quite straightforward. This makes the authors think that the result would not have been significantly different if someone else had done the same study. The gap analysis was done with the help of research papers, as there was a time limitation on this project, it was impossible to read every paper about TPM, which means that there might be some kind of information that was missing. But the big concepts, that were used as “Aggregate dimensions” and “2 order code” were supported by most of the papers and books that were analyzed.

When it comes to benchmarking, it was made by the maintenance manager who was deemed knowledgeable about how the department works, and this was used as a base for the interviews with other sites to see how they work with smart maintenance. This means that the benchmarking did not affect the final result of the current state analysis or the roadmaps. It only affects the interviews in the way that we focused more on the two areas where the factory scored below the Swedish industry mean. But the two areas where the scores were above the Swedish industry mean were also covered in the interviews to some extent. It was these interviews that had some impact on the roadmap, as information included in the answers was proven to work when implementing smart maintenance, as the organization has augmented many decisions.

In the development process for the roadmap, there was a lot of input from scientific articles about Smart Maintenance, Industry 4.0, change management, etc. These articles were almost all the content for the new elements that the roadmap aims to implement. Then there was more content on how to combine the new elements of Smart Maintenance with the existing TPM strategy, which came from the TPM - SM synergies chapter that was researched and written by the authors. This means that the parts of the roadmap that focus on the combination of TPM and SM are developed by the researchers, while the Smart Maintenance content comes from many different reports that say the same or similar things.

As discussed before, time was one of our delimitations. The allocated time for this study was 4,5 months, and this had some impact. Parts of the literature study could, for example, be done more comprehensively since there is a lot of research. One of the topics that could be explored in more detail was TPM. Change management was also one area that could be explored in more detail, since a lot of theories exist. The researcher, however, concluded that the information/theories gathered were good enough, as they were well-documented and widely discussed in academia. The time constraints also impact the ability to extend the research to other Volvo factories. Extending the research to other factories in the Volvo group could have given the researchers more inspiration on best practices. This would possibly impact the roadmap as well. The researcher decided not to present highly detailed step-by-step instructions in the roadmap. As this level of detail could be unnecessary if the roadmap is not fully adopted. For example, the selection of sensors and suppliers depends on many factors, and conducting such an analysis might have been unnecessary, especially considering that they may be required to follow Volvo's internal regulations.

5.5 Ethics

There was a concern in the planning phase of this thesis that the current state analysis results were inaccurate. As employees might not want to go on the record and say that certain thing might not be as good as it should be. The data could be shared with others at the organization, and quotations from the interviews would be in this thesis. However, the interviews were made anonymously, there are no names, timestamps, or locations that are traceable to a person in this report or the raw data. There was also a contract made with each interviewee that assured that the recordings from the interview would be deleted once the recordings were transcribed. This was done to lower the chances of skewed data in the results.

Changing to a more data-driven maintenance strategy might seem scary, as there are people who think that they will lose their jobs because there will be less to do when moving from corrective to preventive maintenance. However, in the short term, there will almost certainly be more to do as implementing technologies like this takes time and a lot of work to get them working properly. When the technologies are working, there might be less to do when it comes to corrective maintenance, but there will be more preventive, and there will almost certainly be more competence needed in the data analysis and operation of the systems require specialized knowledge. Everyone might not have the same role as at the time this thesis is written, but there are no concerns from the authors that employees will lose their jobs.

5.6 Future research

The goal of this master's thesis was to develop a roadmap that can be followed to combine TPM and SM, which was done. However, as there have been no attempts to follow the roadmap, there is no evidence that it works and is sustainable, as it has never been tested, even though it is backed up by research. This would be an interesting area to do further research in and would have to be a long-term project, as such things aren't done overnight. This would probably have to be in collaboration with a company willing to do the transition from TPM into a TPM - SM combination, as we think this is the best way to prove if it works or not. An addition to this would be to measure if it has an impact on the performance by looking at KPIs. Maybe this could be done at the same department as this thesis, as it is their goal to reach the state of a sustainable TPM - SM strategy.

Other areas that could be investigated are if Smart Maintenance is best when combined with another strategy, which was a thought that was discovered in the work with this thesis. Would this be true for factories with a lot of manual assembly and not for process factories, or not true at all? If it were to be true, then which kinds of strategies would be the best combination? This thesis made the comparison between TPM and SM, but are there any other strategies that would be a better fit?

6
Conclusion

This master's thesis aimed to create two different roadmaps that would bring value to academia and the industry. These roadmaps should describe how to implement smart maintenance in a factory that was using TPM, the combination should create a higher technical availability in the factory. To achieve this, there were 4 different literature studies done on subjects that would be needed to write the thesis. These were TPM, Smart Maintenance, change management, and Smart Maintenance connection with TPM. They contributed to the creation of TPM-Practices, TPM-SM synergies, and the roadmaps. There were 25 interviews done that supplied raw data for a current state analysis of the Volvo Trucks Tuve plant, which led to a gap analysis between the theoretical TPM and how it was used in Tuve today.

Synergies between TPM and SM were developed to see the similarities and differences, which later led to the steps of the roadmaps, together with the gaps identified from the current state analysis. Interviews with another Volvo Group site were conducted to get practical examples of how to implement technologies related to SM, which were later used in the roadmaps.

The roadmaps should help the factory in which this thesis was written to achieve a higher maturity of TPM and to implement SM, to achieve a higher technical availability in the factory. This should also be possible in a generic factory that uses TPM as a strategy, and where the goal is to combine it with SM.

Bibliography

[1] i. Team. “A brief history of the 4 industrial revolutions that shaped the world,” Institute of Entrepreneurship Development. (Jun. 30, 2019), [Online]. Available: `https://ied.eu/project-updates/the-4-industrial-revolutions/` (visited on 01/21/2025).

[2] J. Barata and I. Kayser, “Industry 5.0 – past, present, and near future,” *Procedia Computer Science*, CENTERIS – International Conference on ENTERprise Information Systems / ProjMAN – International Conference on Project MANagement / HCist – International Conference on Health and Social Care Information Systems and Technologies 2022, vol. 219, pp. 778–788, Jan. 1, 2023, ISSN: 1877-0509. DOI: `10.1016/j.procs.2023.01.351`. [Online]. Available: `https://www.sciencedirect.com/science/article/pii/S1877050923003605` (visited on 01/21/2025).

[3] R. Roy, R. Stark, K. Tracht, S. Takata, and M. Mori, “Continuous maintenance and the future – foundations and technological challenges,” *CIRP Annals*, vol. 65, no. 2, pp. 667–688, Jan. 1, 2016, ISSN: 0007-8506. DOI: `10.1016/j.cirp.2016.06.006`. [Online]. Available: `https://www.sciencedirect.com/science/article/pii/S0007850616301986` (visited on 01/17/2025).

[4] J. Bokrantz, A. Skoogh, C. Berlin, and J. Stahre, “Maintenance in digitalised manufacturing: Delphi-based scenarios for 2030,” *International Journal of Production Economics*, vol. 191, pp. 154–169, Sep. 1, 2017, ISSN: 0925-5273. DOI: `10.1016/j.ijpe.2017.06.010`. [Online]. Available: `https://www.sciencedirect.com/science/article/pii/S092552731730172X` (visited on 03/05/2025).

[5] J. Biswas, “Total productive maintenance: An in-depth review with a focus on overall equipment effectiveness measurement,” *International Journal of Research in Industrial Engineering*, vol. 13, no. 4, pp. 376–383, Dec. 1, 2024, Publisher: Ayandegan Institute of Higher Education, ISSN: 2783-1337. DOI: `10.22105/riej.2024.453380.1436`. [Online]. Available: `https://www.riejournal.com/article_196785.html` (visited on 01/17/2025).

[6] A. Jain, R. Bhatti, and H. Singh, “Total productive maintenance (TPM) implementation practice: A literature review and directions,” *International Journal of Lean Six Sigma*, vol. 5, no. 3, pp. 293–323, Jul. 29, 2014, Publisher: Emerald Group Publishing Limited, ISSN: 2040-4166. DOI: `10.1108/IJLSS-06-2013-0032`. [Online]. Available: `https://www.emerald.com/insight/content/doi/10.1108/ijlss-06-2013-0032/full/html` (visited on 03/14/2025).

[7] G. L. Tortorella, F. S. Fogliatto, P. A. Cauchick-Miguel, S. Kurnia, and D. Jurburg, "Integration of industry 4.0 technologies into total productive maintenance practices," *International Journal of Production Economics*, vol. 240, p. 108 224, Oct. 1, 2021, ISSN: 0925-5273. DOI: 10.1016/j.ijpe.2021.108224. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0925527321002000 (visited on 03/05/2025).

[8] C. Lundgren, J. Bokrantz, and A. Skoogh, "A strategy development process for smart maintenance implementation," *Journal of Manufacturing Technology Management*, vol. 32, no. 9, pp. 142–166, 2021, ISSN: 1741-038X. DOI: 10.1108/JMTM-06-2020-0222. [Online]. Available: https://research.chalmers.se/en/publication/524190 (visited on 03/13/2025).

[9] "Facts and figures." (), [Online]. Available: https://www.volvotrucks.com/en-en/about-us/who-we-are/facts-and-figures.html (visited on 01/17/2025).

[10] J. Bokrantz, A. Skoogh, C. Berlin, and J. Stahre, "Smart maintenance: Instrument development, content validation and an empirical pilot," *International Journal of Operations and Production Management*, vol. 40, no. 4, pp. 481–506, 2020, ISSN: 01443577. DOI: 10.1108/IJOPM-11-2019-0746. [Online]. Available: https://research.chalmers.se/en/publication/517796 (visited on 05/07/2025).

[11] J. Bokrantz, "Smart maintenance - maintenance in digitalised manufacturing," ISBN: 9789179051914, Ph.D. dissertation, Chalmers University of Technology, 2019. [Online]. Available: https://research.chalmers.se/en/publication/512579 (visited on 01/17/2025).

[12] "Detta är Smart Maintenance | SMASh – Smart Maintenance Assessment." (), [Online]. Available: https://digitalsmash.se/detta-ar-smart-maintenance (visited on 01/17/2025).

[13] A. C. Márquez, *The Maintenance Management Framework* (Springer Series in Reliability Engineering). London: Springer, 2007, ISBN: 978-1-84628-820-3. DOI: 10.1007/978-1-84628-821-0. [Online]. Available: http://link.springer.com/10.1007/978-1-84628-821-0 (visited on 01/17/2025).

[14] T. P. Carvalho, F. A. A. M. N. Soares, R. Vita, R. d. P. Francisco, J. P. Basto, and S. G. S. Alcalá, "A systematic literature review of machine learning methods applied to predictive maintenance," *Computers & Industrial Engineering*, vol. 137, p. 106 024, Nov. 1, 2019, ISSN: 0360-8352. DOI: 10.1016/j.cie.2019.106024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0360835219304838 (visited on 05/10/2025).

[15] R. K. Mobley, Ed., *Maintenance Engineering Handbook*, 8th Edition, McGraw-Hill Education, 2014, ISBN: 978-0-07-182661-7. [Online]. Available: https://www.accessengineeringlibrary.com/content/book/9780071826617 (visited on 03/13/2025).

[16] O. A. Oluwatoyin, S. A. Afolalu, and S. I. Monye, "Maintenance impact on production profitability in industry - an OvervieW," in *2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG)*, Apr. 2024, pp. 1–8. DOI: 10.1109/

SEB4SDG60871.2024.10630377. [Online]. Available: https://ieeexplore.ieee.org/document/10630377/?arnumber=10630377 (visited on 01/17/2025).

[17] I. Alsyouf, "The role of maintenance in improving companies' productivity and profitability," *International Journal of Production Economics*, vol. 105, no. 1, pp. 70–78, Jan. 1, 2007, ISSN: 0925-5273. DOI: 10.1016/j.ijpe.2004.06.057. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S092552730600065X (visited on 05/10/2025).

[18] C. Franciosi, A. Voisin, S. Miranda, S. Riemma, and B. Iung, "Measuring maintenance impacts on sustainability of manufacturing industries: From a systematic literature review to a framework proposal," *Journal of Cleaner Production*, vol. 260, 2020. DOI: 10.1016/j.jclepro.2020.121065.

[19] T. Agustiady and E. A. Cudney, *Total Productive Maintenance: Strategies and Implementation Guide*, 2nd ed. Boca Raton: CRC Press, Dec. 19, 2023, 272 pp., ISBN: 978-1-003-27216-8. DOI: 10.1201/9781003272168.

[20] J. R. Díaz-Reza, J. L. García-Alcaraz, and V. Martínez-Loya, *Impact Analysis of Total Productive Maintenance*. [Online]. Available: https://link.springer.com/book/10.1007/978-3-030-01725-5 (visited on 03/05/2025).

[21] S. Borris, *Total Productive Maintenance: Proven Strategies and Techniques to Keep Equipment Running at Maximum Efficiency*. McGraw Hill Professional, Jan. 21, 2006, 413 pp., Google-Books-ID: cOD1RVcaF7EC, ISBN: 978-0-07-158926-0.

[22] T. Ylipää, A. Skoogh, J. Bokrantz, and M. Gopalakrishnan, "Identification of maintenance improvement potential using OEE assessment," *International Journal of Productivity and Performance Management*, vol. 66, no. 1, pp. 126–143, 2017, ISSN: 1741-0401. DOI: 10.1108/IJPPM-01-2016-0028. [Online]. Available: https://research.chalmers.se/en/publication/246608 (visited on 03/31/2025).

[23] J. Bokrantz, A. Skoogh, C. Berlin, T. Wuest, and J. Stahre, "Smart maintenance: An empirically grounded conceptualization," *International Journal of Production Economics*, vol. 223, p. 107 534, May 1, 2020, ISSN: 0925-5273. DOI: 10.1016/j.ijpe.2019.107534. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0925527319303615 (visited on 05/07/2025).

[24] M. Abubakr, M. A. Hassan, G. M. Krolczyk, N. Khanna, and H. Hegab, "Sensors selection for tool failure detection during machining processes: A simple accurate classification model," *CIRP Journal of Manufacturing Science and Technology*, vol. 32, pp. 108–119, Jan. 1, 2021, ISSN: 1755-5817. DOI: 10.1016/j.cirpj.2020.12.002. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1755581720301681 (visited on 05/17/2025).

[25] A. Varshney, N. Garg, K. S. Nagla, *et al.*, "Challenges in sensors technology for industry 4.0 for futuristic metrological applications," *MAPAN*, vol. 36, no. 2, pp. 215–226, Jun. 1, 2021, ISSN: 0974-9853. DOI: 10.1007/s12647-021-00453-1. [Online]. Available: https://doi.org/10.1007/s12647-021-00453-1 (visited on 05/17/2025).

[26] L. Banjanovic-Mehmedovic and Mehmedovic, "Intelligent manufacturing systems driven by artificial intelligence in industry 4.0 | request PDF," in *Re-*

searchGate, ISBN: 978-1-6684-3694-3. [Online]. Available: https://www.researchgate.net/publication/340934584_Intelligent_Manufacturing_Systems_Driven_by_Artificial_Intelligence_in_Industry_40 (visited on 05/17/2025).

[27] G. L. Tortorella, T. A. Saurin, F. S. Fogliatto, *et al.*, "Digitalization of maintenance: Exploratory study on the adoption of industry 4.0 technologies and total productive maintenance practices," *Production Planning & Control*, vol. 35, no. 4, pp. 352–372, Mar. 11, 2024, https://doi.org/10.1080/09537287.2022.2083996, ISSN: 0953-7287. DOI: 10.1080/09537287.2022.2083996. [Online]. Available: https://doi.org/10.1080/09537287.2022.2083996 (visited on 03/31/2025).

[28] "Enhanced real-time maintenance management model—a step toward industry 4.0 through lean: Conveyor belt operation case study." (), [Online]. Available: https://www.mdpi.com/2079-9292/12/18/3872 (visited on 03/31/2025).

[29] A. Samadhiya, R. Agrawal, and J. A. Garza-Reyes, "Integrating industry 4.0 and total productive maintenance for global sustainability," *The TQM Journal*, vol. 36, no. 1, pp. 24–50, Sep. 1, 2022, Publisher: Emerald Publishing Limited, ISSN: 1754-2731. DOI: 10.1108/TQM-05-2022-0164. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/tqm-05-2022-0164/full/html (visited on 03/31/2025).

[30] F. T. Mohad, L. d. C. Gomes, G. d. L. Tortorella, and F. H. Lermen, "Operational excellence in total productive maintenance: Statistical reliability as support for planned maintenance pillar," *International Journal of Quality & Reliability Management*, vol. 42, no. 4, pp. 1274–1296, Sep. 18, 2024, Publisher: Emerald Publishing Limited, ISSN: 0265-671X. DOI: 10.1108/IJQRM-09-2023-0290. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/ijqrm-09-2023-0290/full/html (visited on 03/31/2025).

[31] "Operations strategy, 7th edition e-book," Pearson Nordics. (), [Online]. Available: https://nordics.pearson.com/products/operations-strategy-7th-edition-e-book (visited on 03/31/2025).

[32] R. Phaal and S. Yoshida, "Architecting strategy: Visual form and function of roadmaps," in *Proceedings of PICMET '14 Conference: Portland International Center for Management of Engineering and Technology; Infrastructure and Service Integration*, ISSN: 2159-5100, Jul. 2014, pp. 2960–2971. [Online]. Available: https://ieeexplore.ieee.org/document/6921121/authors#authors (visited on 03/31/2025).

[33] M. Ghobakhloo, "The future of manufacturing industry: A strategic roadmap toward industry 4.0," *Journal of Manufacturing Technology Management*, vol. 29, no. 6, pp. 910–936, Jun. 27, 2018, Publisher: Emerald Publishing Limited, ISSN: 1741-038X. DOI: 10.1108/JMTM-02-2018-0057. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/jmtm-02-2018-0057/full/html (visited on 03/31/2025).

[34] R. Secchi and A. Camuffo, "Lean implementation failures: The role of organizational ambidexterity," *International Journal of Production Economics*, vol. 210, pp. 145–154, Apr. 1, 2019, ISSN: 0925-5273. DOI: 10.1016/j.ijpe.

2019.01.007. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0925527319300076 (visited on 03/31/2025).

[35] "Breaking down the barriers to organizational change," *ResearchGate*, Oct. 22, 2024. DOI: 10.19030/ijmis.v15i3.4650. [Online]. Available: https://www.researchgate.net/publication/298333073_Breaking_Down_The_Barriers_To_Organizational_Change (visited on 03/31/2025).

[36] M. Beer, S. C. Voelpel, M. Leibold, and E. B. Tekie, "Strategic management as organizational learning: Developing fit and alignment through a disciplined process," *Long Range Planning*, vol. 38, no. 5, pp. 445–465, Oct. 1, 2005, ISSN: 0024-6301. DOI: 10.1016/j.lrp.2005.04.008. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0024630105000634 (visited on 03/31/2025).

[37] G. A. Hollaus, "Internal corporate communication in a VUCA environment," in *Managing in a VUCA World*, O. Mack, A. Khare, A. Krämer, and T. Burgartz, Eds., Cham: Springer International Publishing, 2016, pp. 129–138, ISBN: 978-3-319-16889-0. DOI: 10.1007/978-3-319-16889-0_8. [Online]. Available: https://doi.org/10.1007/978-3-319-16889-0_8 (visited on 05/17/2025).

[38] K. Schwabe, "Winning people's hearts and minds," in *Change 2.0: Beyond Organisational Transformation*, J. Klewes and R. Langen, Eds., Berlin, Heidelberg: Springer, 2008, pp. 67–73, ISBN: 978-3-540-77495-2. DOI: 10.1007/978-3-540-77495-2_6. [Online]. Available: https://doi.org/10.1007/978-3-540-77495-2_6 (visited on 05/17/2025).

[39] "(PDF) self-determination theory in work organizations: The state of a science," *ResearchGate*, Oct. 22, 2024. DOI: 10.1146/annurev-orgpsych-032516-113108. [Online]. Available: https://www.researchgate.net/publication/312960448_Self-Determination_Theory_in_Work_Organizations_The_State_of_a_Science (visited on 03/31/2025).

[40] S. Fowler. "Why motivating people doesn't work...and what does: The new science of leading, energizing, and engaging," Adlibris. (Sep. 30, 2014), [Online]. Available: https://www.adlibris.com/se/bok/why-motivating-people-doesnt-workand-what-does-the-new-science-of-leading-energizing-and-engaging-9781626561823 (visited on 03/31/2025).

[41] M. Matthysen and C. Harris, "The relationship between readiness to change and work engagement: A case study in an accounting firm undergoing change," *SA Journal of Human Resource Management*, vol. 16, no. 0, p. 11, Mar. 22, 2018, Number: 0, ISSN: 2071-078X. DOI: 10.4102/sajhrm.v16i0.855. [Online]. Available: https://sajhrm.co.za/index.php/sajhrm/article/view/855 (visited on 05/17/2025).

[42] S. T. Fife and J. D. Gossner, "Deductive qualitative analysis: Evaluating, expanding, and refining theory," *International Journal of Qualitative Methods*, vol. 23, p. 16 094 069 241 244 856, Nov. 1, 2024, Publisher: SAGE Publications Inc, ISSN: 1609-4069. DOI: 10.1177/16094069241244856. [Online]. Available: https://doi.org/10.1177/16094069241244856 (visited on 04/30/2025).

[43] M. Denscombe, *The Good Research Guide*, 5th ed. England: Open University Press. [Online]. Available: https://r4.vlereader.com/Reader?ean=9780335264711 (visited on 01/20/2025).

[44] J. Bokrantz and A. Skoogh, "Adoption patterns and performance implications of smart maintenance," *International Journal of Production Economics*, vol. 256, 2023, ISSN: 0925-5273. DOI: 10.1016/j.ijpe.2022.108746. [Online]. Available: https://research.chalmers.se/en/publication/533783 (visited on 05/10/2025).

[45] M. A. Benzaghta, A. Elwalda, M. Mousa, I. Erkan, and M. Rahman, "SWOT analysis applications: An integrative literature review," *Journal of Global Business Insights*, vol. 6, no. 1, pp. 55–73, Mar. 2021, ISSN: 2640-6470, 2640-6489. DOI: 10.5038/2640-6489.6.1.1148. [Online]. Available: https://scholarcommons.usf.edu/globe/vol6/iss1/5 (visited on 01/20/2025).

[46] A. Sarsby, *SWOT Analysis*. Lulu.com, 2016, 88 pp., Google-Books-ID: Yrp3DQAAQBAJ, ISBN: 978-0-9932504-2-2.

[47] Abubakar, "(PDF) sensors selection for tool failure detection during machining processes: A simple accurate classification model," *ResearchGate*, Dec. 9, 2024. DOI: 10.1016/j.cirpj.2020.12.002. [Online]. Available: https://www.researchgate.net/publication/348034510_Sensors_selection_for_tool_failure_detection_during_machining_processes_A_simple_accurate_classification_model (visited on 05/17/2025).

[48] C. Lundgren, J. Bokrantz, and A. Skoogh, "Performance indicators for measuring the effects of smart maintenance," *International Journal of Productivity and Performance Management*, vol. 70, no. 6, pp. 1291–1316, 2020, ISSN: 1741-0401. DOI: 10.1108/IJPPM-03-2019-0129. [Online]. Available: https://research.chalmers.se/en/publication/519657 (visited on 05/07/2025).

[49] M. O. Seddini and L. Triqui-Sari, "Towards proactive maintenance : The implementation of digitized SCADA systems for predictive maintenance optimization in production environments," in *2024 IEEE 15th International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA)*, ISSN: 2166-7373, May 2024, pp. 1–7. DOI: 10.1109/LOGISTIQUA61063.2024.10571506. [Online]. Available: https://ieeexplore.ieee.org/document/10571506 (visited on 05/07/2025).

[50] S. Ansari and A. Ansari, "Using IoT enabled predictive maintenance to enhance business operations: Benefits and challenges," in *2024 Global Conference on Wireless and Optical Technologies (GCWOT)*, Sep. 2024, pp. 1–7. DOI: 10.1109/GCWOT63882.2024.10805626. [Online]. Available: https://ieeexplore.ieee.org/document/10805626 (visited on 05/07/2025).

[51] In collab. with L. Moraes and J. Chaves, Apr. 29, 2025.

[52] P. ANGGRADEWI, S. SARDJANANTO, and A. Diah EKAWATI. "Improving quality in service management through critical key performance indicators in maintenance process: A systematic literature review - ProQuest." (), [Online]. Available: https://www.proquest.com/openview/1026a14c9420d85bde33be902a65eef
1?cbl=1046413&pq-origsite=gscholar (visited on 05/07/2025).

[53] S. H. H. Mazloumi, A. Moini, and M. A. M. A. Kermani, "Designing synchronizer module in CMMS software based on lean smart maintenance and process mining," *Journal of Quality in Maintenance Engineering*, vol. 29, no. 2, pp. 509–529, May 27, 2022, Publisher: Emerald Publishing Limited, ISSN: 1355-2511. DOI: 10.1108/JQME-10-2021-0077. [Online]. Available:

https://www.emerald.com/insight/content/doi/10.1108/jqme-10-2021-0077/full/html (visited on 05/07/2025).

[54] B. Tinham, “Seeing is believing,” *Plant Engineer (London)*, vol. 51, no. 2, pp. 8–10, 2007.

[55] W. O. R. Parqui, G. Danielsson, J. L. Da Paixão, M. Sperandio, and A. Da Rosa Abaide, “Analysis of the operating history of brazilian power generation plants using maintenance indicators,” *2024 IEEE URUCON*, pp. 1–4, Nov. 18, 2024, Conference Name: 2024 IEEE URUCON ISBN: 9798350355383 Place: Montevideo, Uruguay Publisher: IEEE. DOI: 10.1109/URUCON63440.2024.10850028. [Online]. Available: https://ieeexplore.ieee.org/document/10850028/ (visited on 05/18/2025).

A

Appendix 1

Main question

- How do you perceive the way you work with operator maintenance?

Probes

- Do you create instructions and standards for the operators?
- Is there anyone trying to encourage operators to take initiative in maintenance?

Main question

- How do you work with preventive maintenance?

Probes

- Do you create maintenance strategies for different types of equipment?
- Do you have any initiatives to move from firefighting to preventive maintenance? (e.g., using data analysis on equipment)

Main question

- Can you describe the education and training you have received in your work?

Probes

- Have you received any training on how your equipment works? If so, what kind of training?
- Do you feel that you have received sufficient training to perform your job?
- How do you view the opportunities for learning and development in your role?
- Are you ever tested on your knowledge?

Main question

- Can you describe how operators and the maintenance team are involved in the selection or purchase of new equipment?

Probes

- How are your experiences and needs taken into account when new equipment is being designed or purchased?
- Do you consider maintenance aspects when purchasing equipment? For example, do you ensure it is easy to maintain, like replacing compressed air with electric alternatives?

Main question

- How do you work with safety around the equipment during repair or maintenance?

Probes

- Are you aware of the risks associated with the equipment? Is this documented in any way, and do you have access to it? (One Point Lessons)
- Do you create standards that include equipment-related risks?
- How are new risks usually identified? What happens when a new risk is discovered?
- How do you perceive the working environment here? (Noise, vibrations, cold/hot?)

Main question

- How do you work with continuous improvement when it comes to equipment?

Probes

- What methods do you use to find and solve recurring problems? (5 Whys, Fishbone diagram, FMEA – to find root causes)
- Do you collaborate with assemblers/engineers in improvement work? If yes, how?

Main question

- How do you ensure that machines contribute to consistent product quality? (e.g., poor calibration, worn sockets, etc.)

Probes

- How do you handle equipment issues when they occur?
- Do you have access to statistical data on equipment failures that affect product quality? If so, how do you work with it?

Main question

- Is there anything you would like to talk about that you think is important or that we have missed?
- What are the biggest challenges you face in your daily work, and if you could change or improve one thing, what would it be?

B

Appendix 2

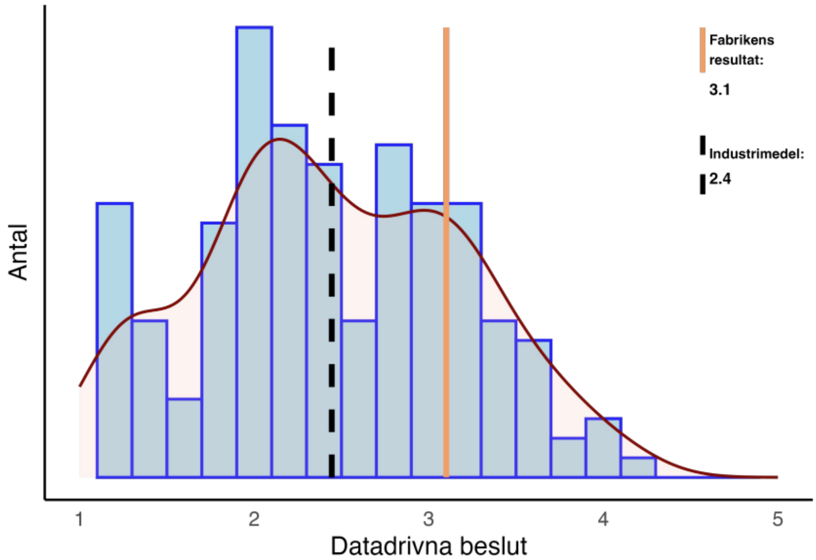

Figure B.1: SMASh result

C
Appendix 3

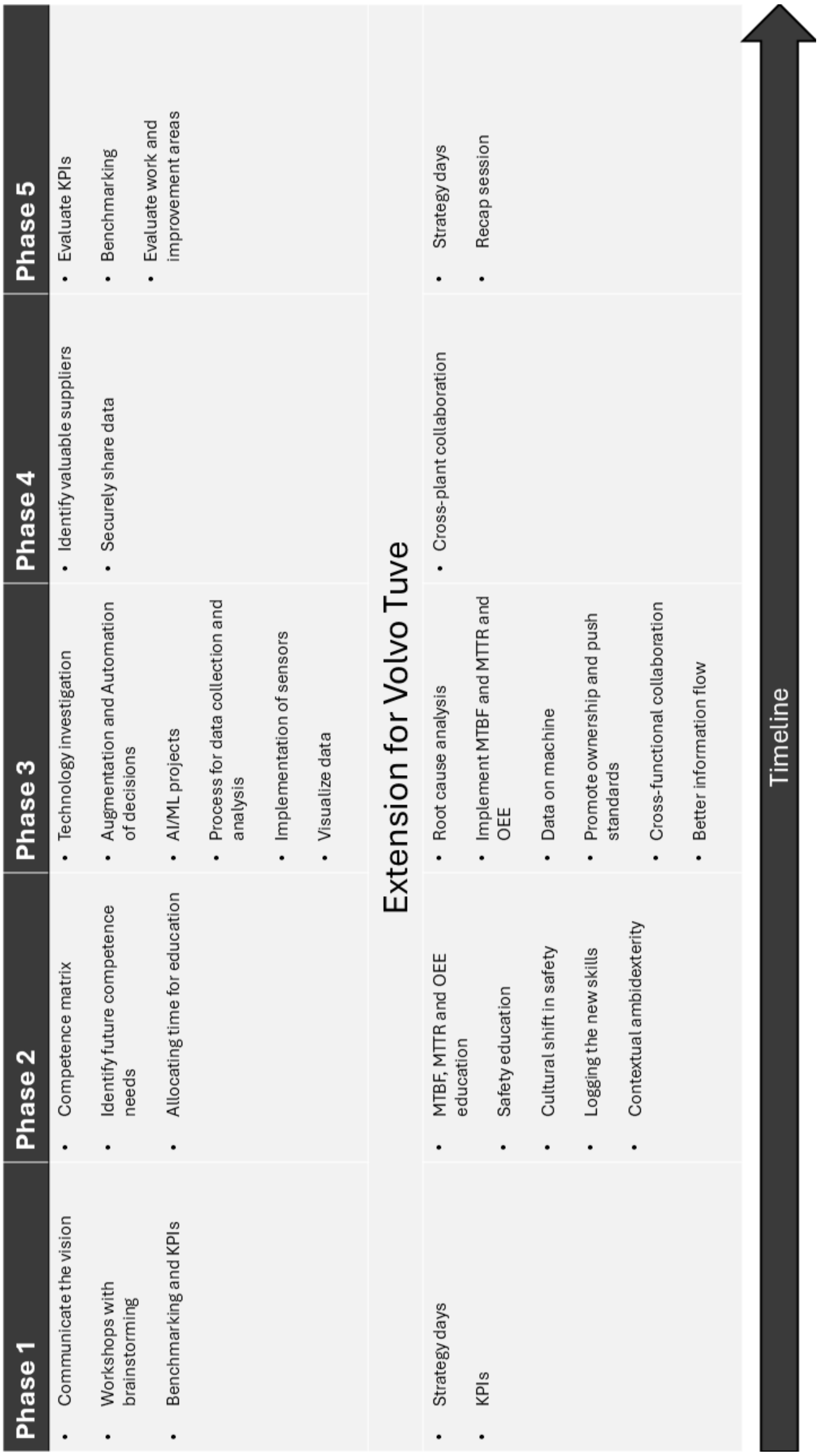

Figure C.1: Roadmap

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY