CHALMERS
UNIVERSITY OF TECHNOLOGY



Managing the Factory of the Future

Suggestions for more human-centric manufacturing management practices at Volvo Cars

Master's thesis in Management & Economics of Innovation and Supply Chain Management

LUCAS ARONSSON
LUDVIG NORDGREN

DEPARTMENT OF INDUSTRAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
www.chalmers.se

MANAGING THE FACTORY OF THE FUTURE

Suggestions for more human-centric manufacturing management practices at Volvo Cars.

LUCAS ARONSSON
LUDVIG NORDGREN

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026

MANAGING THE FACTORY OF THE FUTURE
Suggestions for more human-centric manufacturing management practices at Volvo Cars.

LUCAS ARONSSON
LUDVIG NORDGREN

© Lucas Aronsson, 2026
© Ludvig Nordgren, 2026

This thesis was written in collaboration with Volvo Cars.

Acknowledgements, dedications, and similar personal statements in this thesis reflect the authors own views.

Department of Industrial and Materials Science
Chalmers University of Technology
SE-412 96 Gothenburg Sweden
Telephone + 46 (0)31-772 1000

Cover: Final assembly of EX60 at the Volvo Cars Torslanda factory.
Credit: Volvo Car Corporation

Gothenburg, Sweden 2026

MANAGING THE FACTORY OF THE FUTURE
Suggestions for more human-centric manufacturing management practices at Volvo Cars.

LUCAS ARONSSON
LUDVIG NORDGREN

Department of Industrial and Materials Science
Chalmers University of Technology

SUMMARY

The automotive industry is undergoing a rapid transformation due to the advancements of smart technologies, changing customer behaviours, and increasing demands for sustainability, requiring manufacturing practices to be re-evaluated. Industry 5.0, the latest industrial revolution, has been developed to address this, re-emphasising the role of humans in manufacturing processes and seeking to utilise the unique strengths of humans, such as creativity and reasoning. The study aims to explore improvements to the management of manufacturing at Volvo Cars, building on the human-centric principles of Industry 5.0.

The study examines the current trends in manufacturing management and the current state of management practices within the Volvo Cars Manufacturing System, ultimately proposing specific improvement suggestions for Volvo Cars manufacturing management practices. The study was conducted by a combination of literature review, on-site observations, and interviews.

The study identified four key principles to achieve more human-centric manufacturing. These were the utilisation and continuous development of human-specific strengths; only involve humans when necessary or advantageous; distributing the right information to the right people; and improving working conditions, wellbeing and job satisfaction. The study also identified three currently inhibiting factors to human-centric management at Volvo Cars; time constraints, analogue systems, and human-specific strengths being underutilised. Lastly, four practical improvement suggestions were proposed, designed with the intention of being realistically possible to implement at Volvo Cars within a 5-year timespan, and to function as guidance toward a full-scale transition into Industry 5.0.

Keywords: *Management, Manufacturing, Industry 5.0*, *Human-centric, Digitalisation, Automation, Automotive.*

Acknowledgments

This master's thesis was written in the spring of 2026 as the final part of our respective M.Sc. programs Management and Economics of Innovation and Supply Chain Management.

We would like to express our sincere gratitude to our supervisors at Volvo Cars, Ulrika Silvereden and Magnus Svensson, for their continued support throughout the thesis process. Furthermore, we also thank all other Volvo Cars employees who took time out of their busy schedules to meet with us. Without your valuable input, this study would have been impossible.

At Chalmers, we would like to thank our supervisor Omkar Salunkhe and our examiner Johan Stahre at the Department of Industrial and Materials Science (now Department of Mechanical Engineering) for their support and insightful feedback.

Table of contents

List of Acronyms I
List of Figures II
List of Tables III
1. Introduction 1
1.1 Background 1
1.2 Purpose & Research questions 2
1.3 Limitations 3
2. Theory 4
2.1 Automotive industry – Current trends 4
2.2 Industry 5.0 5
2.2.1 Advantages of Industry 5.0 7
2.2.2 Industry 5.0 in automotive manufacturing 9
2.2.3 Transitioning from Industry 4.0 to Industry 5.0 9
2.3 Lean 12
2.4 Volvo Cars Manufacturing System (VCMS) 14
2.5 Organisation at Volvo Cars 17
2.6 AI in manufacturing 19
3. Methodology 23
3.1 Literature review 24
3.2 Observations 25
3.3 Interviews 26
3.4 Data analysis 27
3.5 Research ethics 28
4. Results 29
4.1 Management in Industry 5.0 – Key principles 29
4.2 Current state of VCMS – Factors inhibiting Industry 5.0 development 34
4.2.1 Time constraints 35
4.2.2 Analogue systems 36
4.2.3 Human strengths underutilised 38
4.3 Improvement suggestions to enable Industry 5.0 39
4.3.1 Improvement suggestion 1 – Digital RTM-boards 42

4.3.2 Improvement suggestion 2 – Designated Andon response order 48
4.3.3 Improvement suggestion 3 – Automated operator error reporting 52
4.3.4 Improvement suggestion 4 – AI assistants & education 56
5. Discussion 63
5.1 Answering research questions 63
5.2 Reflections on improvement suggestions 65
5.3 Implications for VCMS 67
5.4 Future research 67
5.5 Methodology discussion 68
6. Conclusion 70
References 72

List of Acronyms

AI – Artificial Intelligence

BMS – Business Management System

IoT – Internet of Things

KPI – Key Performance Indicator

MES – Manufacturing Execution System

ML – Machine Learning

NLP – Natural Language Processing

OEM – Original Equipment Manufacturer

OIS – Operator Instruction Sheet

QMS – Quality Management System

RTM – Real Time Management

TA – Torslanda A-shop (Body-shop)

TB – Torslanda B-shop (Paint-shop)

TC – Torslanda C-shop (Final assembly-shop)

VCT – Volvo Cars Torslanda

VCMS – Volvo Cars Manufacturing System

WES – Work Element Sheet

List of Figures

Figure 1: Components of VCMS *15*
Figure 2: Research design visualisation *23*
Figure 3: Summary of results *29*
Figure 4: Design suggestion - Andon responder order list *50*

List of Tables

Table 1: Advantages of Industry 5.0 8
Table 2: List of interviews 27
Table 3: Summary of improvement suggestions 40

1. Introduction

In the following section, an introduction to the thesis is outlined through a presentation of the background, aim, and research questions to be explored in the thesis, along with identified limitations to the study.

1.1 Background

Manufacturing within the automotive industry is undergoing a rapid transformation driven by advancements of smart technologies, evolving customer needs, and increasing sustainability focus. Traditional production systems in the automotive industry, drawn from the assembly line methods pioneered by Henry Ford in the early twentieth century, have prioritised standardised processes and high production volumes, focusing on optimising efficiency and reducing costs (Hammad et al, 2026). However, as the industry has evolved into the twenty-first century, the limitations of traditional manufacturing systems have become increasingly apparent. Highly automated production lines, while efficient in stable and high-volume environments, requires large initial investments and often lack the flexibility that is required to respond to unexpected disturbances and the product variability that is increasing with modern customers' demands for customisation (Cai et al., 2026). Conversely, manual production offers adaptability but suffer from considerably lower productivity, higher variability, and operator health risks.

The human-centric philosophies of Industry 5.0 offer a solution for how to combine these two approaches to manufacturing; balancing efficiency, flexibility, volume, and sustainability in one manufacturing system. While Industry 4.0 has primarily emphasised increased efficiency through automation, connectivity, and data-driven optimisation, Industry 5.0 aims to “reintroduce” the human as a central element of manufacturing systems (Ionescu, An & Ionescu, Al, 2025). By combining human strengths such as flexible decision-making, contextual understanding, and adaptability with the precision, consistency, and continuous operation-capabilities offered by automation, human-robot collaborative manufacturing enables a more balanced and resilient manufacturing system (Cai et al., 2026).

As a result of embracing the principles of Industry 4.0 and the advancements of digital technologies, Volvo Cars has adopted several advanced digital tools in their manufacturing,

such as digital twins, real-time data visualisation, and connected factories. Although these technologies and systems have proved highly useful, there remains questions around how best to use them from a management perspective. Therefore, as Volvo Cars now shifts its focus to Industry 5.0, with its increased importance in managing employees, the next challenge will be to integrate these advanced technologies with current systems, tools, management principles, and ways-of-doing-business to form a manufacturing system that provides a seamless, intuitive, and human-centric way-of-working to all manufacturing employees.

The Volvo Cars Manufacturing System (VCMS) is a set of principles and methods currently used by Volvo Cars globally to achieve operational excellence in their operations. To meet the future demands within the automotive industry and achieve the human-centric objectives of Industry 5.0, there is a need for Volvo Cars to evaluate and improve these current practices. Volvo Cars need to make sure that they are continuously increasing effectiveness within their production and management, while meeting the future demands of increased manufacturing flexibility. Achieving the objectives of Industry 5.0 is additionally important to attract the next generation of workforce, who put greater demands on job satisfaction and sustainability. Consequently, finding new ways to make their manufacturing management practices more in-line with the principles of Industry 5.0 is of high importance to Volvo Cars.

1.2 Purpose & Research questions

The aim of the study is to provide Volvo Cars with suggestions for how to improve their manufacturing management practices within VCMS according to Industry 5.0s human-centric principles.

The following research questions have been identified for the thesis:

1. According to Industry 5.0 theory; What will the future of manufacturing management look like? What are the current trends and key principles?
2. Based on these trends and principles; what factors inhibiting Industry 5.0 development within VCMS have been observed?
3. What are some improvement suggestions to make VCMS more Industry 5.0 compliant? What capabilities does Volvo Cars need to implement these suggestions?

1.3 Limitations

Management is a wide-encompassing subject area that includes activities all over the organisational hierarchy, from the boardroom to the breakroom. This thesis will be limited to the lower organisational levels in Volvo Cars manufacturing, from the operators (1st level) that builds the cars, through team-leaders (2nd level), to supervisors (3rd level) that are responsible for one production line. Continuing, Volvo Cars wants this thesis to be a vision for their manufacturing system in a relatively close future. Therefore, the thesis will have a time frame of around 5 years into the future.

This thesis aims to provide improvements to the management of manufacturing for all Volvo Cars factories around the world. However, geographical limitations to the study exists. Observations of current manufacturing operations and processes are limited to Volvo Cars Torslanda (VCT) in Gothenburg, Sweden. Because of time constraints, the scope of this study also excludes prototype development and real-world testing and validation of the final improvement suggestions on the production floor.

This thesis is part of the wider “Future manufacturing system”-thesis project organised between Volvo Cars, Chalmers University of Technology, & Rockwell Automation. The project consists of three master theses, each focusing on different parts of the future manufacturing system. One focuses on the manufacturing workstation itself; what new technologies, machines, robots, etc., should be implemented in the manufacturing process to improve efficiency and flexibility. The other focuses on the operators' skills and training; how to educate and develop the workforce of the future using new digital tools. While some overlap with these subject areas might occur, this thesis will try to steer clear of these areas as much as possible.

2. Theory

In this section, theoretical background forming the basis for the thesis is presented and explained. Initially, current trends shaping the wider automotive industry are investigated. This is followed by sections on Industry 5.0 and fundamental Lean principles utilised extensively at Volvo Cars. Subsequently, a brief explanation of the Volvo Cars Manufacturing System and the different organisational roles at the company, relevant to the thesis, follows. Finally, a section on the development and usage of AI in manufacturing operations is presented.

2.1 Automotive industry – Current trends

The automotive industry ranks among the top of the most innovative, complex, and globally dispersed industries in the world (Mueller & Mezhuyev, 2022). From producing engine-powered horse-drawn carriages in the late nineteenth-century, to developing digital and connected cars capable of driving autonomously, the automotive industry has been undergoing more than a hundred years of innovation and continuous improvement. The complexity of the industry has led to Original Equipment Manufacturers (OEM) and suppliers within the industry to be frontrunners and early adopters of new industrial revolutions.

The automotive industry currently stands on the edge of a revolutionary transformation, driven by the advancements of new advanced technologies and changing consumer demands (Martins, 2023; Madhavaram et al., 2024). As vehicles has evolved into highly complex machines equipped with sophisticated systems capable of autonomous decision-making, the traditional ways of pursuing manufacturing operations and processes are being reshaped (Madhavaram et al., 2024). This shift not only concerns the operational capabilities of vehicles but also mandates a re-evaluation of existing manufacturing processes to respond to the demands of modern technology.

Changing consumer demands and emerging markets further stresses the need for developments and transformation of existing manufacturing operations and practices (Mueller & Mezhuyev, 2022). Consumers are becoming increasingly aware of global sustainability challenges and are placing greater emphasis on sustainable business practices. This requires automotive manufacturers to not only consider sustainability impacts from their

products but from the entire manufacturing process and supply chain. The increased adoption of electric vehicles and other environmentally friendly alternatives has further amplified the transformation toward new production techniques and processes, requiring manufacturers to be innovative and leverage the advancements in modern technology. In addition, emerging markets presents both challenges and opportunities for manufacturers as they strive to meet diverse regulatory standards while at the same time navigating new and highly competitive market dynamics on a global scale.

Along with the increasing demand for sustainable solutions, there has been a notable shift among consumer preferences towards more tailored and personalised solutions (Mueller & Mezhuyev, 2022; Kabasakal et al., 2017). The automotive industry has therefore moved more in the direction of customisation and personalisation in the last decades. Mass customisation has been present within the automotive sector for some time and can be described as a strategy based on the ability to provide customised products or services through flexible processes to differentiate in highly competitive markets (Kabasakal et al., 2017). From a manufacturing management perspective, it relates to flexible manufacturing systems and product architectures, where product architecture design along with product configuration is essential. These elements enable a broader range of choices for customers while at the same time strengthening competitive positioning. On the other hand, personalisation refers to the adaptation of products and services by the producer based on the information derived from consumer behaviour. Unlike mass customisation, which offers predefined options within a flexible system, personalisation involves tailoring offerings more specifically to individual preferences.

To summarise, recent advancements in technology, macroeconomic pressures, and changing consumer behaviours have all contributed to a structural transformation of the automotive industry. Consumers' increased awareness for sustainability practices and demand for more individualised products, along with advancements of vehicle and manufacturing technologies, are the largest reasons for this transformation.

2.2 Industry 5.0

On the surface, Industry 5.0 might seem like a counterproductive concept relative to its predecessors. While each individual leap between Industry 1.0 and Industry 4.0 have brought

significant increases in output volumes and efficiency, the focus of Industry 5.0 lies in improving other metrics (Fazal et al., 2022; Piccarozzi et al., 2024). If optimisation of production based on Industry 4.0 concepts get to run its full course, factories will be fully automated without a human being in sight (Piccarozzi et al., 2024). These, so called lights-out factories, would be highly efficient production lines capable of immense output volumes of specific goods.

However, it has become clear that there are only certain types of products that lends themselves well to being produced like this (Fazal et al., 2022), namely highly standardised products and bulk goods. Recent shifts in consumer behaviours shows that customers put increasing importance on being able to customise their products and are willing to pay a premium for more unique products that the consumer can make a personal statement with. Modern manufacturing must therefore take a step back from increasing mass standardisation and instead focus on flexibility, something that Industry 5.0 provides a solution for. Industry 5.0 promotes increased flexibility in industrial manufacturing by refocusing on the role of humans in the manufacturing process.

Humans have always played a key role in industrial manufacturing; however, they have always been expected to adapt to the machines and the technology they work beside (Fazal et al., 2022). With every advancement in industrial technology, the number of humans needed in the actual manufacturing process have decreased and the remaining employees have had to learn to deal with an increasing number of different machines, digital systems, and advanced technologies in their place. For example, Industry 4.0 introduced a wide range of advanced technologies that has accelerated the digital transformation of manufacturing by the integration of digital technologies into manufacturing operations and processes (Yanytska, 2025). This technology-centric approach has overwhelmed the humans working in manufacturing, leaving some with a feeling that they are there to serve the machines, and suppressing the main strengths that humans can contribute with to the industrial process, creativity, flexibility, and adaptability.

Industry 5.0 has emerged as something of a countermovement, aimed at enabling humans to work more with these uniquely human qualities through the development of new human-centric technologies, as well as changes in the utilisation of various technologies to support a more human-centric approach. Numerous technologies have been identified as core enablers of Industry 5.0 due to their role in facilitating human-centric industrial systems; examples of

such technologies include AI, Machine Learning (ML), cobots, digital twins, and Internet of Things (IoT) (Yanytska, 2025; Pham & Li, 2026). The transition toward Industry 5.0 has not necessarily increased the level of digitalisation within manufacturing but has rather transformed the way digital technologies are utilised and expanded the adoption of technologies that support human-centric practices and ways of working. Yanytska (2025) notes that these human-centric technologies should not be applied in isolation. They should be designed to work as part of interconnected digital ecosystems where humans, machines, and data flows interact continuously. With this way of applying human-centric technologies, not only can higher degrees of process optimisation be achieved, but it also enables emotional, physical, and cognitive support for workers.

2.2.1 Advantages of Industry 5.0

As Industry 5.0 seeks to utilise more of the uniquely human cognitive abilities to bring back the "human touch" to industrial manufacturing, consumer products could benefit massively from these new Industry 5.0 production lines, with more human involvement in the manufacturing process and more opportunities for customisation and personalisation (Piccarozzi et al., 2024). Consumers are also becoming more aware of companies manufacturing practices, working conditions and environmental profiles, demanding fair practices in all areas. Mass standardisation, systemic overproduction, excessive waste, and unfair labour practices are all seen as negatives by the modern consumer and could hurt company reputation and sales. This further increases the importance of developing your manufacturing processes according to Industry 5.0, which promises improvements for all these areas.

There are also other benefits to putting an increased focus on the human beings on the shop floor. Creating an environment where operators are valued for their creativity and cognitive capacities should also lead to benefits in other important areas, such as improved Lean and continuous improvement work, and a higher willingness to partake in training and up-skilling activities (Piccarozzi et al., 2024). Finally, it would also make industrial jobs more meaningful and fulfilling while creating a more pleasant work environment, crucial in retaining and attracting skilled labour. A summarisation of the key advantages of Industry 5.0 compared to Industry 4.0 is listed in Table 1.

Table 1: Advantages of Industry 5.0

Advantage area	**Industry 4.0 focus**	**Industry 5.0 advantages**
Human factors	Little focus on human factors	Focus on improving worker wellbeing, job engagement, work satisfaction, empowerment of workers, and work safety
Operational efficiency and productivity	Automation, efficiency, digitalisation	Enhanced human-machine collaboration Increased utilisation of human-specific strengths
Technology	Cyber-physical systems, automation, digitalisation	Collaborative technologies
Sustainability	Resource efficiency Some but limited focus on sustainability practices	High focus on sustainability - Environmental impact - Financial impact - Social/societal impact
Customisation & Personalisation	Mass standardisation/customisation	More personalisation and customisation Flexible and adaptive production
Resilience & adaptability	Standardised and low flexibility production processes	More resilient manufacturing processes Higher organisational adaptability
Organisational culture	Hierarchical Efficiency-driven	Dynamic, agile, and inclusive cultures Collaborative work environments

2.2.2 Industry 5.0 in automotive manufacturing

The automotive industry stands at the forefront of the transition from Industry 4.0 to Industry 5.0. As mentioned by Mueller & Mezhuyev (2022), the automotive industry has always been frontrunners when it comes to adapting to industrial revolutions, due to its high complexity and need for innovation, and adoption of Industry 5.0 is no exception. Core principles of Industry 5.0 are human-machine collaboration, sustainability, and customisation, particularly relevant to the automotive sector, which faces increasing pressure to deliver customised products, reduce its ecological footprint, and adapt to rapidly changing technologies and markets (Zelazny et al., 2025).

The implementation of Industry 5.0 in the automotive industry is marked by the integration of advanced digital technologies, human-centric designs, and sustainability practices into manufacturing processes (Zelazny et al., 2025). Advanced human-centric technologies and practices are transforming manufacturing systems in the automotive sector and provides solutions to requirements of more customisation, increased operational resilience, and more sustainable manufacturing. However, significant challenges remain, especially with the integration of these technologies with legacy systems and ensuring cybersecurity (Havle & Ucler, 2025). Another challenge is the development of workforce training and upskilling. Tools that have been identified as critical for navigating these complexities are, for instance, multi-criteria decision-making methods and collaborative innovation practices. Responding to these challenges and barriers will be crucial for manufacturing firms in realising the full potential of Industry 5.0 in creating a more sustainable, human-centric, and resilient automotive industry.

2.2.3 Transitioning from Industry 4.0 to Industry 5.0

The transition from Industry 4.0 to Industry 5.0 represents a significant shift in how manufacturing firms approach their manufacturing operations and management, moving away from a technology-driven and automation-focused approach, toward more human-centric, sustainable, and resilient industrial models (Leon et al., 2025). To succeed with this transition, there are several key aspects and critical dimensions for manufacturing firms to consider.

It is not as straightforward as it seems to go from one concept to another, not even in theory. Because, while manufacturing operations will need more human qualities in the future, humans are inherently slower at making decisions than even the most rudimentary automation control systems in use today (Piccarozzi et al., 2024). To keep up with the quick pace needed to maintain an acceptable output and resource efficiency, autonomous automation will still need to be implemented but backed up by the unmatched creativity and flexibility of humans in novel and/or complex situations. The key to successfully transition from Industry 4.0 to Industry 5.0 will therefore be to strike the right balance between human and automation, operator and machine, supervisor and software. It is not about replacing one with the other, but becoming more human-centric, tailoring the technology and systems around the humans, not the other way around. With the human-centric approach to manufacturing systems, operators are seen as the end-users of new process innovations, and the technology is there to serve the humans in becoming more efficient and empowering them to contribute with the unique abilities that only humans possess.

When transitioning, a fundamental requirement for achieving a successful transition is for firms to adopt and integrate various enabling technologies that align with the principles of Industry 5.0 into their core operations and management practices (Yanytska, 2025; Pham & Li, 2026). However, the implementation of these technologies alone is not sufficient. Firms must also ensure that their workforce possesses the necessary knowledge and skills required for humans to effectively collaborate with advanced technologies (Mourtzis & Wang, 2024). To ensure this, firms should invest in upskilling and reskilling of their employees; this includes the development and implementation of training programs that enhances the digital competencies of workers and improves their ability to work alongside intelligent and collaborative technologies. While the implementation of certain technologies may be fundamental for succeeding with the Industry 5.0 implementation, investing in such technologies may introduce significant financial challenges (Leon et al., 2025). The costs associated with investing in advanced technologies, workforce training, and organisational transformation can present substantial barriers for firms, especially smaller ones. Consequently, firms must carefully consider the economic aspects and long-term value when introducing Industry 5.0 initiatives. Sustainability is a central principle of Industry 5.0, and achieving and maintaining financial sustainability is therefore a key factor when moving toward Industry 5.0.

Furthermore, the transition from Industry 4.0 to Industry 5.0 is heavily influenced by the ability of firms to adapt to changes (Leon et al., 2025; Pham & Li, 2026). The shift toward human-centric objectives requires organisations to reassess and redefine their existing strategic goals, structures, and approaches (Leon et al., 2025). This highlights the importance of organisational adaptability and resilience within firms, as they need to be capable of responding effectively to technological, economical, and societal changes. Establishing a long-term vision that promotes flexibility and continuous adaptation is therefore essential for firms in achieving a successful transformation.

According to Leon et al. (2025), collaboration within organisations plays a critical role in enhancing both organisational agility but also overall strategic effectiveness. Promoting collaborative work environments not only strengthens organisational adaptability, but also supports human wellbeing and employee engagement, objectives that are central in Industry 5.0. Fostering solid and collaborative relationships within organisations can therefore significantly contribute to the effectiveness of Industry 5.0 implementation by promoting knowledge sharing among workers and collaborative innovation processes.

Another important aspect regarding the transition from Industry 4.0 to Industry 5.0 is the technological readiness within organisations. Pham & Li (2026) argues that to implement and succeed with Industry 5.0 technologies and practices, firms must deploy essential enabling technologies and ensure that robust digital infrastructure exists, supporting interoperability across systems. Deployment of human-centric technologies such as cobots, IoT, and AI has shown to have a remarkable impact on empowering firms on their journey toward achieving the objectives of Industry 5.0. However, beyond just implementing these technologies, it is crucial that the necessary digital infrastructure exists, including high-speed internet, cloud platforms, cybersecurity, etc., since it provides the foundational layer for integration. To facilitate a seamless integration of Industry 5.0 technologies and practices, it is therefore essential for firms to ensure that they possess the necessary organisational readiness and digital infrastructure.

Leon et al. (2025) further stresses that, while removing barriers to Industry 5.0 implementation is critical, similar attention should be given to identifying the drivers that facilitate and accelerate Industry 5.0 implementation. Firms should not solely focus on what internal and external barriers that need to be overcome when transitioning from Industry 4.0

to Industry 5.0 but also put high focus on leveraging the existing organisational capabilities and drivers that can contribute to a successful transformation.

2.3 Lean

Lean manufacturing, originating from Japanese industries and especially the Toyota Production System, is a production and management approach focusing on maximising customer value while minimising waste (Sundar et al., 2014). It emphasises maximising resource efficiency by reducing and eliminating waste in production, through sorting of value-added and non-value-added activities; where value-added is define as bringing value to the customer. The objective of Lean is to do more with fewer resources through reducing waiting times, inventory, defects, and unnecessary work. This is done through several different principles and methods such as; identifying value from the perspective of the customer, mapping and improving the flow of work, eliminating waste, producing only what is needed, and continuously improving processes. Below, a selection of Lean tools used to achieve such improvements at Volvo Cars are presented:

Real Time Management

Real time management (RTM) is a management process involving the continuous monitoring of key information in real time (Putnik et al., 2014). RTM has seen rapid growth as a management tool in manufacturing systems building on advanced information and communication technologies such as radio-frequency identification technologies and other wireless sensor networks, IoT, and other ubiquitous technology devices, enabling massive data collection and processing in real time. The main objective of RTM is to facilitate rapid adaptation to the dynamic internal (organisation) and external (market) changes by using real time- data collection, data processing, data analysis, and decision-making, resulting in dynamic reconfigurations of production plans, scheduling, process plans, organisational architectures, and resources including tangible and intangible assets, based on criteria such as productivity, cost, quality, agility, environment, and sustainability. RTM challenges traditional planning, which functions as a static control mechanism that is ill-suited to turbulent environments, by emphasising real time responsiveness, often integrated with cyber-physical systems and AI to handle massive data streams.

At its core, RTM transforms manufacturing systems into agile, data-driven entities that are capable of predictive and proactive management (Putnik et al., 2014). Tsai et al. (2026) describe RTM within an AI-assisted flexible Manufacturing Execution System (MES) framework, where real-time data visualisation, digital twins, and distributed intelligence enable quick processing of large data streams, resulting in significant performance gains on Key Performance Indicators (KPI) such as output rate, quality, and changeover times. This aligns with the broader perspective of Industry 4.0, where RTM overcomes the traditional limitations in real time handling, flexible scheduling, and adaptive decision-making. It can further be augmented by operational methodologies within Industry 4.0 roadmaps as described by Utiyama et al. (2025), who propose a three-step roadmap. The roadmap involves requirements, real time control, and predictive capacity, that combines Lean principles, for example waste reduction, with factory physics such as bottleneck detection to achieve real time shop-floor coordination, fast response times, and reduced lead times and work-in-process, resulting in improved overall equipment effectiveness.

Furthermore, RTM also involves the integration of visualisation tools for shop-floor tasks, as highlighted by Mathiasen &Clausen (2024), who emphasise the provided opportunities for real time sharing of process and resource details that comes with the increased digitalisation of shop floors. Visualisation boards, which provide ubiquitous technology-enabled renderings of such details, plays a significant role in this regard. Critical to the effectiveness of this role is the fit between the design of the visualisation board and shop-floor needs. Mathiasen and Clausen (2024) highlights the need for visualisation tools in ensuring task-technology fit, distinguishing between real time data for monitoring dynamic operations and non-real time data for performance analysis, while addressing mismatches in enterprise architectures.

In conclusion, while its full capabilities and limits remain under investigation, RTM represents a shift from heuristic-driven applications to systematic and technology-driven frameworks that allows for predictive and proactive management suited for modern manufacturing.

Andon

In Lean manufacturing, Andon refers to systems that are used to visually inform problems and abnormalities occurring at the production floor (Liker & Hoseus, 2008). Traditional Andon systems consist of diverse signalling devices such as pull cords, buttons, and/or lights installed next to the production line, allowing operators to trigger Andon and alert when

problems occur (Fan et al., 2024). This prompts supervisors, team leaders, and/or maintenance teams to quickly address issues before the production line is forced to stop, reducing defective outputs and quality issues. Although the traditional Andon system is of high simplicity, it is widely used in factories all over the world. It is a cost-effective way of reducing quality defects and, with its ease-of-use, is an integral part of quality control at many production lines of various sizes and industries across the world.

With the introduction of Industry 4.0 and smart technologies, Andon systems have also evolved from purely mechanical devices to intelligent and automated systems (Fan et al., 2024). The first updates enabled electrical connections to indicator lights for automated fault alerts, improving response times. Later, integrated computer technology allowed Andon systems to monitor multiple production parameters in real-time and accurately diagnose abnormalities. In the twenty-first century it has evolved toward more intelligent systems that uses sensors, networks, and cloud platforms, connecting data to advanced computer systems for in-depth diagnostics, real-time optimisation, and predictions. In recent times, AI has been increasingly used to power these intelligent systems, making it possible to autonomously detect, locate, and fix errors from end-to-end. In summary, Andon systems have evolved from just pure mechanical operator-driven signalling tools toward intelligent and computer-integrated systems, allowing factories to monitor and control quality with more precision and efficiency.

2.4 Volvo Cars Manufacturing System (VCMS)

Volvo Cars Manufacturing System (VCMS) is a set of principles used by Volvo Cars globally to achieve the best possible quality, delivery, and safety through operational excellence. Internally, the main components of VCMS are often visualised in the form of the VCMS-rocket (see Figure 1). Each component contains a more detailed set of principles, methods, tools and ways-of-doing-business. A summary of each component's description, as stated in Volvo Cars Business Management System (BMS), are listed below:

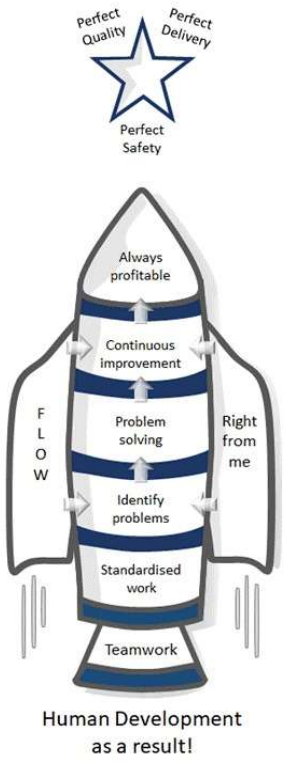


Figure 1: Components of VCMS

Teamwork

Within VCMS, teamwork is defined as cross-functional collaboration where all roles within the span of control and support share responsibility for results. It serves as both the foundation and driving force of operations, enabling coordinated planning, problem solving, and continuous improvement. Effective teamwork fosters engagement, builds human capital, and supports the development of high performing and capable people. As a result, the capabilities for Volvo Cars grows when capital is built in human development.

Standardised work

Standardised work establishes consistent and predictable processes as the basis for all activities. It extends beyond just the direct work on the products; the industrial system requires a mass of additional actions to operate at the highest level. Hence, standardised methods and instructions are applied for all planned tasks. By making work predictable and plannable, standardisation enables systematic improvement and continuous identification of process enhancement, serving as the fundamental building block for all industrial, and office-based, activities at Volvo Cars. There are three types of standardised work: Type 1, which is cyclic without variation; Type 2, which is cyclic with variation; and Type 3, which is other standardised work carried out outside the standard cycle time of the production line. Out of

the three, Type 1 is preferable since it is the easiest to predict and schedule, with Type 3 being the least preferable.

Right from me

"Right from me" represents a mindset of individual responsibility for delivering perfect quality at every stage of the process, for both internal and external customers. With this approach, smart processes can be built that makes problem detection easier, criteria are visualised, making it clear that requirements are met, and support can be provided to correct deviations and return them to acceptable levels. Andon and RTM are two principles used to deliver robust performance, enabling process control in real-time with high sensitivity for problem exposure.

FLOW

In VCMS, flow refers to a connected and synchronised supply chain, connecting all processes and elements to the real customer rate of demand. The ideal flow sees products pulled continuously through the complete supply chain in one stream at the rate of the customer demand. The three key elements of this concept are "Pull", "Continuous single piece flow", and "Customer demand". "Pull" refers to the principle of not overproducing or overspeed ahead of the actual process demand. "Continuous single piece of flow" refers to the idea of having one consolidated flow, both within logistics and value-added processes, meaning no unnecessary handling, split, merge, or parallel processing. The last element "Customer demand" relates to the rate of customer demand for products that is integrated into flow through a principle called TAKT. The TAKT, which is the rate of customer demand, must be met to satisfy the customer demand, typically through operating at a higher rate than the customer demand to overcome the effects of losses.

Identify problems

Identification of problems is of high importance in manufacturing operations. To identify a problem is to recognise the difference between a correct status and a problematic status. It can be related to products as well as to processes and ways of working. By having a standardised way of working, performing "right from me" based on customer expectations, and operating at a repetitive pace, real issues will be more easily exposed and identification of problems possible. Andon and RTM are the two most valuable inputs for recognising deviations.

Problem solving

Problem solving in VCMS is used as a logical language to improve the business. At all levels an analytical approach should be practised and mastered to drive an effective solving of problems. By grasping the situation and breaking the issue down, problem statement and points of cause can be made to effectively choose improvement actions.

Continuous improvement

In VCMS, continuous improvement is a state of mind where the purpose is to always try to be better and challenging existing standards, paradigms, and blocking points. It is required at all levels of the organisation, where the human capital should be empowered and encouraged to be curious, perseverant, and motivated to create and make a difference. The concept of continuous improvement is to never be satisfied and always strive for improvement, even if the current state does not possess any apparent issues. Another term for continuous improvement is the Japanese word “Kaizen”.

Always profitable

Within VCMS, “Always profitable” reflects the outcome of consistently applying all described elements of VCMS to create a sustainable organisation and processes. Profitability is achieved through high performance in quality, safety, and delivery, supported by an integrated system that continuously builds competence. This approach links operational excellence with human development, recognising people and their capabilities as key-drivers of long-term, sustainable profitability.

Human development

Human development in VCMS is viewed as a direct outcome of systematically addressing business needs and performance gaps. By applying the right principles and methods, employee capability continuously increases alongside business performance. This creates a positive and connected cycle where business objectives are achieved with human development as a result. Volvo Cars therefore put high focus on continuous on-the-job development.

2.5 Organisation at Volvo Cars

As stated in the limitations, the scope of this thesis is limited to the lower organisational levels in Volvo Cars manufacturing operations. This includes the operators (1st level), team

leaders (2nd level), and supervisors (3rd level). This section outlines each of these actors' roles and responsibilities. Most of the listed responsibilities are from general guidelines in BMS applicable across Volvo Cars manufacturing sites globally. However, on top of that, certain responsibilities not listed in BMS have been observed in a selected number of production lines at VCT and therefore added to these role descriptions.

Operator

The operator is the employee responsible for building the cars. They have the authority to carry out tasks according to defined responsibilities in terms of predefined processes, procedures, systems, tools, and templates, as well as escalating issues to team leaders and supervisors. Their responsibilities are to carry out standardised work, execute Andon utilisation, propose and apply problem solving and improvements, perform decided maintenance tasks and repairs, execute safety ownership, contribute to team development, and generally act according to VCMS and other Volvo Cars guidelines. According to company guidelines, the operators are the employees that deliver the most value to the customer and everything in the manufacturing process and environment should be optimised to make their job as simple and efficient as possible.

Team leader

The purpose of a team leader is to support and coordinate a production team to deliver products and services on time according to the described standards of Volvo Cars. A production team within Volvo Cars manufacturing operations is a group of operators and a team leader responsible for the execution of operations for a specific number of workstations at one production line. There are typically four to five teams per production line, however, it can differ between lines.

A team leader has the authority to coach and divide tasks within the own team, as well as escalating unsolvable issues to support functions or supervisor. The responsibilities of a team leader are to be the first responder to Andon calls made by operators within their own team, training and coaching of team members, support team members over cycle- and repairing concerns, support team process improvement activities and standardised work, as well as support the development of the team and support the strategic framework. They are also participating and responsible for the documentation in RTM meetings, as well as responsible for reporting deviations and reporting errors back to their operators.

Supervisor

A supervisor manages a group or team of operational contributors within manufacturing, i.e. is responsible for one production line and the teams that are included. The supervisor directly supervises and coordinates the activities of production and operating workers. The supervisor acts according to functional descriptions, established models, and specific directions and guidelines communicated by the local manager.

A supervisor has several different responsibilities. They are responsible for the deliveries, improvements, and coaching of their production teams towards decided priorities. They are the first responder to their teams, the leader responsible for executing RTM for their production line and should always act immediately on deviations. They should continuously drive improvements to optimise performance of safety, quality, delivery, and environment, as well as operating according to compliance standards, terms, and instructions. Furthermore, they are responsible for people management in their area and should train and coach their team members daily, as well as breaking down tasks and give assignments to increase team members skill levels. Additionally, the supervisor is responsible for absence reporting and personnel scheduling for their team members. They are also responsible for representing their production line at meetings with higher managers in the factory, such as other supervisors or superintendents.

2.6 AI in manufacturing

Artificial Intelligence (AI) is broadly defined as the science and engineering of making systems behave in ways that traditionally require human intelligence, such as reasoning, learning, and decision-making (Rakholia et al., 2024). In manufacturing, AI is significantly transforming conventional practices toward a paradigm shift in the entire lifecycle of production processes and management. This transformation is mainly driven by the capabilities of AI to process and analyse large datasets, adapt in real-time, and make intelligent decisions, resulting in significant influential changes. By integrating AI into manufacturing environments, manufacturers may streamline their operations, increase their product quality, and improve their output while simultaneously cut expenses. The transformation toward smart factories with the introduction of Industry 4.0 is accelerated by the integration of AI where AI algorithms combined with networked systems and IoT devices enables highly automated and intelligent manufacturing systems. However, with the

introduction of Industry 5.0, other extensions of AI technologies and algorithms are needed, playing a different role, supporting and collaborating better with humans.

AI plays a key role in achieving the objectives of Industry 5.0 by working as a controlling, monitoring, and optimising supporting tool for the entire manufacturing process (Nguyen & Tran, 2023). There are many different types of AI; from simpler types such as Machine Learning (ML), where computers are taught to recognise patterns, to the latest advanced generative AI capable of producing text, images, and videos (Mundlamuri et al., 2025). A recently developed technology is Augmented Intelligence which refers to an integration of AI and human intelligence (Nguyen & Tran, 2023). The purpose of Augmented Intelligence is to enhance human intelligence rather than replacing it. It means that AI should function as support in analysing extensive datasets, recognise patterns humans would miss, and provide recommendations or insights, but leave the final judgement to humans. This is a more human-centred intelligent system than traditional AI systems and is an appropriate solution that aligns well with the objectives of Industry 5.0.

Current manufacturing systems are characterised by high complexity and variability, with a need for efficiency, flexibility, and sustainability (Gao et al., 2024). Production systems are among the most complex man-made systems, consisting of large networks of machinery and human resources, technological and logistical processes, as well as material, information, and financial flows. Therefore, applications of AI in the designing and planning of these systems have become of high interest, utilising automated problem solving, learning, and reasoning. The use of AI in this matter primarily focuses on modelling the systems, and optimising design, scheduling, and operations in general.

Quality assurance and maintenance is one of the most notable areas where AI is revolutionising the industrial sector (Rakholia et al., 2024). AI can analyse large amounts of data, such as various sensors, images, and historical data to identify defects or deviations from the desired specifications, as well as recognising fault patterns and abnormalities. This enables manufacturers to identify and correct quality defects in real-time with reduced errors. AI-based predictive maintenance systems also benefit from this through detection of trends and abnormalities, allowing for proactive maintenance and reduced downtime.

AI is also leading to developments in robotics and the automation of production processes, resulting in opportunities for improved human-robot collaboration (Rakholia et al., 2024). As mentioned by Vlacic et al. (2024), there is a need for automated systems to become more

cooperative, with humans and AI technologies showing remarkable potential to enable such cooperation. Collaborative robots may be enhanced with the use of AI, working alongside human-operators to perform routine tasks with high accuracy and speed while at the same time make use of human-specific strengths (Rakholia et al., 2024). AI-powered automation makes the integration of industrial systems and components easier, enhancing workflow efficiency and overall productivity. Intelligent robotics has therefore shown to have a considerable impact on the manufacturing industry by increasing output, streamline operations, and enriching the human-robot interaction.

Even though AI has experienced remarkable growth and influential changes across the manufacturing industry in recent years, there are several challenges that need to be addressed and future directions to be explored for it to reach its full potential. AI algorithms heavily depend on extensive datasets to make accurate decisions and predictions, and obtaining relevant data from various sources and ensuring its quality can pose a significant challenge (Nguyen & Tran, 2023). Establishment of robust data collection processes, integration of data from disparate systems, and assurance of data accuracy must all be improved in the future to aid in the AI rollout.

In manufacturing environments, a complex coordination of interconnected systems is apparent (Nguyen & Tran, 2023). Seamless integration and interoperability between these systems and AI systems are vital for optimising manufacturing operations with use of AI. Standardised interfaces that facilitate smooth interoperability and data exchange between systems should also be the focus of future development work

Another challenge with the integration of AI in manufacturing, also previously seen with digitalisation and automation, is the concerns among employees regarding job displacement and workforce restructuring (Nguyen & Tran, 2023). To address this, it is essential to prioritise investments in reskilling and upskilling the existing workforce, enabling them to effectively collaborate with AI systems. Implementation of development programs that concentrate on acquiring skills that complement AI technologies should be of emphasis in future directions. Future research should also put emphasis on development of AI models that offer transparent explanations, fostering trust and acceptance among users and stakeholders.

Digital manufacturing systems are vulnerable to a large variety of threats, and cybersecurity is already of high importance (Nguyen & Tran, 2023). However, the implementation of AI amplifies this need even further. Therefore, securing sensitive data and intellectual properties

are of utmost importance when integrating AI into manufacturing operations. Future work should prioritise implementation of robust cybersecurity measures, encryption techniques, and ongoing monitoring to detect and prevent potential attacks. With the growing adaptation of AI in manufacturing, it is also essential to establish regulatory frameworks and ethical guidelines to address critical concerns like data privacy, liability, and algorithmic bias.

3. Methodology

The study was conducted using a multitude of different methods, combining a literature review, case-study observations, and interviews to gain a comprehensive understanding of the current state and future development potential, both externally and within the company. The study implemented an inductive research approach based exclusively on qualitative data; this is preferred in a study needing to be flexible in continuously adapting to new findings (Bell et al., 2022).

The study can be split into two distinct phases, and a visualisation of the research design can be seen in Figure 2. The initial half consisted of literature review and observations of the current state at Volvo Cars. The results from these two methods of data collection were subsequently analysed with key principals, inhibiting factors and areas of improvement being identified. Based on these, five rough-cut improvement suggestions were proposed. These five improvement suggestions were later presented to representatives of Volvo Cars at a mid-way presentation. Based on their feedback, four suggestions were selected for continued development, with one being abandoned.

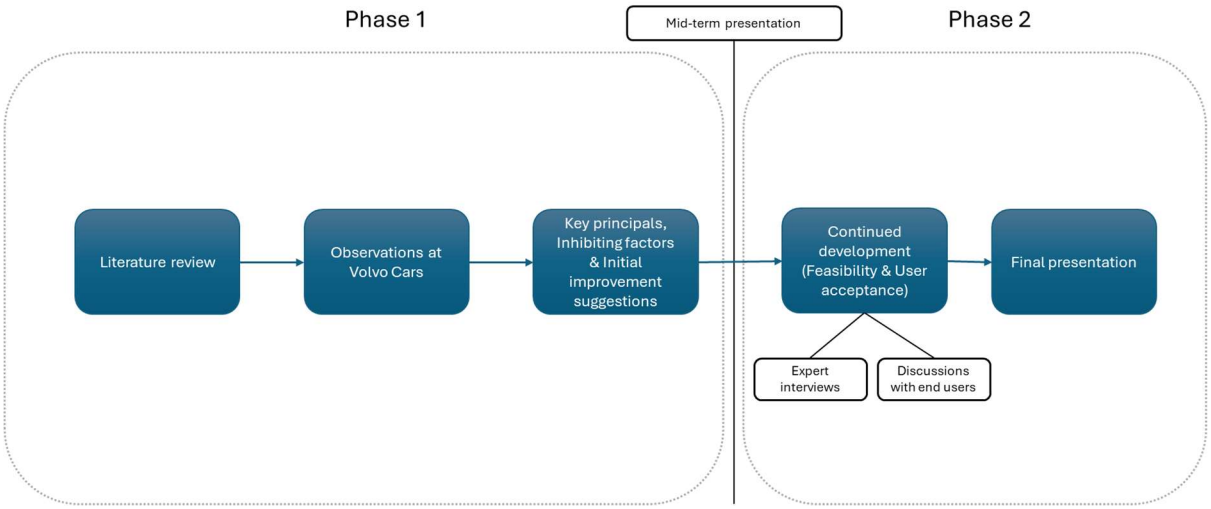


Figure 2: Research design visualisation

In the second phase of the study, interviews with in-company experts were used to investigate the current in-house technical knowledge and financial viability relating to each improvement suggestion, as well as to assess the current state of similar solutions within the company. Broader discussions about the respective improvement areas were also included in these

interviews. User acceptance was verified by discussions with potential end users of the proposed improvements, including operators, team leaders, and supervisors.

This two-phased research design enabled a more efficient use of resources, allowing improvement suggestions that experts at Volvo Cars deemed to have little or no potential to be eliminated at an early stage. More time and energy could then be spent on developing the remaining, more promising solutions.

3.1 Literature review

A structured literature review was conducted as the primary mean of gaining an informed understanding of the current state and future trends in automotive manufacturing, of Industry 5.0, and the forces shaping the wider automotive industry. The findings from the literature review were synthesised into a list of guiding principles that were subsequently used to analyse the current state of Volvo Cars manufacturing management and VCMS, and aid in developing improvement suggestions. Due to the wide scope and undefined inclusion criteria, this review can best be described as a narrative literature review, a type of literature review suitable for qualitative and inductive studies (Bell et al., 2022).

For the literature review, both peer-reviewed scientific papers, and corporate consultancy reports were used as source material. This choice was made deliberately to form a more complete picture, through the combination of academic theory and real-world experience. Scientific papers were found through relevant databases such as Chalmers Library, Google Scholar, and Scopus. Corporate- and consultancy reports were found through the respective company's websites and selected industry journals. Initially, a small selection of keywords was used as search terms to find both scientific and corporate papers. As a subsequent step, terms and concepts of interest found in the reviewed literature was in-turn used as search words to find literature further explaining these terms and concepts. In this way, a cascading and iterative selection of relevant literature was performed. Search terms used at some point during the literature review include: *Manufacturing system, Production system, Manufacturing management, Industry 5.0, Industry 4.0, Human-centric, Lean, Automotive industry*.

3.2 Observations

On-site observations of daily operations were conducted at Volvo Cars' Torslanda final assembly shop (TC) in Gothenburg, Sweden. This was a crucial step in the research process for two reasons; to gain familiarity of the manufacturing system in question, and to establish a current state from which to identify inhibiting factors and improvement areas. This observational phase of the study resembled a case study of the representative case, as defined by Bell et al. (2022).

The first step of these observations was a walking tour of the final assembly shop to gain a better understanding of the wider factory ecosystem. This was followed by a day of observing and interacting with the operators, so called participant observations (Sirris et al. 2022). This day was spent stationary at a single workstation to learn the fine details of daily manufacturing operations, including seeing from an operator's perspective how they interact with management systems and senior employees, such as team leaders and supervisors. Operators rotate tasks frequently at TC; therefore, the opportunity was given to interact with around 10-15 different operators despite being stationary at one workstation. Seeing the management activities from the perspective of the operators was valuable to get a feel for how these practices and systems fit into the daily work and the hectic environment on the production line.

During the observation phase, time was also spent shadowing team leaders and supervisors. Shadowing is a qualitative research methodology in which the researcher spends time with the subject, with minimal intrusion, to learn about their behaviours and habits (Sirris et al., 2022). While shadowing it is important to mitigate the so-called Hawthorne effect of people changing their behaviour simply because they know they are being observed (Oswald et al., 2014). There are multiple different strategies that can be employed as an observer to be perceived as less threatening and imposing, thereby making the subject more comfortable in acting normally. Some of these strategies that were employed during this study include being approachable and light-hearted, not recording the subject, being discrete during notetaking, and asking questions to the subject to understand their thoughts and ideas relevant to the situation (Bell et al., 2022; Oswald et al., 2014). Furthermore, another major factor in this study aiding in not making the subjects feel uncomfortable during observation is the fact that the observers where university students, and therefore from an external organisation without any direct power or influence over the company or the individual subjects. All factors

considered, there was therefore only reason to suspect a minimal amount of behavioural change from the observed subjects in this study.

Furthermore, to confirm information and gain a deeper understanding of the company and its operations, the field notes from the observations were cross-checked with documentation and guidelines available in BMS. This system carries an extensive amount of proprietary information and are only accessible to Volvo Cars employees. BMS holds standardised work instructions and role descriptions for both operators, team leaders, and supervisors, as well as standardised instructions for many important management practices used throughout the company.

3.3 Interviews

To further develop each improvement suggestion, interviews were conducted with Volvo Cars employees possessing relevant knowledge of the systems, technologies or practices involved in each suggestion. These interviews were semi-structured in nature, the preferred approach according to Bell et al. (2022) in situations where it is advantageous to allow the interviewee to freely express their thoughts, opinions and ideas while still being able to guide the conversation in certain desirable directions. Therefore, a small list of questions was written before each interview to help initiate and guide the conversations, but the interviewees were then allowed to elaborate freely on topics of interest. Interviews were conducted both online and in-person, with a majority of interviews being held in-person with individuals working at VCT. Interviews with employees based at foreign Volvo Cars sites were held online. Due to confidential information might being discussed during the interviews, no audio or video recordings were made. Instead, notes were taken during interviews which were destroyed after the conclusion of the study.

Initially, suitable interviewees were found primarily through referrals from the thesis supervisors at Volvo Cars, whose experience and large networks were crucial in finding the right individuals to contact. Implementing this kind of direct, purposive sampling allowed for all interviews to provide relevant information to the study. At the conclusion of each interview, interviewees were also asked to refer other colleagues with relevant knowledge for additional interviews. This method is called snow-ball sampling and is an effective tool to quickly identify a larger number of relevant interview subjects (Bell et al., 2022). A list of all

interviews conducted, including a description of their role/position within the company, can be seen in Table 2.

Table 2: List of interviews

Interviewee shorthand:	Role description/Employment Area:
Respondent 1	ATACQ-system Support office
Respondent 2	Power BI Developer
Respondent 3	DevOps Manager
Respondent 4	Production control
Respondent 5	Advanced Technology & Innovation
Respondent 6	Data engagement & AI
Respondent 7	Domain architect - Quality
Respondent 8	Team leader TA
Respondent 9	Supervisor TC

3.4 Data analysis

The data from both the literature review and observations were analysed by means of thematic analysis. A thematic analysis is one of the preferred ways of dealing with qualitative data originating from various types of different sources (Bell et al., 2022). Throughout the literature review, each piece of literature was analysed and grouped into common themes by searching for repetitions, similarities, and differences between the different pieces, as recommended by Ryan & Bernard (2003). After each new article was read, it was discussed and, if deemed relevant to the thesis scope, integrated into the existing body of analysed literature, further refining the themes. These overarching themes were later given appropriate names and presented as the key principles for developing more human-centric management practices (see Section 4.1). A similar process was undertaken after the on-site observations; this time with the field notes being thematically analysed instead of the theoretical literature. Thoughts and concerns recurring repeatedly during the observations were synthesised into the list of inhibiting factors (see Section 4.2). Finally, by combining the insights and ideas gained from both the literature and the observations, the initial improvement suggestions were created.

The data from the interviews, however, could not be analysed using a thematic analysis framework. Since each interview was unique, held with interviewees of different

organisational roles and each focusing on different subjects, there would also be very little value in comparing all the interviews looking for similarities and differences. Although some interviews provided insightful information for multiple improvement suggestions, only between 2-5 interviews were ultimately deemed relevant for each improvement suggestion. Instead of comparing the interviews between each other, the interviews were used to build on the previously collected knowledge from the literature review and observations, gaining deeper understanding of the proposed improvement suggestions and the current state of the underlying technology, organisation, standards, etc. at Volvo Cars relevant to each suggestion (see Section 4.3 with subsections). The interview notes were analysed iteratively after each interview and the relevant information was assigned to the corresponding improvement suggestion, where it was used to build a more detailed understanding of the feasibility of each suggestion. Information not deemed relevant for further developing any improvement suggestion were discarded.

3.5 Research ethics

As according to Chalmers 2026 GDPR guidelines, a plan for collection and handling of personal data throughout the study was made before conduction observations and interviews. The types of personal data collected has been kept to a minimum and was limited to name and title/role. Great care has been taken to anonymise all answers and observations, and no names of participants are featured in the report. Certain official titles have been modified when deemed to have been too unique to the individual to maintain anonymity. This is crucial to ensure privacy and avoid causing harm to individuals, which might occur if managers can track certain “undesirable” answers to individual employees (Bell et al., 2022). Every interviewee in the study has been informed of our intended use of their answers and given their consent to participate anonymously in the study. At the end of the study, all field notes from observations, interview answers, and any other personal data were deleted or physically destroyed to ensure continued anonymity after the conclusion of the study.

4. Results

Initially, based on literature review, the key principles to follow when developing Industry 5.0 and human-centric management practices in a future automotive manufacturing environment have been defined. Subsequently, based on these key principles and the conducted current state observations, factors that are currently inhibiting the development of more human-centric management practices at Volvo Cars are identified. Finally, four improvement suggestions to help counteract these inhibiting factors are presented. These improvement suggestions have been selected to be relatively simple to implement within a five-year timespan and are therefore ideas that have previously been designed, tested, or used on a smaller scale at the company. This section therefore also aims to motivate why Industry 5.0 has made it important to once again try getting these previously tested ideas into large-scale use. The improvement suggestions proposed in this thesis are in no way expected to completely resolve an inhibiting factor but should be regarded as a starting point on a larger transformative journey and must be backed up by future continuous efforts to resolve the causes behind each inhibiting factor. A summarisation of results can be seen in Figure 3.

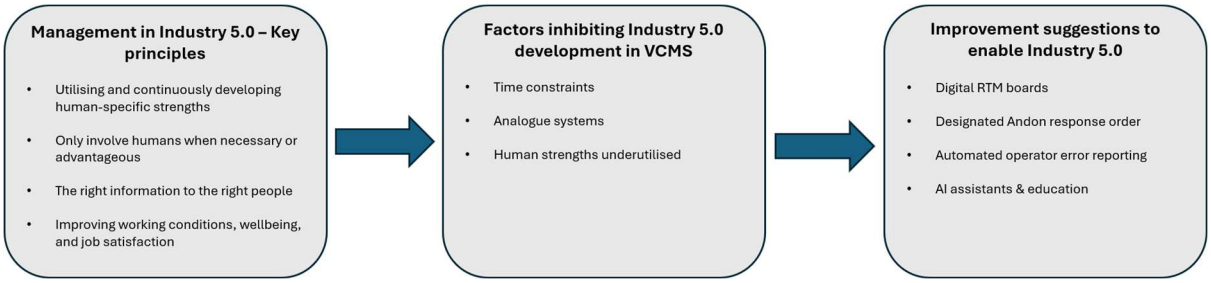


Figure 3: Summary of results

4.1 Management in Industry 5.0 – Key principles

To form an understanding for how to develop VCMS in a more human-centric direction and make Volvo Cars management practices more Industry 5.0 compliant, key principles to adhere to during such development needed to be formulated. Based on literature review findings about the future of the automotive industry and automotive manufacturing, Industry 5.0 and human-centric technology, the following key principles that must be considered in any future developments of VCMS have been identified:

Utilising and continuously developing human-specific strengths

As Industry 5.0s core paradigm is human-centricity, it only makes sense that one of the most important key principles would be regarding the cultivation of human talent. Humans will increasingly be put in focus when it comes to production engineering, and equipping your employees with the right knowledge and skills will become even more important the further this development is continued (Alves et al., 2023). It will, however, not be sufficient to count on humans being able to perform acceptably without developing their knowledge and skills. Thorough and efficient training of employees must be undertaken to give them new and improved capabilities in an evolving world. The accelerating rate of innovation and technological advancement of both automotive products and manufacturing technologies further highlights the need to continuously invest in competence development of factory employees to retain a competitive advantage and make the most of these new innovations by complementing them with human intelligence (Ionescu, An & Ionescu, Al, 2025).

It will also be important to invest in the correct training, focusing on the right areas. Continuously developing skills that are needed to perform the required operations on the production line will naturally remain important to improve efficiency throughout the manufacturing process. However, Industry 5.0 stresses the importance of focusing more training and knowledge development on other areas, areas where humans and their specific skills can make a larger difference (Piccarozzi et al., 2024). While robots theoretically could assemble a car just like a human operator, they cannot think creatively and participate in solving problems. If employing human operators is to make sense on a future production line, these human-specific skills must be highlighted, utilised and nurtured to a higher degree than what has been the case under Industry 4.0.

Only involve humans when necessary or advantageous

Crucial to human-centric manufacturing will be knowing when to utilise humans and when to automate. This becomes a question of alternative costs; humans should be employed to do only what humans can do better than machines, and vice versa. As automation technology is constantly evolving, the range of capabilities where humans are superior is also shrinking continuously. However, Automation in Industry 5.0 needs to become more human-centric with automation systems effectively collaborating with humans (Vlacic et al., 2024). Unlike in Industry 4.0, where automation systems respond to commands that are sent in a passive

and noninteractive manner, automation in Industry 5.0 aims to function as an actively interactive process between human operators and automated systems. At the same time, while Industry 5.0 promotes humans as the central element of manufacturing operations, it is still vital that automation frees humans from physical and mentally burdensome work. Repetitive tasks should still be done autonomously, but function in a more cooperative manner. The wisdoms of humans such as creative and logistic thinking should be integrated with automated systems and is something that Vlacic et al. (2024) mentions are lacking with current automated systems. Current technologies for actively and precisely integrating human workers with automated systems are still under development. Vlacic et al. (2024) argues that human-centric technologies, particularly AI, are something that have empowered this transformation toward more human-integrated automation systems.

While increased digitalisation and automation bring many great benefits for manufacturing firms, there are still challenges with using such technologies. One of the most apparent challenges include cybersecurity, which faces vulnerability in large systems such as production systems (Buri & Kiss, 2025). As more devices are connected to a network, which is the case with increased digitalisation and automation in production systems, the more vulnerable the system becomes. It is therefore crucial for companies to build and continuously improve appropriate protection systems. Another challenge with increased digitalisation and automation in production environments is the impact and transformation of the labour market and the nature of human work. As new types of technologies enter industrial operations, the nature of human work changes with increasing concerns for adapting existing workforce to new technologies and upskilling them to possess necessary digital skills to utilise these technologies.

For now, however, humans have the upper hand when it comes to creativity, useful for problem-solving, continuous improvement, and other crucial work in an Industry 5.0 manufacturing environment. Also, while robots can lift heavier and move with higher precision, humans have a finer sense of touch and are more flexible to perform varying tasks on the production line. Utilising the strengths of both to enhance the other is the hallmark of Industry 5.0, compared to earlier doctrines where humans where diminished in favour of machines.

The right information to the right people

While information continues to be one of the most valuable assets of any company, Industry 5.0 puts increased emphasises on the need of controlling the flow of information, that the information should be distributed only to the person needing it (Alves et al., 2023). Humans, unlike computers, can only process a limited amount of information before being overwhelmed. Meanwhile, the increase of digitalisation, data collection and available information within manufacturing environments has led human employees to become bombarded with information and data from all types of manufacturing processes, control systems and other human beings. A key principle in developing a more human-centric management system is therefore to design both practices and information systems that minimise the amount of unnecessary information reaching each employee. The right information needs to find the right person, at the right time, and in the right format, but it is equally important that it only reaches the right person. Cluttered inboxes and management screens full of unnecessary information are not human-centric. Less information overload will enable workers to make faster and more accurate decisions while reducing stress, cognitive overload, and unnecessary interruptions. And as the volume of information increases, so does the importance of guiding the information to the correct receiver.

Key to effective information guidance is widespread digitalisation, especially of communication channels and human-machine/system interfaces. Digitalisation in industrial operations can be referred to as the connection of physical and organisational elements of industrial processes and services with digital platforms (Buri & Kiss, 2025). It is one of the key pillars of Industry 4.0 with its primary focus to enhance efficiency and productivity of production operations through the deeper integration of digital technologies. One of the key objectives of Industry 4.0 is to connect previously disparate technological and organisational processes through various digital solutions, accelerating decision-making and reducing the number of errors. Through digitalisation, companies are increasingly relying on data to make decisions, relying more on automation in production, and putting a high focus on utilising intelligent technologies and algorithms in their processes. One of the key elements of digitalisation in the industrial sector is the design and deployment of smart factories, where production tools can communicate with each other and optimise production processes autonomously, enabling rapid decision-making through collection of data from sensors and other embedded systems.

As the shift from Industry 4.0 toward Industry 5.0 is transforming the industrial environment, it is likewise redefining the role and application of digitalisation in manufacturing (Buri & Kiss, 2025). As the concept of Industry 5.0 aims to integrate human capabilities and sustainability considerations into industrial systems, it goes beyond just simple automation and digitalisation. While Industry 4.0 focuses on the development and usage of intelligent systems and machines, Industry 5.0 emphasises the importance of human-machine collaboration and putting back technology in the hands of humans. Rather than completely replacing human work, digitalisation should be used as a complementing tool, supporting humans in their work. The power of this principle becomes clear when applied to information guidance.

Improving working conditions, wellbeing, and job satisfaction

As humans become increasingly important in Industry 5.0, making sure that employees have safe and pleasant working conditions are becoming more of a priority for manufacturing companies. While each of the previously mentioned key principles will aid in improving working conditions, wellbeing and job satisfaction, there are many other factors that influence these crucial factors, most notably organisational questions. Already with the implementation of Industry 4.0, a shift in industrial organisation was seen through deployment of advanced technologies in industrial processes (Pham & Li, 2026). However, with the introduction of Industry 5.0, the organisation in industrial processes is further redefined, moving more into a socio-technical system that integrates advanced digital technologies with human-centric, sustainable, and resilient values.

Unlike in Industry 4.0, where organisations can be seen as maximising systems efficiency, organisations within Industry 5.0 focuses more on being platforms for co-creation between humans and machines, where human wellbeing, ethical considerations, and ecological responsibility are embedded into core industrial operations. The findings of Olsson et al. (2024) demonstrates that to re-interpret manufacturing management through the lens of Industry 5.0, firms and managers need to adapt a human-centric perspective by focusing on organisational prerequisites, such as holistic understanding, inclusive organisational change, leadership practices, learning, and innovation processes.

One organisational factor that Pham & Li (2026) argues is crucial for succeeding with the transition toward Industry 5.0 is for organisations to adopt a visionary leadership. Leadership

plays an important role in translating principles of Industry 5.0 into actionable strategies, and it demands a shift in mindset, moving from traditional focus on efficiency and productivity toward human wellbeing. Pham & Li (2026) describes visionary leaders as those who can guide their teams with foresight, align technological initiatives with societal values, and navigate complex transformations decisively and ethically. While distinct, visionary leadership shares important overlaps with transformational leadership, where leaders inspire, motivate, and empower employees to drive deep organisational changes and contribute strategically. The two leadership styles overlap in shaping strategic direction, enabling systematic change, and fostering innovation, three factors that are crucial when implementing Industry 5.0 practices.

The transition from Industry 4.0 to Industry 5.0 also involves cultural and structural organisational changes. While organisations within Industry 4.0 are typically characterised by hierarchical and efficiency-oriented structures, Pham & Li (2026) argues that it is foundational for organisations to adapt more dynamic, agile, and inclusive cultures to achieve the broader goals of Industry 5.0. Dynamic cultures foster experimentation, learning, and responsiveness, which is critical for effective adoption and integration of emerging technologies. Agile cultures promote responsiveness to uncertainty and continuous changes, encompassing shared values and practices to empower individuals and teams to adapt quickly, collaborate effectively, and embrace innovation. It fosters a mindset of continuous improvement and cross-functional teamwork that is especially important in organisations facing digital transformations. Inclusivity further strengthens adaptive capacity, as argued by D'souza & Tapas (2024) who mentions that inclusive practices enhance collaboration and organisational learning, moving towards a more human-centric transformation.

4.2 Current state of VCMS – Factors inhibiting Industry 5.0 development

Based on the observations at Volvo Cars manufacturing operations, a current state was established and analysed against the key principles from the previous Section 4.1. This yielded three main factors currently inhibiting VCMS development into Industry 5.0. These three factors will be outlined below, along with an explanation of the current state as it

regards to that factor and what general areas of improvement should be prioritised to counteract that inhibiting factor.

4.2.1 Time constraints

A typical working day for a team leader or supervisor at Volvo Cars is packed with various tasks and is spent in a hectic, high-paced production environment. Consequently, many team leaders and supervisors expressed a feeling of being limited by time constraints and stressed during an average working day. In a next-generation human-centric manufacturing environment, this needs to change. Not only can it lead to chronic stress and consequently prolonged sick leave, but in a human-centric manufacturing environment there needs to be an increased amount of time available for continuous employee training.

Each team has a good understanding of the skills of each employee, thanks to an employee skill matrix which is located at each team board, and a large company-wide portfolio of training programs and certifications that each operator could undertake. However, during observations, 75% of team leaders expressed that there is simply no time, or a very limited amount of time to teach operators new skills or mentor them through certification processes. With Industry 5.0 putting a premium on continuously developing human skills (Mourtzis & Wang, 2024), more time needs to be made available for both operators, team leaders, and supervisors to allow for competence development. Time constraints among employees have therefore been identified as one of the current factors holding back VCMS from being able to develop from Industry 4.0 to the more human-centric Industry 5.0.

In daily operations, maintaining productivity and output from the team usually takes top priority, and for good reason. However, with a limited amount of time available during a working shift, other important parts of VCMS, not directly influencing todays output- or quality numbers, must often take the back seat. This most often affects the problem solving and continuous improvement efforts, which unfortunately also happens to be the areas of VCMS where human-specific skills such as creativity are the most needed, a key part in Industry 5.0 according to Piccarozzi et al. (2024). While all improvement suggestions in this thesis will free more time for team leaders and supervisors in their daily work, Improvement suggestion 2 – Designated Andon response order (see Section 4.3.2) specifically targets making more time, and creating a calmer, more focused environment for tasks requiring deep thinking and human creativity.

4.2.2 Analogue systems

A considerable amount of analogue management and information sharing tools were observed in the factory. Examples include working instructions such as Operator Instruction Sheet (OIS) and Work Element Sheet (WES) documents only being available in printed form at each workstation, personalised physical stamps being used to sign of documents and whiteboards being used to display and analyse critical KPIs. Although efforts are underway to reduce the amount of paper consumed during manufacturing through the Paperless Factory initiative, around 2,5 kilograms of paper are still needed to produce a single car according to Respondent 3.

Whiteboards are used in permanent applications; as RTM-boards to track process data and support the RTM activities, as team boards to help team leaders in organising and displaying important information to his or her team, or as supervisor boards giving supervisors an overview of his or her organisation and help in planning long-term project. Whiteboards are also used in temporary applications, such as during continuous improvement and problem-solving projects.

From an Industry 5.0 perspective, whiteboards and other types of analogue information sharing systems and practices have a significant drawback in that it doesn't allow for automatic information guidance (Tsai et al., 2026). Digitalising as many information interfaces as possible, preferably all, between humans is a prerequisite to be able to automatically guide the right information to the right recipients. Some information guidance can still be done with analogue-based systems and practices, but firstly; it requires a human to address each piece of information manually, and secondly; such an analogue system can only handle a limited amount of information before it gets overloaded. It is therefore clear that digitalising these crucial information sharing points must be a priority to be able to take VCMS and its management practices into the Industry 5.0 regime.

Another telling example of how little Volvo Cars TC management practices depends on advanced technology and digitalisation was observed during interaction with two team leaders. Both of their company-issued smartphones had been sent to be repaired, yet they were able to continue normal operations with Microsoft Teams running on their private phones. This visualises a large potential for implementing more digital tools in personal hand-held devices.

It should be pointed out the digitalising already has been a central part of previous industrial revolutions, both Industry 3.0 and Industry 4.0 (Yanytska, 2025). Volvo Cars have taken these regimes to heart and are far along when it comes to digitalisation. They have plentiful data being collected about most important aspects of their manufacturing operations, and there are systems in place behind the scenes to receive, store, and process this information. However, as Industry 5.0 is about improving the interchange and interaction between humans and machines, using analogue technology to display and analyse crucial process information on a daily, or even, hourly basis is not ideal, and represents a gap that Volvo Cars must fill on their digitalisation journey.

Closer observation further reveals that most of the information displayed using analogue means is already available in various databases and digital systems. Meaning that using analogue technology is not only suboptimal in a human-machine interface perspective, limiting information guidance and sharing speed; but is also an unnecessary extra administrative step in daily operations for team leaders and supervisors. These employees must currently retrieve all necessary information from their computers and transfers it to analogue mediums (writing on whiteboards, printing papers to hang on an information board, etc.). This is a highly inefficient use of both employee time and skills, and not consistent with Industry 5.0s human-centric principles of only involving humans when necessary, as stated in Section 4.1.

While a sweeping digitalisation of all currently analogue documentation and information boards in the factory would be advisable to achieve Industry 5.0 standards, the on-site observations have revealed that digitalising the RTM-boards should be the initial priority. These boards must be updated on a more frequent basis than other boards, currently every 2-3 hours compared to once per shift for the team board; meaning a digitalisation of the RTM-boards would save considerably more manhours in administrative work than digitalising any other information board would. Additionally, the digitalisation of the team boards or information boards used for problem solving requires additional features and investments. Such boards must enable direct and intuitive human interaction and thereby requires features like touchscreens and interactive user interfaces to realise the intended benefits of a digitalisation. If these features are absent, the advantages relative to the current analogue systems would be minimal since updating the boards would require a separate input channel, such as a laptop or workstation PC, as Respondent 2 explained. Since the primary purpose of the RTM process is the monitoring and analysis of performance data, such boards only

require limited interactive functionalities to still benefit from digitalisation, underscoring the reasons for prioritising the digitalisation of RTM-boards over other currently analogue information boards in the factory. In Section 4.3.1, a more detailed proposal for digitalising RTM-boards has been developed.

4.2.3 Human strengths underutilised

As one of the key principles for developing VCMS into an Industry 5.0 regime was to utilise humans only when necessary, during observations a close eye was kept on how and where humans were utilised in the management process, and in which steps team leaders and supervisors were assisted by various automation solutions. After having done only brief observations it was clear that the lower managers need to perform numerous repetitive, and relatively simple, tasks in their daily work at TC. As seen in the key principles (Section 4.1), repetitive tasks not requiring human creativity are the types of tasks that should be automated in a human-centric Industry 5.0 environment (Piccarozzi et al., 2024). Most of these tasks observed to currently being performed in TC are administrative, including manually filling in whiteboards, etc. as previously discussed. Other tasks are operational, such as finding error codes, or in supporting operators, such as in error reporting. Unlike admin work, which could theoretically be completely automated, these are crucial tasks that must be performed but could be made more efficient by employing automation aids. This would free up time for humans, allowing them to focus on tasks which they can solve better than machines can.

Conversations with operators revealed that the work environment and culture of a specific line or team could have a big impact on how the operators act and how well they perform. While all lines should follow the same routines specifying a liberal use of Andon whenever needed, the culture on a specific line could be to minimise Andon usage. Multiple operators have testified to a working culture in which using Andon repeatedly could lead to “playful” taunting from coworkers or team leaders being displeased. As one operator puts it: “I was almost afraid of pulling Andon when I was a new operator”. This not only leads to an unpleasant working environment for operators but also holds back human creativity and problem-solving skills by not giving team leaders the proper opportunity to investigate and solve an issue. Continuously working to develop a positive working environment and workplace culture is crucial to both the long-term employee wellbeing and team efficiency (Leon et al., 2025). Along the same lines, Respondent 5 points to the importance of giving

praise instead of negative feedback to foster comradery and job satisfaction. Meanwhile, Respondent 4 highlights the fine balance between increased data collection and having operators feel monitored on the job. Despite the obvious benefits of collecting more data, it is crucial that employees feel free to act without constant supervision, particularly when asked to show their personality and relying on their own creativity.

While the Industry 5.0 literature highlights the need for giving employees more autonomy to act and make decisions (Piccarozzi et al., 2024), the highly standardised and high-paced manufacturing environment at Volvo Cars makes this difficult. Finding new ways to standardise creative processes, with the right balance between allowing flexibility and maintaining control, will be key to both empowering and improving working conditions for employees working on the factory floor.

4.3 Improvement suggestions to enable Industry 5.0

Based on the inhibiting factors from Section 4.2, four improvement suggestions have been developed to help make the management of Volvo Cars manufacturing operations more human-centric. All improvement suggestions are summarised in Table 3 by a summary of addressed inhibiting factors, expected advantages, feasibility, required capabilities, and implementation effort. Regarding the presentation structure for each proposal, all improvement suggestions are presented through an analysis and presentation of the current situation, analytical interpretations based on inhibiting factors from Section 4.2, description of future vision and design proposal, and an assessment of feasibility and required capabilities.

Table 3: Summary of improvement suggestions

Improvement suggestion	**Addressed inhibiting factors & expected advantages**	**Feasibility**	**Required capabilities & implementation effort**
Digital RTM boards	Addresses **Time constraints** and **Analogue systems** by automating information updates and removing manual administrative work Addresses **Underutilisation of human-specific strengths** by freeing up time for team leaders to engage in activities that leverages from human capabilities Increases reliability by reducing risk for human errors and the effect of absences Allows for real-time updates of information Allows for additional functions (AI analysis & prediction, merging of other boards)	Required sensors, data, and back-end systems for tracking information digitally already exist Concept builds on an already existing RTM structure, only requiring integration of data sources for information to be digitally displayed and automatically updated RTM is already done digitally at different locations in VCT – e.g. at higher organisational levels or in TA The digital RTM screen in TA has received positive feedback	Hardware investment in terms of digital visualisation screens Software development and integration of already existing production and data systems Rough time estimation of developing a similar digital RTM board as the one in TA for TC: 4-6 weeks (initial development of one board) Approximately 1 day per board (for replications)
Designated Andon responder order	Addresses **Time constraints** and **Underutilisation of human-specific strengths** by allowing team leaders later in the order to have more time and better focus on activities that leverages from human capabilities	Similar ways of working observed on certain production lines in TC indicates utility, although further research/testing is required Most team leaders know all operations on the production line and rules are already in place for tracking responsibility when team leaders respond to Andon calls outside their own team Realistically only applicable to production lines where number of Andon calls are relatively	The production line needs to have a relatively low number of Andon calls Physical layout of the line needs to allow for quick Andon response times by fewer responding team leaders Organisational changes to existing Andon responding procedures – requiring clear instructions, training, and alignment between all involved workers

		low and physical layout of the line allows for quick response times by fewer responding team leaders	
Automated operator error reporting	Addresses **Time constraints** and **Analogue systems** by digitalising the process of collecting operator signatures for errors, reducing the administrative burden and time for team leaders Addresses **Underutilisation of human-specific strengths** by freeing up time for team leaders to engage in activities that leverages from human capabilities Potential reduction of compliance errors by allowing for automatic reminding of missing signatures Allows for additional digital training features: Digital OIS & WES, Self-assessment and/or additional training automatically triggered for repeated errors	Required hardware in the form of digital tablets already exists at approximately 50% of workstations in VCT Data and back-end systems exist, currently one-way communication from digital tablet to QMS Technically feasible to add additional functions to the electronic rotation card application on the digital tablets	Integration between operator interfaces and QMS to be a two-way communication The software development effort required for implementation is estimated to be 1-2 weeks of programming Redesign of the process for collecting operator error signatures Training and instructing operators and team leaders to adapt to the new procedure
AI assistants & education	Addresses **Time constraints** by supporting administrative work, saving time for workers Addresses **Underutilisation of human-specific strengths** by allowing workers to spend more time on tasks that demands human cognitive skills The reduced administrative burden could be expected to improve working conditions	Approximately 80% of AI in Volvo Cars manufacturing is applied within maintenance & quality due to economies of scale. Administration is another large-scale area that could see similar benefits from economies of scale. AI tools are already in widespread adoption at Volvo Cars, in the form of Microsoft Copilot. In terms of cybersecurity, Volvo Cars uses a secure enterprise version of Microsoft Copilot, allowing almost all information to be shared with the AI.	Education and training on AI capabilities and usage: Educating employees on how to use AI in their daily work Developing trust among the workforce and reducing fear of job losses/displacements Educating employees to identify AI implementation opportunities by themselves

4.3.1 Improvement suggestion 1 – Digital RTM-boards

In this section, a proposition for an improvement suggestion regarding the RTM process is presented, more precisely a digitalisation of the RTM boards. It is presented through a current situation description and analysis, future vision presentation, and feasibility assessment.

Current situation

The current situation of the RTM process was established through observations in VCT, internal documents (BMS), and interviews with employees of Volvo Cars. The empirical findings were later analysed with the identified inhibiting factors of Section 4.2 in mind.

Empirical findings

Volvo Cars currently work with RTM practices within its production lines to track operational performance and ensure production stability according to Volvo Cars BMS. KPIs such as Andon utilisation, quality defects, and other operational performance metrics are monitored and documented regularly by team leaders with the objective of identifying production issues and enabling timely corrective actions. According to BMS, the purpose of RTM in Volvo Cars is to support continuous control over production performance and to ensure that quality standards and delivery targets are meet.

Observations and interviews confirm that the RTM process involves periodic meetings in which team leaders responsible for different sections of the production line and the supervisor for the production line participate. Observations and interviews further reveal that RTM meetings occur frequently throughout the shift, often every 2-3 hours. During these meetings, team leaders collect data and record performance metrics related to their respective production area. Examples of such metrics are number of Andon activations, the duration of production line stoppages caused by errors, and quality issues. The current procedure of collecting and recording KPIs has been observed to be as follow:

1. Team leaders collects data from their workstation PCs on the desired performance metrics from the central Quality Management System (QMS) called ATACQ and writes them down on a physical paper, handheld device or simply remembers them.

2. These metrics are then manually recorded on a physical RTM board, more precisely a whiteboard, located next to the production line.

Observations show that, following the documentation of these metrics, the team leaders and supervisor participating in the meeting reviews the data and discusses the operational performance of the production line in the preceding period. The discussions primarily focus on identifying problems, understanding causes, and determining corrective actions. If needed, issues may be escalated to problem solving methods.

Four main drawbacks with the current RTM process were identified through observations and interviews:

1. **Time waste.**
   Observations have revealed that manual data collection and documentation require time during RTM meetings. Observations and lean theory suggest that this activity does not directly contribute to value creation and is a waste (Sundar et al., 2014).
2. **Absence of team leaders.**
   It has been observed and revealed through interviews that team leaders are relatively often absent from RTM meetings due to them being needed elsewhere, for example Andon support. Respondent 9 stated that approximately 25-50% of team leaders are always absent from RTM meetings depending on the Andon situation. As noted by Respondent 9 and revealed through observations, absence of team leaders during RTM meetings lead to substitute reporting, which may reduce data accuracy and increase administrative workload for other team leaders.
3. **The human error.**
   Observations revealed occasional inaccuracies in recorded data, such as missing or incorrect values, which later required correction.
4. **Not actual real-time.**
   Performance data is only updated at RTM meeting intervals (every 2-3 hours), resulting in a time lag between events and managerial response. Through observations and an interview with Respondent 9, it has been revealed that this meeting frequency usually leads to more reactive management than proactive. This aligns with Putnik et al. (2014), who argues that one of the main advantages of RTM is that it allows the management to become more proactive, but only if the key information is monitored in real time.

Analytical interpretation and connection with inhibiting factors from Section 4.2

The identified limitations can be related to the identified inhibiting factors from Section 4.2. The manual handling of data represents non-value-added work, contributing to the identified inhibiting factor of *Time constraints.* Furthermore, the task does not leverage from human cognitive skills, indicating an *Underutilisation of human-specific strengths.* The reliance on an analogue process is interpreted as the reason for both inefficiencies and data limitations, relating to the identified inhibiting factor of *Analogue systems.*

Future Vision

To address the limitations associated with the manual operation of the RTM board, a digital RTM board is proposed. Instead of relying on manual collection of data, and documentation on a physical whiteboard for performance recording, a digital screen connected to existing software installed at the production line is imagined. The suggestion is expected to reduce the need for manual data collection in the RTM process, addressing all identified inhibiting factors from Section 4.2.

Design proposal

Observations reveal that KPIs included in RTM meetings such as Andon activations and production stoppage times are already recorded within digital systems (QMS) integrated with the production line and is the data source from which team leaders retrieve performance data for RTM meetings. The proposition of a digital RTM board is to integrate these existing data sources with a digital visualisation screen located next to the production line. The suggestion would remove the need for team leaders to manually collect and document performance data on a whiteboard, and allow for automatic updates in real-time, where performance is tracked more regularly than current situation of every 2-3 hours.

The proposition is not to fundamentally change the structure or purpose of the RTM process but increase its operational efficiency. The RTM meetings should continue to focus on monitoring and reviewing production performance. However, a digital RTM board would reduce time required by team leaders for non-value-added administrative work, responding to the inhibiting factor of *Time constraints*. The time saved could be utilised on activities that utilises human-specific strengths such as continuous improvement or problem solving, responding to the inhibiting factor of *Underutilisation of human-specific strengths*. Lastly,

the proposition responds to the inhibiting factor of *Analogue systems*. Digitalising an analogue process reduces the risks from manual data transfer errors, allows for real-time visibility enabling more proactive management, and increases RTM meeting efficiency by allowing for more time on analysing and reviewing performance data.

Extended capabilities

Based on interviews and literature about AI in manufacturing (Section 2.6), a digital RTM board could also provide opportunities for enhanced analytical capabilities. Advanced data-processing and analysing technologies such as AI could be integrated into the system to support with identification of worrying values, fault patterns, and negative performance trends that may not be visible for human observers (Gao et al., 2024). According to Gao et al. (2024), such capabilities could improve visualisation, support earlier fault detections, and reduce the time required for manual analyses during RTM meetings, indicating larger capabilities for proactive management than reactive. It has been revealed through observations and interviews that AI integration into manufacturing operations and processes of Volvo Cars is however limited. Respondent 5 and 6 argued that AI are discussed about a lot within the automotive industry in general and Volvo Cars in specific, but actual implementations and integrations are relatively limited. Maintenance and quality control have been stated as the manufacturing areas within Volvo Cars where AI is used and integrated most. The usage of AI in other manufacturing areas such as manufacturing performance analytics, is limited as revealed from observations and interviews. Respondent 6 stated that the most apparent issue with AI integration into other manufacturing areas is the education and training of workers to understand the capabilities of AI and how to use it effectively. This issue is further discussed within Section 4.3.4.

Other than providing enhanced analytical capabilities, observations and interviews indicates that a digital RTM board would provide opportunities for additional features and information to be displayed. The manufacturing operations of Volvo Cars have been observed to possess large amounts of data and information. A digital board can be interpreted as providing increased visualisation possibilities of more information, such as actor specific information and real-time sustainability. From Respondent 2, it has been revealed that an operating digital RTM board in Volvo Cars' Torslanda body shop (TA) possesses several other functionalities than just displaying performance data used in the RTM process. A further suggestion could also be to integrate multiple boards into one, having different modules or tabs for different

board functions. In this case, the RTM board, team board, and supervisor board could all be merged into a single digital screen. This solution would not only require the board to be touch-sensitive but also have an interactive, editable interface, as discussed in section 4.2. This bundled solution would however require less investments compared to digitalising all boards on their own, since only one piece of physical hardware would be required.

Feasibility assessment

Within this section, the feasibility of the proposed improvement suggestion is presented. Required capabilities, derived from observations are outlined. In addition, similar solutions already in possession of Volvo Cars are described, and lastly, the technical feasibility of implementing a similar solution already existing at VCT into TC is examined.

Required capabilities

Much of the required digital infrastructure has been observed to be already existing at Volvo Cars. Digital systems that capture performance data such as Andon activations, etc., are already operational. The primary requirements for implementing the proposed solution have been identified to be an integration of existing tracking systems with a digital visualisation interface. The required investments therefore consist of a digital screen and software integration to enable automatic data transfers between the already existing digital tracking systems and the digital screen. This would be the basis for basic functionality of automatic real-time display of performance metrics and once established, additional investments in AI-integrated systems could be implemented to further develop the RTM process.

Similar solutions at Volvo Cars

A similar solution of a digital RTM board has been observed to be already implemented in VCT, more precisely in the body shop TA. Through interviewing a team leader interacting with the board daily, the implementation has received positive feedback from its users. Respondent 8 expressed a positive attitude toward the specific implementation and digital screens in general, stating that it has provided team leaders and supervisors with a better overview of the manufacturing processes, while also providing more information and deeper insights. However, the respondent also expressed a preference for using whiteboards for performing tasks such as action planning, since they are possible to write on, a feature that has not yet been developed with the implemented digital RTM board. This aligns with Mathiasen & Clausen (2024) and their theories on task-technology fit, i.e. the need to

investigate which technology is the best toll for each task. Still, Respondent 8 finds the digital RTM board valuable overall as a complement for tracking performance data and accessing useful information from the manufacturing operations.

From observations, the software used for the digital RTM board in TA is the business intelligence and digital visualisation platform: Power BI, developed by Microsoft. Currently, as revealed through observations, Volvo Cars has a partnership with Microsoft, using their software systems in certain everyday operations.

Regarding the development time of the digital RTM board in TA, Respondent 2 revealed that the complete system required approximately two years of full-time work by a single developer. This timeframe however, included the development of all functionalities integrated within the system according to Respondent 2. The specific functionality associated with displaying performance data relevant to the current RTM process was estimated to have required approximately five weeks of development. Furthermore, Respondent 2 estimated that replicating the existing board within TA would require only 1-2 days. Regarding investment cost for the digital screen, the screen used in TA was estimated by Respondent 2 to cost 18 000 SEK.

Technical feasibility

Regarding the feasibility of implementing a similar solution to the digital RTM board in TA for TC, Respondent 2 stated that such an implementation would be technically feasible. However, the solution would need to be developed entirely from scratch due to different data sources being used in TA compared to TC. Regarding the anticipated timeframe for developing such a solution, Respondent 2 provided a preliminary estimation of 4-6 weeks of development. This estimate included 1-2 weeks for the development and programming of a so-called “buffer data” dataset, followed by 3-4 weeks of development and programming of the board layout.

The estimated development time was furthermore described as dependent on several factors, including the number of developers involved, their competences with utilised software, and their familiarity with the manufacturing processes within TC. It should also be noted that the estimated development time provided by Respondent 2 was based on the development of a board intended for production areas of similar sizes to the existing implementation in TA. The layouts of the production lines have been observed to differ between TA and TC, and the current digital RTM board in TA serves a production area constituting of approximately

seven different lines according to Respondent 2. Furthermore, Respondent 2 estimated that once an initial board had been established from scratch, replications of it to be used at more lines would only require approximately one working day of development per board.

4.3.2 Improvement suggestion 2 – Designated Andon response order

The following section presents an improvement suggestion regarding the current Andon responding process at Volvo Cars. The proposal is presented through a current situation description, future vision, and feasibility assessment.

Current situation

The current situation of the Andon response process is presented through empirical findings, consisting of observations, internal documents (BMS), and interviews, together with analytical interpretations based on identified inhibiting factors from Section 4.2.

Empirical findings

At Volvo Cars assembly operations, it has been observed that team leaders' primary responsibility is to provide support to operators after Andon calls. As a standard guideline in BMS, team leaders are the first responders to Andon calls within their own team, stating that every time an operator pulls the Andon chord, it should be the team leader responsible for each team that responds to their respective Andon calls. It has been observed that every time a team leader needs to respond to an Andon call, they need to abruptly pause whatever other work they are engaged in, such as continuous improvement and problem-solving of escalated deviations. Through conversations with team leaders, it has been revealed that by regularly needing to attend to Andon calls, it is harder to complete other creative tasks since focus is constantly broken.

When multiple Andon calls occur simultaneously on a production line, it has been observed that team leaders outside the regular team might need to step in and support operators whose regular team leader is unavailable. Observations reveal that all team leaders are allowed to help anywhere on the production line, and through discussions and interactions with team leaders in TC, it is revealed that most team leaders know all individual operations of their production line. According to Respondent 9, the team leader responding to the Andon call is

the one who takes responsibility for the car. According to Respondent 9, this is documented on papers located next to each workstation where affected operator documents serial number of affected car and responding team leader signs the paper to take on responsibility.

Analytical interpretation and connection with inhibiting factors from Section 4.2

The current approach to Andon response has been identified to reflect the inhibiting factor of *Underutilisation of human-specific strengths*, with team leaders not being able to fully engage with activities that leverages from human-specific strengths such as continuous improvement and problem-solving. The limited time that is available for team leaders to engage in such activities further reflect the inhibiting factor of *Time constraints*.

Future Vision

The suggested improvement is presented with a future vision, where design proposal, expected advantages, and disclaimers are outlined.

Design proposal

To address the identified issue of team leaders regularly being disturbed by Andon calls during other important work, implementing an Andon responder order list is proposed. The suggestion would see all team leaders on a specific line being "bundled together" to collectively serve the Andon response needs of one line, i.e. multiple teams. The Andon responder order list would indicate in which order these team leaders would respond to Andon calls. The first team leader on the list would always be the first one to respond to Andon calls, a "first responder" to the entire line. Only when two Andon calls are made simultaneously would the next team leader on the list need to pause their other work and step in to assist with Andon calls, and so on.

The responder order should be set and approved by the supervisor of the production line for each shift, in accordance with affected team leaders. It should be set and approved before or in the beginning of each shift, for example at the daily start-up meeting between supervisors and team leaders. The list should be located near the production line, easy to access and visible for all team members, for instance on the team board that is located next to each production line. The list could be displayed both on a current analogue team board or a

proposed future digital team board. A proposed design for how the responder order list could be visualised on a team board is presented in Figure 4. The numbers and texts to be written down by the supervisor is shown in italic within the figure.

Andon responder order – Pre-trim 3		
Date: *XX/XX/XXXX*		
Order:	Name:	Non-Andon focus:
#1	*Team leader name*	
#2	*Team leader name*	
#3	*Team leader name*	
#4	*Team leader name*	*XXX (e.g. root cause analysis)*
#5	*Team leader name*	*XXX (e.g. 1-1 with supervisor at 14:00)*

Figure 4: Design suggestion - Andon responder order list

Although fundamentally an organisational improvement not needing new technological investments, the suggestion could be complemented with new technology further improving the effectiveness and intuitiveness of this new way of working, in line with the theories of Fan et al. (2024) regarding new technologies improving Andon. For example, the Andon calls could be automatically directed to the specific team leader that should respond to a call by means of a personal electronic device (smartphone, smartwatch, etc.) or by personalising the Andon sound being played in the factory to each team leader. That way, the team leaders would more clearly know when it's their turn to respond to an Andon call and when they can disregard a call and keep on working with other tasks.

Expected advantages with proposal

The purpose of the suggestion is to provide team leaders with more time and increased focus on tasks that leverages from human-specific strengths, such as continuous improvement and problem-solving. Later responders are expected to be less required to respond to Andon calls compared to the current situation, freeing up time for team leaders to engage in other activities. The reduced time required for Andon support is also expected to enable team leaders positioned later in response order to devote greater attention to other activities. In summary, the objective is to shift from a model in which all team leaders engage to a limited

extent in tasks that rely on uniquely human capabilities, to one in which a smaller number of team leaders can dedicate a higher degree of focus and effort to these activities.

Disclaimer with proposal

An important disclaimer is that this suggestion is expected to only be realistically applicable for production lines where the number of Andon calls are relatively low. At production lines where the number of Andon activations are consistently high, the suggestion is expected to have a very limited effect since most or all team leaders would be tied up with Andon calls anyway. At production lines where the number of Andon activations are lower, the suggestion is expected to have a greater impact and be more realistically applicable.

Additionally, the physical distances between all workstations on the production line needs to be taken into consideration when deciding if the proposition would be feasible. If the physical spread of a production line limits team leaders in being able to respond to Andon calls within acceptable timeframes, the proposition is to not implement the suggestion at that specific production line. The suggestion is therefore not meant to be implemented as a mandatory standardised method to be used at all production lines, but rather as a standardised tool that supervisors could decide to use if they find it suitable for their production line.

Feasibility assessment

The feasibility assessment of the presented improvement suggestion has been done through empirical findings derived from observations and analytical findings derived from analyses of observations.

Empirical findings

Observations and discussions with team leaders, indicated that similar informal working arrangements are already existing in certain areas of the factory. Several team leaders reported that they try to work in a similar manner as the one laid out in the proposal of this study, with some team leaders devoting greater focus to activities such as continuous improvement and problem-solving, while other focus more heavily on Andon support. These observations were made on a production line characterised by a relatively low frequency of Andon activations compared with other observed production lines in VCT. In addition, the physical layout enabled team leaders to move efficiently between all workstations, thereby

facilitating timely responses to Andon calls. This evidence supports the expectations of suitability of the suggestion for production lines of similar characteristics.

Analytical findings

The suggestion is primarily an organisational change, something that Leon et al. (2025) highlights the need for in organisations implementing Industry 5.0. Consequently, implementation would require little to no technological investments. Since the suggestion is proposed to be implemented as a managerial tool that supervisors may adopt where deemed appropriate, evaluations of suitability of the proposed suggestion would be needed on a case-by-case basis prior to implementation. Such assessments should consider contextual factors such as frequency of Andon activations and physical layout of production line. Furthermore, the concept is relatively intuitive and already in informal use, suggesting that only limited training and organisational adaptation would be necessary.

In cases where a production line is found to be unsuitable for full-scale implementation, for instance due to large physical distances between workstations, the approach could be applied on a smaller unit. The responder order could for instance be implemented within a subsection of the production line or between a limited number of team leaders.

Furthermore, formalising and standardising a working method that is currently applied informally at specific production lines within Volvo Cars, could be expected to provide Volvo Cars with an additional managerial tool for improving operational efficiency and enhancing working conditions of team leaders. The proposal represents a balance between the high degree of standardisation observed within the production at Volvo Cars and the increased need for flexibility within Industry 5.0, emphasised by Piccarozzi et al. (2024).

4.3.3 Improvement suggestion 3 – Automated operator error reporting

This section presents a proposal for improving the process where team leaders manually collect operator responsibility signatures for reported errors. First, the current situation is described through empirical findings derived from observations, internal documents, and interviews, followed by an analysis based of the inhibiting factors identified in Section 4.2. Subsequently, a future vision is outlined in the form of a design proposal, including its expected advantages and disclaimers. At last, the feasibility of the proposed solution is assessed based on empirical observations, interviews, and analytical evaluation.

Current Situation

The current situation of the operator error process is described through empirical findings derived from observations, internal documents, and interviews. Subsequently, the current situation is analysed based on the identified inhibiting factors from Section 4.2.

Empirical findings

According to Volvo Cars BMS, the current state description of the operator error reporting process is as follows:

All errors are to be continuously reported in the ATACQ QMS-system by the team leader responsible for the production area where the error or defect has been discovered. The only exception where an error does not need to be reported into the system is if the error has been corrected by the own team that caused it. Immediately when the team responsible for an error that has been detected is notified of the deviation, a so-called offline deviation, the affected team leader is to make sure that the deviation does not happen again and pursues with corrective actions if necessary. The operator responsible for the error should also be aware of his or her mistake, to make sure that they understand what they have done wrong and how to not do it again.

Observations at VCT identified an additional step in the error-reporting process whereby operators are required to formally take responsibility for committed errors through a physical signature. Through conversations with team leaders, it is revealed that error data from the preceding shift are retrieved from the QMS by team leaders once per shift and exported to a standardised Excel template used for storing, visualising, and monitoring error trends and errors committed by the whole production line, individual operators, or individual operations. According to team leaders, the information is used by team leaders and supervisors to identify recurring issues and determine whether corrective actions are required. Subsequently, team leaders print out a list of reported errors and meet with the affected operators on the production line. During these interactions, the error is reviewed and the operator confirm receipt of information. In addition, the operator signs the document, acknowledging responsibility for the deviation. It has been observed that this procedure is conducted after the initial notification and discussion of the error and that the primary purpose therefore is administrative, namely, to document operator acknowledgment through collection of

signatures. These administrative steps should be considered waste according to Lean theory (Sundar et al. 2014).

Analytical interpretation and connection with inhibiting factors from Section 4.2

Two main drawbacks have been identified with the current operator error reporting process:

1. **Takes precious time from team leaders.**
   From manually finding and copy-pasting data into a spreadsheet, to physically walking around collecting signatures from operators, the process could be more streamlined and time-efficient.
2. **No repeat training.**
   It has been observed that operators are simply asked to not repeat their mistake but are not given any tips or tricks on how to avoid making the same error again.

The current process and its identified drawbacks can be related to all inhibiting factors from Section 4.2. The first drawback of time-consuming procedures for team leaders, relates specifically to the inhibiting factor of *Time constraints*. Since the process can be identified as mainly administrative, it does not leverage from human capabilities, reflecting the inhibiting factor of *Underutilisation of human-specific strengths*. The usage of an analogue process in terms of manual collection of signatures, reflects the inhibiting factor of *Analogue systems*.

Future Vision

The future vision is outlined in terms of presenting the design proposal together with its expected advantages and relevant disclaimers. The design proposal and expected advantages are derived from analyses of combined findings from literature and observations.

Design proposal

To improve the efficiency of the operator error reporting process and address the identified drawbacks, a digitally integrated feedback system is proposed. Rather than requiring team leaders to print physical documents and manually collect operator signatures, error responsibility would be handled digitally through an integration between QMS and the digital workstation tablets currently used for one purpose: allowing operators to sign in and out from workstations through an electronic rotation card. Operators would receive notifications of

reported errors directly on the workstation tablet and confirm responsibility through a digital signature.

To ensure that the process does not interfere with other manufacturing activities, signatures could be completed during periods of available time, such as workstation rotations or downtime. Additional mechanisms, such as mandatory signing for operators before logging into a workstation or team leader/supervisor verification that the deviation has been discussed enough with the operator, could be implemented to ensure compliance.

The proposed solution could also allow for additional supporting features. The WES, OIS, and/or other training materials could potentially be displayed alongside error notifications, thereby providing refreshments and reinforcing learnings on how to perform the operation in question. If operators have a better way of doing operations, tips and tricks could be shared through a built-in best-practice sharing feature, supporting continuous improvement. The system could potentially also indicate if there are other operators working in proximity that have made the same mistake recently, enabling operators to share tips and tricks in person at the production floor.

Expected advantages with proposal

The primary benefit of the proposal is expected to be a reduction in administrative workload for team leaders, allowing more time to be allocated to value-adding activities that leverages from human-specific strengths. Furthermore, the digitalisation of an analogue process is expected to reduce paperwork, simplify documentation, improve traceability, and decrease the risk of missed or delayed signings from operators. It has been revealed through conversations with team leaders that physical documents must currently be stored for one year at the production line. Several team leaders have also highlighted challenges associated with tracking physical signatures when operators are absent due to vacation, illness, or temporary employment arrangements, challenges that could be expected to be mitigated through automated reminders in a digital system.

Disclaimer of proposal

It should be noted that the proposal only seeks to automate the process of collecting operator error signatures. Team leaders would continue to communicate deviations directly to operators and review the reported errors through the QMS. According to Respondent 1, fully

automated error allocation would require fundamental changes to current reporting practices in terms of clear instructions on who is responsible for deviations.

Feasibility assessment

Regarding feasibility, all necessary data needed for the suggestion has been observed to already be stored and collected digitally in QMS. The required physical hardware has also been observed to exist to a certain degree. According to Respondent 1, approximately 50% of all workstations in VCT are applied with a digital tablet, having an electronic rotation card application running on them. As revealed through observations, the QMS is fed with data coming directly from the digital workstation tablets, indicating that there exists a direct link between the QMS and the tablets. It has however been observed that this communication is currently only utilised one-way, from the electronic rotation card application to the QMS. The proposal is to close this circle, allowing the QMS to send data back to the electronic rotation card application.

According to Respondents 3, 4, and 7, the technical feasibility of the proposal could be seen as relatively high. The respondents further revealed that the technical requirements for adding additional features into the electronic rotation card application can be seen as limited. According to Respondent 3, the integration of a notification and signing feature would be relatively easy to implement from a technical aspect and only require approximately 1-2 weeks of programming. Respondents 3, 4, and 7, mentioned that the challenges associated with the proposal and similar solutions in general, are to persuade all affected decisionmakers to comply and prioritise. This issue recures often in Industry 5.0 implementation, according to Pham & Li (2026) and Leon et al. (2025).

4.3.4 Improvement suggestion 4 – AI assistants & education

This section presents the suggestion of increased AI assistance and education within manufacturing at Volvo Cars. The suggestion is presented with a different structure compared to other improvement suggestions presented in this report. First, the current AI situation within the manufacturing of Volvo Cars is presented in terms of empirical findings derived from observations and interviews. Subsequently, a future vision and required capabilities are described based on literature findings, observations, and interviews. At last, an example use

case for AI within the manufacturing at Volvo Cars is outlined to demonstrate the capabilities of AI. The use case is presented in terms of a current situation based on empirical findings, future vision including a design proposal, and a feasibility assessment based on observations and interviews.

Current AI usage at Volvo Cars manufacturing

It has been revealed through interviews with multiple respondents (Respondents 3, 5, 6, and 7) that AI is being discussed extensively within the automotive industry, but any real developments and implementations remain limited. As Respondent 7 stated: “Everyone talks about AI, but I don’t see that much of it”. From the interviews and literature review it is shown that only certain areas within manufacturing have come a long way of developing and integrating AI technologies into its operations. The most prominent areas within manufacturing where AI technologies are being increasingly utilised are within maintenance and quality control. In other areas such as performance analytics and administration, the development and integration of AI technologies have been observed to be modest. According to Respondent 5, three applications for maintenance control are being implemented across various Volvo Cars factories; MIDAS in VCT, IMES in China, and MAT in Gent, with the idea further being to develop a MIDAS 2.0, where certain parts from other systems are selectively chosen to be integrated into one globally dispersed system. According to Respondent 5, approximately 80% of AI that has been deployed in automotive manufacturing, lies within these areas. However, the specific AI technology predominantly used within these maintenance applications is the older field of Machine Learning (ML) and not more modern and advanced AI. For the sake of simplicity and not making the thesis unnecessarily technical, the term AI will henceforth be used as a collective term for all the different kinds of AI technologies.

An example of AI being integrated into quality control operations at Volvo Cars can be found in Volvo Cars’ Torslanda paint shop (TB). Here, cameras using AI technology to detect visual defects to cars between various stages in the painting process has been developed and integrated into daily operations. According to Respondent 6, using images as input data for AI has shown to be the simplest choice for the time being, since this solution requires minimal integration with other systems and departments during the development work. However, Respondent 6 mentioned that this choice requires that engineers and developers

possess necessary expertise about the cameras and how to program AI to analyse the images. Respondent 1 further argued that implementing AI technology into these specific operations at TB has been prioritised due to the possibility of distributing the investment costs across the entire factory, leveraging economies of scale. Respondent 6 argues that investments in modern technology such as AI is hard to motivate on a relatively short timeframe such as five years. Due to the rapid advancements and innovations of such technologies, there is a possibility that implemented technologies could become outdated within just a few years. Most important, according to Respondent 6, is to not just evaluate what value possible implementations possesses in the moment, but what value they will possess in the future and throughout their lifespan before becoming obsolete.

Future vision

It has been observed that team leaders and supervisors are currently required to do a relatively large number of administrative tasks as part of their daily work. Examples of such tasks are deviation reporting, personnel scheduling, e-mail handling, etc. According to Lean theory, tasks that does not bring value to customers are non-value adding and should be completed as quickly and efficient as possible (Sundar et al., 2014). The integration of technological support to assist with these tasks could therefore contribute to improved workflow efficiency and allow humans to focus on more value-adding responsibilities that emphasises human-specific strengths, aligning with the core principles of Industry 5.0 (Yanytska, 2025; Pham & Li, 2026). According to Piccarozzi et al. (2024), tasks that can be performed equally well or better by automation technologies should be supported or automated. At the same time, Industry 5.0 emphasises human-centricity and human-machine collaboration, highlighting the need for solutions that augments rather than replaces humans (Nguyen & Tran, 2023). AI represents one such enabling technology, with potential to support a range of administrative processes within manufacturing while maintaining human oversight and control. The proposal of this report is therefore to increase the usage of AI within manufacturing processes at Volvo Cars.

Analytical interpretation and connection with inhibiting factors from Section 4.2

The proposed improvement in terms of increased AI assistance has been identified to address both the inhibiting factors of *Time constraints* and *Underutilisation of human-specific*

strengths. The proposal addresses *Time constraints* by supporting administrative work and saving time for employees to engage in activities that leverages from human-specific strengths, consequently addressing the inhibiting factor of *Underutilisation of human-specific strengths*.

Required capabilities

As Respondent 6 mentioned, the most apparent issue when it comes to developing and integrating AI technologies into manufacturing operations, is the lack of knowledge among workers. The literature review emphasised this as well; to successfully integrate and exploit the possibilities of AI technologies, there is a need for human workers to possess the necessary and required skills for utilising such technologies in an optimal way (Nguyen & Tran, 2023).

Respondent 6 mentioned that it is important that human operators understand the capabilities of AI and related advanced technologies, to be able to deliver propositions themselves on areas or subjects where AI can be integrated. According to Respondent 6, this could exponentially enhance the capabilities of AI at Volvo Cars, leading to more innovations and improvements, compared to if just a few actors possess relevant AI expertise. Respondent 6 further expressed that it is important to not just automate operations or processes, without incorporating the necessary knowledge into the human workforce; every worker should be educated to understand these technologies, to be able to integrate AI into their own daily tasks, such as administration, continuous improvement and problem-solving for team leaders and supervisors. To achieve this, Respondent 6 believes that AI technologies must be as easy and ingrained to work with as other digital tools that has been used for a long time such as e-mail and Excel.

According to Nguyen & Tran (2023), it is important to enlighten the purpose of implementing new technologies such as AI to the human workforce. The introduction of AI might frighten humans regarding job displacements; hence, explaining the intended purposes of implementing AI as a supporting tool rather than a replacement solution, is of utmost importance when managing within an Industry 5.0 context.

In conclusion, it has been revealed through both the literature review and interviews with employees of Volvo Cars, that one of the main investments that is required when implementing AI into manufacturing operations is education and training of the human workforce.

Example of an AI use case – reporting deviations

To demonstrate the possible capabilities of AI integration into manufacturing operations, an improvement suggestion to a certain task within Volvo Cars manufacturing operations have been selected. This report therefore proposes a solution for the application of AI to support in the specific activity of reporting deviations.

Empirical findings on the current situation of reporting deviations

According to observations and BMS, quality deviations are registered in the QMS to ensure that identified product defects are corrected before the vehicles leave the factory. As stated in BMS, when a deviation is detected, the responsible employee is required to notify a team leader through either Andon, via a device (mobile, tablet, smartphone, etc.), or directly so corrective actions can be taken. It is also stated in BMS that depending on the nature and origin of the deviation, relevant teams and/or departments must also be informed to prevent recurrence.

According to observations and BMS, the responsibility for reporting a deviation lies with the team leaders responsible for the production area where the deviation was detected. As part of the reporting process, it has been observed that team leaders must assign an appropriate error code for the deviation from the QMS database. Observations and conversations with team leaders in TC indicate that this task can be challenging due to the large number of available error codes. Team leaders have expressed the feeling that particularly those with lesser team leader experiences, experiences difficulties in identifying the most suitable error codes within relatively quick timeframes. In some observed cases and through conversations with team leaders, locating and selecting appropriate error codes required several minutes, introducing delays and uncertainties into the reporting process.

At specific production lines, it has been observed that the specific lines have developed mitigating actions internally for themselves. In TC, a categorisation of error codes into decision trees has been observed among certain teams. Respondent 5 also mentioned a solution used in Volvo Cars' factory in Gent, where teams have created so called "fast input lists", where the most repeated errors are stored and easier to access quickly. All these mitigating actions have been observed to be developed by each team themselves. No general actions or global guidelines have been observed to exist for addressing this problem.

Future vision - Design proposal

To support team leaders when assigning error codes during deviation reporting, the integration of AI is proposed. Specifically, to address the challenges of identifying and assigning appropriate error codes for deviations. Through interviews, it has been revealed that the integration of AI into this process can be leveraged in different ways. A first solution is that the QMS in which deviations are reported into should incorporate AI-assisted functionality. The other solution is that the affected parts of the QMS (error codes) would be accessible to transfer to a second-part AI tool, preferably Microsoft Copilot, which is an AI tool already available for almost every Volvo Cars employee.

With both solutions, the proposed technological approach would be based on AI-driven text classification, which is a supervised learning task within Natural Language Processing (NLP), whereby a system automatically assigns predefined labels or categories to textual input based on its content (Mohapatra et al., 2022). Within this framework, the proposal is that team leaders would input a textual description of the deviation, after which the AI system would analyse the content and assign the most appropriate corresponding error code from the existing system. Subsequently, team leaders would review and validate the AI-generated assignment to ensure its accuracy, aligning with the principles of Industry 5.0 regarding augmenting technologies rather than replacing (Nguyen & Tran, 2023). This proposal can be expected to potentially reduce time required to manually locate and identify suitable error codes for deviations, and thereby improving efficiency. Furthermore, by minimising engagement with what has been observed as a repetitive and low-value task, the proposed solution may contribute to enhanced work satisfaction among team leaders, in line with the theories of Sundar et al. (2014).

Feasibility of proposal

The feasibility of the suggested improvement is not as simple to estimate as previous suggestions proposed within this report. Integrations of AI technologies into such manufacturing operations as the reporting of deviations have not yet been generally established within the manufacturing at Volvo Cars, according to multiple respondents (Respondents 3, 5, 6, and 7). Regarding the first proposed solution of integrating AI-functionality into the existing QMS, cybersecurity and legal challenges arise that need to be investigated, according to Respondent 3 and 6. Respondent 3 and 6 further argue that since

no or little similar implementations have been developed within the manufacturing of Volvo Cars, the answer to these challenges are hard to estimate.

The other solution of utilising existing AI-tools within Volvo Cars such as Microsoft Copilot, is perceived as an easier and more feasible solution within a short timeframe according to Respondent 3 and 6. From a technical point of view, this solution can be expected to require minimal or a relatively small amount of technical development, since the operating AI system already exists. Only small integrations handling the transferring of data from the QMS into the AI-model could be expected to be required. As mentioned by Respondent 6, the usage of already existing systems within Volvo Cars such as Microsoft Copilot could be expected to additionally require lesser educational training than compared to if a completely new AI-system would be used. Additionally, from a cybersecurity perspective, an already implemented solution saves considerable time and money compared to rolling out a brand-new solution, according to Respondent 6. Volvo Cars runs a fenced-in enterprise version of Microsoft Copilot which the IT department has approved to access a large amount of company documents; for most employees Microsoft Copilot is cleared to access all files which the employee themselves can access.

5. Discussion

In the following section, answers to each research question in the thesis, reflections on proposed improvement suggestions, implications for VCMS, future research, and methodology are discussed.

5.1 Answering research questions

RQ 1: According to Industry 5.0 theory; What will the future of manufacturing management look like? What are the current trends and key principles?

The first research question aimed to investigate what the future of manufacturing management will look like; what the current trends are and which management principles are becoming increasingly important to follow. While Industry 4.0 has primarily focused on automation, digitalisation, efficiency, and productivity, Industry 5.0 seeks to put a larger emphasis on human-centricity, sustainability, and resilience (Ionescu, An & Ionescu, Al, 2025). Manufacturing management in Industry 5.0 is moving towards a more integrated socio-technical perspective, where digital technologies and human capabilities are designed to complement one another rather than compete (Piccarozzi et al., 2024). To achieve this, future manufacturing management systems should be designed around human capabilities instead of requiring the employees to adapt to the technology.

Four key principles to consider when developing Industry 5.0 and human-centric management practices were identified in this project. These were “utilisation and continuous development of human-specific strengths”, “only involving humans when necessary or advantageous”, “distributing the right information to the right people”, and “improving working conditions, wellbeing, and job satisfaction”. Together, these principles indicate a shift toward increasing emphasis on optimising the interaction between humans, technologies, and processes within manufacturing, rather than just process and operation optimisation, which is one of the main differences between Industry 4.0 and Industry 5.0 (Leon et al., 2025).

RQ 2: Based on these trends and principles; what factors inhibiting Industry 5.0 development within VCMS have been observed?

The second research question examined which improvement opportunities could be identified for VCMS based on the identified key principles from the previous research question. A current state of Volvo Cars manufacturing operations was established through on-site observations at VCT and analysed against the key principles. From this analysis, three inhibiting factors to Industry 5.0 development of VCMS were identified; time constraints, analogue systems, and underutilisation of human-specific strengths.

The findings suggest that these inhibiting factors are interconnected. Analogue systems have been observed to require employees to spend significant amounts of time on administrative activities such as manually collecting, transferring, and documenting information. Consequently, these activities create time constraints where employees get limited time for engaging in activities where human-specific strengths such as creativity, reasoning, and problem-solving are utilised; resulting in underutilisation of human-specific strengths. The findings therefore demonstrate an important contradiction within the current usage of VCMS. While Volvo Cars promotes continuous improvement, problem-solving, and teamwork through VCMS; activities that are all central to Industry 5.0 management (Piccarozzi et al., 2024); the identified inhibiting factors have been observed to limit the engagement in and utilisation of such activities.

The findings indicate that the primary opportunities for improvement of VCMS do not lie within redesigning the underlying principles and methods of the system but rather involves refining management processes and practices to enhance the effectiveness and utilisation of the principles already embedded into the system. The identified improvements involve simplifying work processes, reducing unnecessary administrative burden, improving information accessibility, and creating environments that better enable employees to utilise cognitive skills. Consequently, management processes and practices at Volvo Cars should become more aligned with the identified Industry 5.0 principles to increase the benefits from already existing VCMS principles.

RQ 3: What are some improvement suggestions to make VCMS more Industry 5.0 compliant? What capabilities does Volvo Cars need to implement these suggestions?

The third research question explored which concrete improvements that could be suggested to address the identified inhibiting factors of Industry 5.0 development at Volvo Cars, and what capabilities Volvo Cars require to implement these suggestions. Four improvement

suggestions were proposed; digital RTM boards, designated Andon responder order, automated operator error reporting, and increased use of AI assistance combined with AI education.

Collectively, all improvement suggestions share some common objectives. Digital RTM boards, automated operator error reporting, and increased use of AI assistance leverage digitalisation to reduce non-value-adding administrative activities and mitigate time constraints (Mathiasen & Clausen, 2024). Specifically, digital RTM boards and automated operator error reporting are intended to replace analogue systems with digital alternatives, addressing the inhibiting factor of analogue systems. A common objective among all suggestions is that they aim to reduce the identified inhibiting factors of time constraints and underutilisation of human-specific strengths. The suggestions seek to increase the effectiveness of operators, team leaders, and supervisors, as well as improving their ability to engage with activities such as continuous improvement and problem-solving; activities that have been identified as leveraging from human-specific strengths such as creativity and reasoning, key employee skills to highlight in Industry 5.0 (Piccarozzi et al., 2024).

The further this study has progressed, it has become clear that Volvo Cars already possesses a lot of the required technological capabilities needed to become more human-centric in their management practices. Instead, large parts of the Industry 5.0 investments will need to be directed towards workforce education, organisational changes and developing new working procedures and standards. Additionally, the technological solutions that Volvo Cars possesses, although functional on their own, will require extensive integration to allow for digital systems to communicate more seamlessly with each other, and simplify daily work for employees through more intuitive interfaces. That way technology can remove more of the non-value-added work burden from humans and give employees more time for tasks in which human-specific skills are required. The Industry 5.0 transformation at Volvo Cars truly is about changing the perspective from having the humans serve the technology to having the technology serve the humans, just as the Industry 5.0 theory states (Yanytska, 2025).

5.2 Reflections on improvement suggestions

Although the improvement suggestions have been developed primarily to make daily work simpler and more effective for operators, team leaders and supervisors, and are not significant enough to replace employees, it is still realistic to believe that the resulting reduction in

required manhours could lead the company to explore organisational restructuring. Most affected by such restructurings would be team leaders, whose daily work sees the largest improvement to efficiency by the proposed improvement suggestions out of all organisational roles. While the reduced need for team leader manhours is nowhere near great enough to warrant the removal of one team leader per line per shift, the threshold for calling in additional team leaders during high demand might be increased. This could potentially lead to cost savings by reducing the required number of team leader manhours.

There could also be changes to working standards and procedures as a result of implementing the improvement suggestions. For example, thanks to the RTM-boards updating themselves continuously, all interested parties could simply walk up to the board and update themselves on-demand without the need of gathering all team leaders. This would theoretically mean that a reduction in RTM-meeting frequency could be implemented with additional meetings called when a problem occurs or the need for a meeting arises for other unforeseen reasons, as proposed by Mathiasen & Clausen's (2024) research on implementation of visual boards. This could free up even more time for team leaders and supervisors to work creatively or support operators in their value-added tasks.

During the cause of the thesis, a wide range of opinions have been detected regarding the implementation of new technology and procedures. Certain people are thrilled about the potential prospect of new tools aiding in their daily routine. Other people are highly sceptical; they would like things to remain as they are and regards it as unnecessary to replace something that is already tried and tested. While there is a general opposition to testing new ideas amongst these people, digitalisation seems to be the main cause of concern. It will therefore be crucial to show the value of increased human-centric digitalisation, incrementally implementing new digital solutions while highlighting the benefits of the previously implemented step to secure acceptance among all users; in line with the theories of Olsson et al. (2024) and Pham & Li (2026).

However, every so often the rare situation presents itself that could allow implementing large changes with minimal risk of upsetting hesitant employees. One such opportunity could be when building a new factory and setting up new manufacturing operations. With a blank slate to start from, this inherit opposition to change can be circumvented and new technology, procedures, and organisation can be introduced without disrupting ongoing operations. Such an opportunity is currently available for Volvo Cars, who are building a brand-new full-size

factory in Košice, Slovakia. Here, all improvement suggestions presented in this study could be part of the manufacturing operations from day one. This would not only make the new Košice factory more human-centric and Industry 5.0-compliant, but it could also serve as a full-scale testing facility, verifying the effectiveness of the improvements and building acceptance before pushing implementation to other Volvo Cars manufacturing sites. All improvement suggestions lend themselves well to gradual implementation. Testing them thoroughly at one factory would be an efficient and minimally disruptive way to evaluate usefulness before launching globally.

5.3 Implications for VCMS

For VCMS, the findings suggest that the system already contains several principles and values associated with Industry 5.0. Teamwork, continuous improvement, and human development are all principles that are highlighted in Industry 5.0 theory (Ionescu, An & Ionescu, Al, 2025; Piccarozzi et al., 2024). However, observations and analyses of Volvo Cars current manufacturing management practices reveals that the execution and utilisation of these principles are constrained by several factors. Therefore, the findings suggest that VCMS does not require a fundamental redesign but rather an evolution in how existing principles are applied. The core values of VCMS, such as human development, teamwork, and continuous improvement, align well with Industry 5.0 theory. However, observations indicate that the practical implementation of these values requires changes and additions to existing manufacturing management processes and practices to effectively address the identified current issues and key principles associated with Industry 5.0 and human-centric manufacturing.

5.4 Future research

Both Lean and Industry 5.0 theory clearly points out that non-value-added tasks such as administrative work should be minimised to increase efficiency and improve human-centredness. However, at Volvo Cars, a certain value is attributed to such tasks. The main argument for why doing simple and repetitive administrative work still could be advantageous, is that it enhances learning for the employees. Working with important information, even when doing something tedious with it, improves understanding of the data

through repeated exposure. Meanwhile, according to Lean theory, every minute spent on such work should be considered as waste (Sundar et al., 2014), and eliminating such tasks from employee's workload would not only streamline and simplify their daily work but save money for the company. Exploring if this is an effective way of learning relative to the extra cost incurred could therefore be an important topic for f-uture research.

5.5 Methodology discussion

The methodological approach of this study, conducting a literature review, on-site observations, and interviews, provided a broad and comprehensive understanding of both future trends in manufacturing management and the current state of management practices within manufacturing of Volvo Cars. The use of multiple qualitative methods increases the credibility of the results by validating and comparing findings between literature, observations, and interviews (Bell et al., 2022).

The literature review provided a strong theoretical foundation to the report, where key concepts and principles for the study such as Industry 5.0 and human-centric manufacturing were defined and described. By studying the latest research in the relevant areas for this thesis, findings could be made on the latest updates within the industry. However, as the automotive manufacturing industry and IT technology field are rapidly evolving sectors with constant advancements of technologies (Mueller & Mezhuyev, 2022), it means that some findings might become outdated relatively quickly as new technologies or practices emerge.

The observational component of the study, in the form of on-site observations in VCT, was particularly valuable in the sense that it established an understanding for how management practices are currently applied at Volvo Cars. Through direct interaction with operators, team leaders, and supervisors, along with passive shadowing, a comprehensive understanding of current management practices was established. It was valuable for gaining insights that would otherwise be hard to obtain from interviews and discussions alone.

In the observational phase, a limitation to the study is that all on-site observations made were done at VCT in Gothenburg. While VCT represents one of the largest and most mature factories of Volvo Cars, the study aims to provide recommendations to the manufacturing system of Volvo Cars on a global scale. By having the observational study limited to VCT, findings about the current state of VCMS on the factory floor was obtained only from one

factory. Since different factories across the world have different organisational, cultural, technological, and operational contexts to varying extent, some of the findings from VCT may not be fully representative of other Volvo Cars factories. This observational limitation further affects the ability to generalise the findings for all Volvo Cars factories around the world. Although interviews were held with employees of other Volvo Cars sites, this does not replace the action of physically observing operations at the factory. The findings in this thesis should therefore be interpreted as being primarily grounded in a VCT context, but be applicable for other Volvo Cars factories as well, potentially after additional validation.

The interview phase of the study provided deeper insights into the feasibility of proposed improvement suggestions and the research in general. Through semi-structured interviews with employees of Volvo Cars, discussions and findings of other relevant topics to the study that were not considered before the interviews could be obtained, compared to using a more structured approach where all questions were predetermined. The limited number of interviews within the study further mean that findings should not be interpreted as representing the views of all Volvo Cars employees, in line with theories on limited sample size (Bell et al., 2022). Overall, finding suitable employees to interview proved tricky, with multiple employees declining participation over time- and scheduling constrains. However, using snowball sampling and references from known colleagues when contacting new potential interviewees seemed to help mitigate some of these constraints, making people more willing to respond and agree to interviews.

6. Conclusion

This thesis has aimed to explore how the Volvo Cars Manufacturing System (VCMS) can evolve toward more human-centric manufacturing management practices aligned with the principles of Industry 5.0. Through a combination of literature review, on-site observations at Volvo Cars Torslanda (VCT), and interviews with Volvo Cars employees, the study investigated what the future of manufacturing management will look like, identified improvement opportunities and developed concrete improvement suggestions for VCMS, and explored what capabilities Volvo Cars need to implement such suggestions. The main limitations to the thesis were that on-site observations were limited to VCT, minimising the generalisability of findings for other Volvo Cars factories. Also, the rapid advancements of technologies within the automotive manufacturing industry means that findings may become outdated within a relatively short timeframe. In addition, the proposed improvement suggestions have not been physically tested or validated at the production floor.

The findings indicate that future manufacturing management requires stronger focus on human-centricity, where technology is used to support humans rather than replacing them. While automation and digitalisation will remain important, manufacturing management systems are expected to increasingly prioritise the role of humans, leveraging human-specific strengths such as creativity, reasoning, and problem-solving by designing machines and systems around human capabilities. This is suggested to not only improve production flexibility and resilience, but also enhancing working conditions, employee wellbeing, and job satisfaction. Four key principles to consider when developing human-centric management practices according to Industry 5.0 were formulated in the study: Utilising and continuously developing human-specific strengths; only involving humans when necessary or advantageous; distributing the right information to the right people; and improving working conditions, wellbeing, and job satisfaction.

The identified opportunities for improvement within VCMS was found not to be about redesigning the entire system and its underlying principles and methods but refining and adapting existing manufacturing management processes according to Industry 5.0, to enhance the utilisation of already existing principles. Inhibiting factors to human-centric development of VCMS were found to be time constraints, analogue systems, and underutilisation of human-specific strengths. For Volvo Cars to comply with Industry 5.0 and human-centric manufacturing, there is a need to address these factors by simplifying work processes,

reducing unnecessary administrative burden, improving information accessibility, and better enable employees to utilise human-specific capabilities.

The concrete improvement suggestions for VCMS that were developed in the study to counteract the identified inhibiting factors were: digital RTM boards, automated operator error reporting, designated Andon responder order, and fostering increased use of AI assistants and AI education. The study suggests that a lot of the technological capabilities required for adapting and implementing human-centric manufacturing management practices are already possessed by Volvo Cars. However, these technologies will need further integration to allow for digital systems to communicate more effectively with human employees and simplify working procedures. Apart from integrating existing technologies, the main investments required by Volvo Cars will need to be directed towards workforce education, organisational changes, and developments of new working procedures and standards.

References

Alves, J., Lima, T.M., & Gaspar, P.D. (2023). *Is Industry 5.0 a Human-Centred Approach? A Systematic Review. Processes*, 11(1), 193. https://doi.org/10.3390/pr11010193

Bell, E., Bryman, A., Harley, B. (2022). *Business Research Methods* (6th ed.) Oxford University Press.

Buri, Z., & Kiss, J.T. (2025). *Digitalisation in the Context of Industry 4.0 and Industry 5.0: A Bibliometric Literature Review and Visualisation. Applied System Innovation*, 8(5), 137. https://doi.org/10.3390/asi8050137

Cai, Q., Han, J., Zhou, X., Zhao, S., Li, L., Liu, H., Xu, C., Chen, J., Liu, C., & Zhu, H. (2026). *Human–robot collaborative manufacturing toward efficiency and sustainability: A comprehensive review. Sustainability*, 18(1), Article 515. https://doi.org/10.3390/su18010515

D'souza, C.P., & Tapas, P. (2024). *Diversity 5.0 framework: managing innovation in Industry 5.0 through diversity and inclusion. European Journal of Innovation Management*, 28(5), 1834–1857. https://doi.org/10.1108/EJIM-02-2024-0139

Fan, J., Hao, H., Xu, Y. (2024). *Application and Optimization of Deep Learning-Powered Intelligent Andon System in Lean Manufacturing. CAICE '24: Proceedings of the 3rd International Conference on Computer, Artificial Intelligence and Control Engineering*, 170–175. https://doi.org/10.1145/3672758.3672786

Fazal, N., Haleem, A., Bahl, S., Javaid, M., & Nandan, D. (2022). *Digital Management Systems in Manufacturing Using Industry 5.0 Technologies. Advancement in Materials, Manufacturing and Energy Engineering*, 2, 221–234. https://doi.org/10.1007/978-981-16-8341-1_18

Gao, R.X., Kruger, J., Merklein, M., Möhring, H.C., & Vancza, J. (2024). *Artificial Intelligence in manufacturing: State of the art, perspectives, and future directions. CIRP Annals-Manufacturing Technology*, 73, 723–749. https://doi.org/10.1016/j.cirp.2024.04.101

Hammad, M., Panaousis, M., Ali, H., & Khan, W.A. (2026). *Smart manufacturing blueprint: Navigating Industry 4.0 across diverse sectors.* Springer Nature. https://doi.org/10.1007/978-3-032-00214-3

Havle, C.A., & Ucler, C. (2025). *Evaluation of Industry 5.0 Technologies in Automotive Industry Using Integrated IVIF MCDM Methodology.* In: Kahraman, C., et al. *Intelligent and Fuzzy Systems.* INFUS 2025. Lecture Notes in Networks and Systems, vol 1529. Springer, Cham. https://doi.org/10.1007/978-3-031-97992-7_38

Ionescu, A.-M., & Ionescu, A.-C. (2025). *Human-centric smart manufacturing systems: Challenges and opportunities for sustainable industrial transformation. Sustainability*, 17(17), Article 7842. https://doi.org/10.3390/su17177842

Kabasakal, I., Demircan Keskin, F., Ventura, K., & Soyuer, H. (2017). *From Mass Customization to Product Personalization in Automotive Industry: Potentials of Industry 4.0. Journal of Management Marketing and Logistics*, 4(3), 244–250. https://doi.org/10.17261/Pressacademia.2017.486

Leon, O., Puente, J., Fernandez, I., & Luna, M. (2025). *Challenges in Transitioning from Industry 4.0 to Industry 5.0: A Multicriteria Analysis. Journal of Industrial Integration and Management*, 10(1), 109–151. https://doi.org/10.1142/S2424862224500192

Liker, J.K., & Hoseus, M. (2008). *Toyota culture: The heart and soul of the Toyota way.* McGraw-Hill. https://doi.org/10.1036/9780071712576

Madhavaram, C.R., Sunkara, J.R., Kuraku, C., Galla, E.P., & Gollangi, H.K. (2024). *The Future of Automotive Manufacturing: Integrating AI, ML, and Generative AI for Next-Gen Automatic Cars. International Multidisciplinary Research Journal Reviews*, 1, 20–28. https://doi.org/10.17148/IMRJR.2024.010103

Martins, F.C. (2023). *Customer Preferences for their Journey into the Future of the Automotive Industry* (Master's thesis, Universidade NOVA de Lisboa, Portugal). https://www.proquest.com/openview/8c1fe781dcfbed1d545e49a6b2cadf07/1

Mathiasen, J.B., & Clausen, P. (2024). *Fitting digital visualization board transitions to shop floor tasks.* Wiley, 411–432. https://doi.org/10.1002/joom.1290

Mohapatra, S.K., Sarangi, P.K., Sarangi, P.K., Sahu, P., Sahoo, B.K. (2022) *Text classification using NLP based machine learning approach*. *AIP Conf. Proc,* 2463(1): 020006. https://doi.org/10.1063/5.0080301

Mourtzis, D., & Wang, L. (2024). *Industry 5.0: Perspectives, concepts, and technologies.* In *Manufacturing from Industry 4.0 to Industry 5.0*, 63–96. https://doi.org/10.1016/B978-0-443-13924-6.00003-X

Mueller, C., & Mezhuyev, V. (2022). *AI Models and Methods in Automotive Manufacturing: A Systematic Literature Review. Recent Innovations in Artificial Intelligence and Smart Applications*, 1–25. https://doi.org/10.1007/978-3-031-14748-7_1

Mundlamuri, R., Gunnam, G.R., Mysari, N.K., & Pujuri, J. (2025). *The Evolution of AI: From Classical Machine Learning to Modern Large Language Models. IEEE Access*, 13, 178301–178341. https://doi.org/10.1109/ACCESS.2025.3621344

Nguyen, H.D., & Tran, K.P. (2023). *Artificial Intelligence for Smart Manufacturing in Industry 5.0: Methods, Applications, and Challenges.* In *Artificial Intelligence for Smart Manufacturing.* Springer Series in Reliability Engineering, 5–33. https://doi.org/10.1007/978-3-031-30510-8_2

Olsson, A.K., Eriksson, K.M., & Carlsson, L. (2024). *Management toward Industry 5.0: A co-workership approach on digital transformation for future innovative manufacturing. European Journal of Innovation Management*, 28(1), 65–84. https://doi.org/10.1108/EJIM-09-2023-0833

Oswald, D., Sherratt, F., & Smith, S. (2014). *Handling the Hawthorne effect: The challenges surrounding a participant observer. Review of Social Studies*, 1(1), 53–73. https://www.research.ed.ac.uk/en/publications/handling-the-hawthorne-effect-the-challenges-surrounding-a-partic/

Pham, H.S.T., & Li, S.B. (2026). *Towards Industry 5.0: A conceptual model for leading organisational change in digital age. Journal of Organizational Change Management*, 39(1), 125–161. https://doi.org/10.1108/JOCM-03-2025-0264

Piccarozzi, M., Silvestri, L., Silvestri, C., & Ruggieri, A. (2024). *Roadmap to Industry 5.0: Enabling technologies, challenges, and opportunities towards a holistic definition in management studies. Technological Forecasting & Social Change*, 205, 123467. https://doi.org/10.1016/j.techfore.2024.123467

Putnik, G.D., Alves, C., & Avila, P.A. (2014). *Real Time Management in Manufacturing Systems: A State-of-the-art Review. 2100 Projects Association Joint Conferences*, 1, 221–228. https://doi.org/2183-3060/2014/0101-036

R. Rakholia, A.L. Suárez-Cetrulo, M. Singh, & R. Simón Carbajo. (2024). *Advancing Manufacturing Through Artificial Intelligence: Current Landscape, Perspectives, Best Practices, Challenges, and Future Direction. IEEE Access*, 12, 131621–131637. https://doi.org/10.1109/ACCESS.2024.3458830

Ryan, G., & Bernard, H.R. (2003). *Techniques to Identify Themes. Field Methods,* 15(1), 85-109. https://doi.org/10.1177/1525822X02239569

Sirris, S., Lindheim, T., & Askeland, H. (2022). *Observation and Shadowing: Two Methods to Research Values and Values Work in Organisations and Leadership.* In *Researching Values.* Palgrave Macmillan, Cham, 133–151. https://doi.org/10.1007/978-3-030-90769-3_8

Sundar, R., Balaji, A.N., & Satheesh Kumar, R.M. (2014). *A Review on Lean Manufacturing Implementation Techniques. Procedia Engineering*, 97, 1875–1885. https://doi.org/10.1016/j.proeng.2014.12.341

Tsai, C., Duraipandi, O., & Ali, D.A. (2026). *Research on real-time data display and production management in a digitalized management factory with an artificial intelligence-assisted flexible manufacturing execution system. Future Technology*, 5(1), 263–277. https://doi.org/10.55670/fpll.futech.5.1.23

Utiyama, M., Alliprandini, D.H., Figueroa, H.P., Gondim, J.F., Goncalves, L.T., Navas, L.B., & Zeno, H. (2025). *Integration of lean manufacturing and factory physics in an Industry 4.0 roadmap for augmenting operational performance. TQM Journal*, 37(2), 544–565. https://doi.org/10.1108/TQM-07-2023-0210

Vlacic, L., Huang, H., Dotoli, M., Wang, Y., Ioannou, P.A., & Fan, L. (2024). *Automation 5.0: The Key to Systems Intelligence and Industry 5.0. IEEE/CAA Journal of Automatica Sinica*, 11(8), 1723–1727. https://doi.org/10.1109/JAS.2024.124635

Yanytska, L. (2025). *The rise of human-centric manufacturing in the Industry 5.0 era. International Journal of Advanced Manufacturing Technology*, 139, 5067–5077. https://doi.org/10.1007/s00170-025-16192-5

Żelazny, R., Kocot, D., & Kocot, M. (2025). *Facing the Challenges of Industry 5.0 – the Case of the Automotive Sector in Poland. Transport Problems: An International Scientific Journal*, 20(4), 167–180. https://doi.org/10.20858/tp.2025.20.4.14

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
www.chalmers.se



CHALMERS
UNIVERSITY OF TECHNOLOGY