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Anticipating Key Technological Innovations in Maintenance Operations

Design and development of a technological impact model for the Royal Netherlands Army mechanic

MSc Mechanical Engineering

Thesis

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Summary

In recent years, the Dutch Ministry of Defense (DMOD) has faced increasing pressure to maintain a robust and technologically advanced army. However, updating assets does not always equal improvement, as new technologies can bring unforeseen challenges. A prime example is the implementation of Composite Rubber Tracks (CRTs) on the CV90 infantry fighting vehicle. Although CRTs offer advantages such as reduced weight, vibrations, and sound [1, 2]; they present a significant challenge for army mechanics [3]. Unlike steel tracks, CRTs cannot be disconnected, requiring a large and cumbersome rack for replacement. As a result, CV90 drivers cannot replace the tracks themselves anymore, and the army mechanic has to carry a rack of more than 6 meters in length onto the battlefield. For that reason, CRTs represent a prime example of why it is important to proactively identify the impact of new technologies, so that potential problems can be mitigated in time.

This thesis investigates how the Royal Netherlands Army (Dutch: Koninklijke Landmacht) (RNLA) can determine the impact of key Technological Innovations (TIs) on ground-based military systems, address associated challenges, and take the necessary measures to maintain these systems effectively in the future. The main research question (RQ) guiding this study is: "How can the Logistic Centre of Excellence (in the role of maintenance policy advisor) anticipate the impact of technological innovations in ground-based military systems on the mechanic's work, and support effective maintenance operations in the future?"

To address the main RQ, the Design Science (DS) research methodology of Peffers et al. has been used [4]. In doing so, the research first identifies TIs that are likely to impact the maintenance of ground-based military systems. These TIs are categorized based on their impact on maintenance processes, distinguishing between changes in the system itself and changes in the tools used for maintenance. The selection of TIs is informed by various sources, including technology trend lists, research projects, and interviews. Subsequently, different impact analysis methods are compared to identify relevant impact attributes. However, based on the literature research, ample impact models were found that were specifically designed for determining the impact on the mechanic's work.
Therefore, an impact model is designed that allows the RNLA to determine the impacts of TIs on its mechanics, and addressing additional sub-research questions (SRQs). The model considers changes in tasks, skills, facilities, support equipment, training, manpower, and job quality. The impact model has been constructed using three different case studies.

The case studies have shown that most, if not all, relevant impact elements have been addressed; however, it has also highlighted the inherent complexity and uncertainty of the future, underscoring the difficulty that is impaired with predicting the impact. Additionally, the case studies revealed that TIs do not necessarily make the work easier for the army mechanic and often bring additional complexities. This key finding emphasizes the need to proactively assess the impact of new TIs related to the mechanic.

As a result, this research represents the initial step in anticipating changes in the mechanics' work. This approach enables the identification of risks and opportunities posed by TIs for RNLA mechanics. Therefore, the impact model facilitates the transition toward a more effective approach, while underlining the necessity not only for mechanics to adapt to technology but also for technology to adapt to mechanics.

Theoretical implications of the research are discussed, emphasizing the importance of considering micro-level impacts of technology on maintenance personnel. The practical implications of the research are also highlighted, underscoring the need for the RNLA to anticipate future impacts. Although the impact model provides insights into potential future impacts, it also has limitations, particularly in addressing uncertainties.

In conclusion, the research contributes to scientific knowledge by offering a method for assessing the impacts of TIs on mechanics in the near future. The method helps to better grasp the complexities and challenges inherent in predicting and managing future impacts, providing a framework to address these issues within the RNLA.

Preface

After nearly 12 months of intensive work, many interviews and interesting meetings, a logistics symposium, hand-on experience with military equipment, such as tinkering with a tank and riding in the boxer, alongside attending various sports classes, participating in two races, and fueled by countless gallons of coffee, this report ends a very interesting period of study at the Dutch Ministry of Defense. This graduation project completes my time at the University of Twente, and is a result of my career as a Mechanical Engineering student. Therefore, I would like to take this opportunity to thank several people.

I would like to thank my first supervisor at the University of Twente, Jan-Jaap Moerman. From the beginning of my internship up to and including the end of my thesis, I appreciated your guidance and constructive feedback. This study could not have been what it is without the support and direction you have provided. In addition, special thanks are extended to the other supervisors of the University of Twente: Jan Braaksma and Willem Haansta, who helped me start this graduation project and provided valuable insights along the way.

Gratitude is also owed to the people of the Center of Excellence of Logistics (CoELog). For the continuous assistance, the enjoyable coffeebreaks in the inspiration room, and the many special activities that I could have been part of. A special thanks goes to my supervisors, Mark Tamis and Ruben Cornelissen, for their time, helpful discussions, and constructive feedback. I also would like to thank the commander of the CoELog, Ernst van de Steenoven, for his advice, life lessons, and unique insights; or as he might say: "Er gaan ook dingen goed".

Furthermore, I would like to express my appreciation to the fellow students with whom I have had the pleasure of graduating together at the CoELog. Britte Beusen, Rene van Osch, Anke van Bakel, Thijmen Wolken, and Jan Leusink; Your companionship, combined with our engaging conversations and shared experiences, has made this journey even more memorable and fulfilling.

My sincere thanks go to the individuals who have assisted me in conducting this study. Although I cannot mention everyone by name, I am grateful for their warm welcome into their organization and their enthusiastic assistance. Without their knowledge and support, this research would not have been possible.

I would also like to express my gratitude to my friends in Enschede, for the countless memorable experiences. A big thanks goes out to the housemates from 'Huize De 7e Kater,' with whom I have survived the lockdowns during the pandemic and shared countless memories. Moreover, a special thanks goes out to my friends from 'HJC Agoge', with whom I have enjoyed many memorable moments.

Special thanks go out to my fellow mechanical engineering students, particularly Tim Dissevelt, Jasper Horn, Mohamed Eldesouky, and Rob van der Duim, with whom I have spent countless study sessions, endured projects that seemed endless, and faced the ever-challenging exam weeks together. Your camaraderie and support have been invaluable throughout this journey.

In addition, I extend my gratitude to Julia Wezendonk and Jasper Wieringa for the shared experiences of graduating at the Ministry of Defense. Your companionship and shared experiences have been invaluable during the last year of my study.

I would like to express my appreciation to my parents, grandparents, and brothers for their support. Not only during my thesis, but always.

Finally, I hope that this study not only will help the CoELog and the University of Twente in their further endeavors, but also contributes to the academic world of research.

Stijn Koopmans
Soesterberg, April 2024

Contents

List of Abbreviations

AI Artificial Intelligence

AM Additive Manufacturing

AR Augmented Reality

BDU Battery Disconnecting Unit

BDR Battle Damage Repair

CAN-BUS Controller Area Network - Binary Unit System

CDE Concept Development & Experimentation

CI Configuration-item

CoELog Centre of Excellence of Logistics (Dutch: Kenniscentrum Logistiek)

COMMIT Command of Materiel and IT (Dutch: Commando materieel & IT)

DLM Depot Level Maintenance

DMOD Dutch Ministry of Defense

DoT Department of Tech (Dutch: Afdeling Tech)

DS Design Science

ECU Electronic Control Unit

ES Equipment Support (Dutch: Materieeldienst)

ETC Education and Training Command (Dutch: Opleidings- & Trainingscommando)

EV Electric Vehicles

HEL High-energy lasers

HFEA Human Factors Effect and Analysis

HV High-voltage

ICE Internal Combustion Engine

ILM Intermediate Level Maintenance

ILS Integrated Logistic Support

KI Knowledge & Innovation

LIAA Lifetime Impact Identification Analysis

LRU Line-Replaceable Unit

MatlogCo Materiel Logistics Command

MDR Maintenance, Diagnosis and Recovery (Dutch: Onderhoud, Diagnose, en Berging)

MSU Maintenance Support Unit (Dutch: Hersteleenheid)

OLM Organic Level Maintenance

PdM Predictive maintenance

RAS Robotic & Autonomous Systems

REC Regional Education Centre

RNLA Royal Netherlands Army (Dutch: Koninklijke Landmacht)

RQ research question

STM School Technology & Maintenance (Dutch: School Techniek & Onderhoud)

SRQ sub-research question

TCR Techniek College Rotterdam

TI Technological Innovation

TIM Technology Impact Method

UGV Unmanned Ground Vehicle

VR Virtual Reality

WSM Weapon System Management

XR Extended Reality

Chapter 1

Introduction

The incursion of Russia into Ukraine in 2020 sent shockwaves across the globe, underscoring the critical necessity of maintaining a robust and readily deployable military force. It served as a stark reminder that the pillars of freedom and security must never be taken for granted. The DMOD stands as a bulwark against threats, striving tirelessly for a secure future. Central to this mission is the imperative for armed forces that are adaptable and capable of swift expansion [5].
Integral to the effectiveness of the DMOD are its technologically advanced equipment and systems, which play a central role in operational success. Ensuring the materiel readiness of these systems falls upon the shoulders of the mechanics, who need to have the knowledge and skills to ensure that these systems are consistently prepared for deployment and action.
However, technology is evolving rapidly, and this also applies to the Defense Industry. Technologies such as Artificial Intelligence (AI), Additive Manufacturing (AM), Virtual Reality (VR), digitization and Robotic & Autonomous Systems (RAS) are becoming much more common, causing a change in the way an organization operates. Consequently, the rapid developments in technology demand new skills from technical employees.

Recent acquisitions of new assets have exemplified the challenges faced by maintenance organizations, particularly with respect to Intermediate Level Maintenance (ILM). This predicament arises from the procurement of highly complex systems in insufficient quantities, leading to a discrepancy between the demands placed on these systems and the demands allocated for their upkeep. For instance, this issue is evident in the acquisition of the CV-90 combat vehicle.
This is due to the fact that the increasing complexity of these systems necessitates greater efficacy from maintenance organizations (and its mechanics). Unfortunately, there has been a persistent shortage of funding allocated to the RNLA maintenance organization, further increasing the challenge. One contributing factor to this problem is the allocations of military ranks (and corresponding salaries) within the RNLA maintenance organization, rendering it less competitive in the job market. This is especially concerning considering the already prevalent shortage of technically educated personnel. Consequently, the maintenance organization struggles to attract and retain skilled employees, further hindering its ability to meet the evolving demands of modern technology.

An illustrative example of an impactful TI can be found in the initial adoption of the Controller Area Network - Binary Unit System (CAN-BUS) in vehicles. This innovation revolutionized the mechanics approach to problem-solving, shifting from traditional and primarily physical diagnostics to digital methodologies. Consequently, mechanics, particularly those of older generations with less comprehensive training in these advanced systems, face new challenges that require proficiency in not only mechanical, but also electrical engineering principles. As such, this research aims to anticipate and address future challenges faced by mechanics and assist the RNLA in effectively navigating the complexities introduced by emerging technologies.

1.1 Introduction to case organization

A key component of the armed forces is the RNLA, with the main task of contributing on the ground to freedom, security, and prosperity in the Netherlands and abroad. Comprising skilled and proficient soldiers, the RNLA is equipped to conduct combat operations, provide humanitarian aid or support during disasters under all circumstances. [6]
The effective utilization of technologically advanced systems is fundamental to the RNLA's ability to fulfill its duties. However, like (almost) all technological systems, they require continuous maintenance to remain operational. Ensuring the availability of three key elements: adequately trained mechanics, spare parts, and sufficient time is essential to maintain these systems at peak performance [7].
This is where the Equipment Support (Dutch: Materieeldienst) (ES) (in Dutch: Materieeldienst) assumes a crucial role. The prime responsibilities of the ES encompass supply, maintenance, relocations, infrastructural support, and logistic services. The ES focuses on the maintenance of the equipment that a commander has available. Serving as the only logistics organization, the ES is not solely tasked with duties during combat operations; it also plays an indispensable role in peace management, providing essential support to uphold the materiel readiness at peak level.

Department Description

This research has been conducted at the Centre of Excellence of Logistics (Dutch: Kenniscentrum Logistiek) (CoELog) of the RNLA. The CoELog is approximately 30 years old and strives for robust logistics. One of the tasks of the CoELog is to keep an eye on all technological developments in the field of logistics, including the work of the RNLA mechanic.

1.2 Problem statement

As mentioned in the previous section, the fundamental task of the RNLA is to execute operations that contribute to peace, freedom and security in the Netherlands and abroad [6]. To effectively execute these operations, the army needs high-tech equipment. However, maintaining these advanced systems requires adequate training and education for army maintenance personnel. They need to be able to perform maintenance activities to ensure that the assets remain operational.
In recent decades, the RNLA has almost continuously faced a large number of technological developments that have had their effect in the equipment acquired. This is certainly true for ground-based weapon systems. It can be argued that there was a technological revolution rather than a technological evolution. Simultaneously, the RNLA experienced major adverse effects of cutbacks resulting from relaxations in the geopolitical security situations [8]. This combination often caught the maintenance organization off guard, constantly dealing with unexpected challenges. Consequently, at this moment the maintenance organization was unable to adjust in the required manner. It just is not adapted to the actual requirements. Therefore, the main problem is the lack of insight into the impact that future TIs will have on the required skills and capacities. To ensure that personnel are properly trained and equipped to deal with continually changing technological assets, the organization needs to know the effects of TIs on the professional maintenance tasks that the RNLA mechanics have to perform.

1.3 Current state of research

1.3.1 Research context

This research takes place in the domain of Asset Management, which can be defined as: "coordinated activity of an organization to realize value from assets" [9]. Asset Life Cycle Managment (ALCM), a sub-discipline of Asset Management, focuses even more specifically on the whole life cycle of assets, and "refers to the management of assets over their complete life cycle, from before acquisition to disposal, taking into account economic, environmental, social and technical factors and performances" [10].

Various classifications of life cycle phases have been proposed for ALCM, "ranging from only three phases (acquisition phase, utilization phase, recycling phase) to 8 phases (strategy, plan, evaluate/design, create/procure, operate, maintain, modify, dispose)" [11]. However, to provide clarity in the context of this research, we adopt the framework of Weapon System Management (WSM), which identifies three main phases: the provide-in phase, use phase, and disposal phase.
Given that this research centers on the impact of future technologies, it primarily focuses on the "provide-in" phase. This phase involves the acquisition of new assets or significant modifications/expansions to existing ones.

1.3.2 Research gap

This research, delves specifically into the frequently overlooked impact of TIs on mechanics. While the existing literature in maintenance engineering and asset management offers numerous methods to assess impacts or risks, most of these approaches focus on macro-level (technical) considerations, disregarding the pivotal role played by personnel—the mechanics—in maintenance organizations [12, 10, 13, 14, 15]. This can be explained because organizations commonly focus on the developments from a 'technology push' perspective, with the result that the impact on the work as a consequence of technology is often more the issue than the other way around [16].

Mechanics represent not just the workforce, but the linchpin of maintenance operations, whose adaptation to and utilization of TIs profoundly influence organizational success [17]. However, the current lack of focus on their challenges in the midst of technological change underscores a critical gap in the field [18].

In contrast to other sectors where the impact of TIs on the workforce has garnered attention, such as studies reviewing the recent accounting literature focusing on emerging technologies' effects on accountants' roles and skills [19], there is a notable absence of similar investigations concerning mechanics.

Therefore, this research endeavors to develop an instrument tailored to analyse the impacts of TIs on mechanics within maintenance organizations. By doing so, it aims to assist these organizations not only in understanding the challenges faced by their workforce, but also in proactively anticipating and mitigating future issues.

This instrument, yet to be developed, promises to offer a unique contribution to the field by filling a crucial gap in existing methodologies. By recognizing and addressing the human element in maintenance operations, it has the potential to revolutionize how organizations manage technological change and optimize their workforce's performance.

In summary, this research not only sheds light on an underexplored aspect of asset management, but also offers a practical tool to improve organizational resilience and efficiency in the face of TIs.

1.4 Research questions

In this section, the RQs are proposed. First, the main RQ is provided which is supported by 3 SRQs. The goal of this research is to assist the RNLA maintenance managers (which are supported by the CoELog) in ensuring that their mechanics at all maintenance levels are future proof by developing and designing an instrument that can support them in identifying TIs, determining the impact, and selecting the right skills and capabilities methods to ensure that all systems can be maintained. In turn, this will help ensure that the RNLA can effectively perform its tasks. Therefore, the main RQ is formulated as follows:

1.4.1 Main research question

"How can the Logistic Centre of Excellence (in the role of maintenance policy advisor) anticipate the impact of technological innovations in ground-based military systems on the mechanic's work, and support effective maintenance operations in the future?"

1.4.2 Sub-research questions

The main RQ will be answered using several SRQs, which are discussed in this section.

1. Which TIs are foreseen to have an impact on maintaining (or supporting maintaining) ground-based military systems?

This question aims to identify which TIs are anticipated to have an impact on maintaining or supporting ground-based military systems. It emphasizes the importance of recognizing these TIs and understanding their potential effects. Additionally, identifying the TIs is a necessary step to evaluate their impact, aligning with the main research question.

2. How can the Logistic Centre of Excellence (in the role of maintenance policy advisor) be supported in determining the future impact of specific TIs on the mechanics maintenance tasks and skills?

This question is pivotal for the main RQ as it delves into the CoELog's responsibility in foreseeing the effects of TIs on mechanics. It investigates the necessary information that the normsetter (advised by the CoELog) eventually requires to effectively face challenges, capitalize on opportunities, and proactively mitigate future problems arising from TIs.

3. Which tools/instruments are available to identify the impact of both types of TIs and successfully cope the challenges?

This question considers the existing literature on risk assessment/impact analysis tools. It is essential as it establishes a scientific foundation for addressing the main RQ.

Moving forward, the subsequent chapters of this master's thesis will refer to the SRQs as SRQ1, SRQ2, and SRQ3 respectively. This adjustment will improve clarity in discussing the research objectives and findings.

1.5 Research method

The research originated from a practical problem outlined in section 1.2, which can in short be described as insufficient insight into the impact of TIs on the RNLA mechanic required skills and capacities. Consequently, the research goal is to assist the organization in addressing this challenge by developing a tool or instrument to improve the understanding of the impact of TIs on its mechanics. Therefore, the DS research method has been selected because of its suitability to address practical problems. The process of this method, as described by Peffers et al. [4], is depicted in Figure 1.1. In the remainder of this section, this method and its utilization within this research is explained.

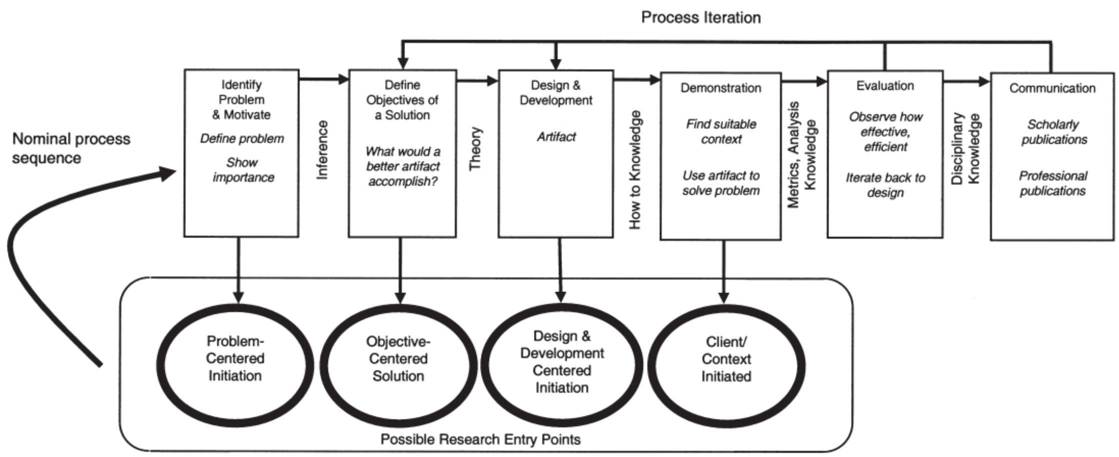

Figure 1.1: Design science research methodology process model from Peffers et al [4]

Step 1: problem identification & motivation; As this research starts with a problem-centered initiation, the first step is the problem identification & motivation. In this step, the specific research problem is defined and the value of a solution is justified [4]. The practical problems that DS research aims to solve, are often complex and have both social and organizational components. This complexity can cause the problems to become 'ill-structured.' The challenge is often not finding or identifying the problem, but rather framing the problem [20]. In this paper, the problem has already been stated in section 1.2. Identification of the problem has been done in close collaboration with the CoELog.

Step 2: define solution objectives; The solution objectives show how the artifact is expected to support solutions to the problems addressed in the first step. The objectives are inferred rationally from the problem specification. In collaboration with the input of the CoELog, the design objectives of this research are described in chapter 4.

Step 3: design & development; An artifact is created. Artifacts are potentially constructs, models, methods, instantiations or new properties of technical, social, and/or informational resources [4]. An artifact can essentially be any designed object in which the research contribution is embedded in the design [4]. The artifact in this research is an impact analysis model, from which the initial design is described in chapter 6. This initial version has been designed using the input from the literature, described in chapter 5 and the input from the normsetters (N-1, N-2, and N-3), using the interview questions described in section A.2.

Step 4: demonstration; In the fourth step of the DS process, the artifact is demonstrated by solving one or more instances of the problem. For this research, this is done using case studies. In these case studies, several experts from multiple disciplines have been interviewed to receive input for impact analyses (which can be found in Table 1.1), the interview questions used are described in section A.3. The demonstration of the initial design is described in chapter 7. The resources required for this include effective knowledge of how to use the impact model [4].

Step 5: evaluation; In this step, the artifact is evaluated on how well it supports the solution to the problem. This evaluation is based on the knowledge and experience gathered from the previous step in which the artifact was demonstrated. This can, for example, contain a comparison with the solution objectives, which are described in the second step of the DS process. The evaluation can also contain quantifiable measures of a system performance, such as empirical evidence or logical proof. However, since this research focuses mainly on non-quantifiable impact characteristics, the evaluation is performed primarily using feedback from the CoELog, which is described in chapter 8.

Step 6: redesign; After evaluating the results of the demonstration, the decision can be made whether to iterate back to one of the previous DS research steps to improve the design or continue with communication and leave further improvements to subsequent projects [4]. This decision, dictated by the nature of the research venue, has been made to make a design iteration, which is stated in subsection 8.2.2.
The redesign of the impact model is then demonstrated in chapter 9. After the redesigned impact model has been demonstrated, the results are discussed in chapter 10.

The complete process followed by this research is visualized in Figure 1.2.

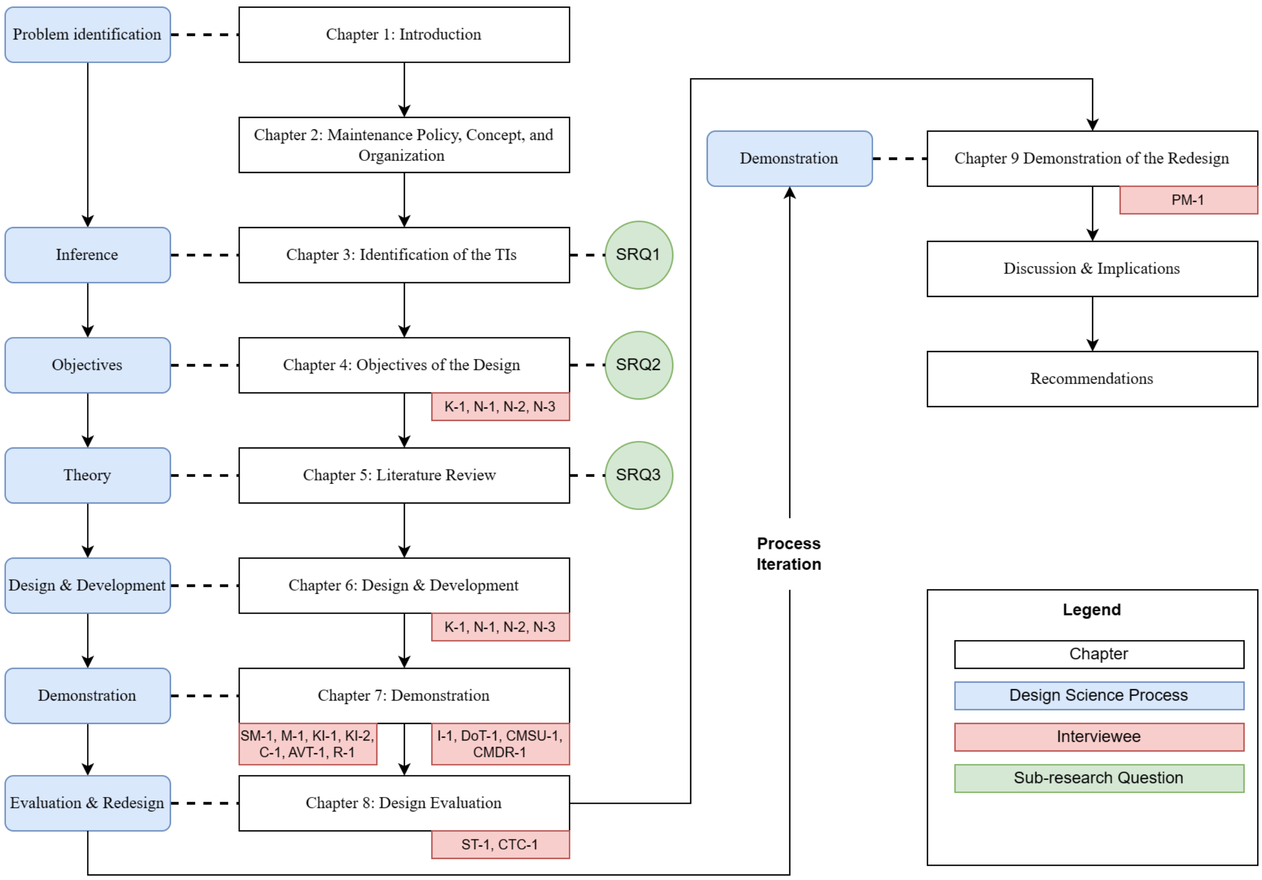

Figure 1.2: The diagram illustrates the research outline, showcasing the application of the DS research methodology throughout the study. It highlights the specific chapters where the SRQs are addressed and the relevant interviewees who have been involved, providing a visual representation of the research process.

1.5.1 Interviews and input

In this section, an overview of all the people involved in this research is presented in Table 1.1. A total of 18 people were interviewed for the outcome of this research. A semi-structured interview design was used to interview participants, as the interviewees have a wide range of background. Depending on the background of the interviewee, more detailed (follow-up) questions were asked for specific topics. The semistructured approach also allowed flexibility when developing the impact model, which provided the ability to add, change, or remove questions as the model developed. Therefore, the set of standard questions differs with each version of the impact model. The interview question sets used are shown in Appendix A.
The interviewees were selected on the basis of their various backgrounds. This variety allowed researchers to integrate different perspectives on the impact elements discussed. Interviewees are referred to using alpha-numeric abbreviations, which are found in Table 1.1. The reason for this is that even though it is not a common method, it is found valuable for this research to use this display method as it improves the readability.
The different (sub)departments of the interviewees are:

- Command of Materiel and IT (Dutch: Commando materieel & IT) (COMMIT)
- Concept Development & Experimentation (CDE)
- Education and Training Command (Dutch: Opleidings- & Trainingscommando) (ETC)
- Materiel Logistics Command (MatlogCo)
- 13th Light Brigade
- CoELog
- WSM
- RAS
- Maintenance Support Unit (Dutch: Hersteleenheid) (MSU)
- Maintenance, Diagnosis and Recovery (Dutch: Onderhoud, Diagnose, en Berging) (MDR)
- School Technology & Maintenance (Dutch: School Techniek & Onderhoud) (STM)
- Techniek College Rotterdam (TCR)

Number of People	Company	Department	Subdepartment	Function	Reference in Paper	Participation	Date of interview
1	DMOD	COMMIT	Knowledge & Innovation (KI): Energy & Mobility	Manager	KI-1	Initial interview & Case 1: Focus-group session	26-10-2023 22-11-2023
2	DMOD	COMMIT	WSM	Normsetter	N-1	Initial interview	30-10-2023
3	DMOD	COMMIT	WSM	Normsetter	N-2	Initial interview	1-11-2023
4	DMOD	COMMIT	WSM	Normsetter	N-3	Initial interview	3-11-2023
5	DMOD	CDE	RAS unit	Sergeant major Maintenance Advisor & Support	SM-1	Case 1 Interview	15-11-2023
6	DMOD	ETC	STM	Instructor	I-1	Case 2 Interview	16-11-2023
7	DMOD	MatlogCo	WSM	Maintainer	M-1	Case 1 Interview	21-11-2023
8	DMOD	COMMIT	KI: Energy & Mobility	Manager	KI-2	Case 1 Focus-group session	22-11-2023
9	DMOD	COMMIT	WSM	Chairman	C-1	Case 1 Focus-group session	22-11-2023
10	DMOD	MatlogCo	Department of Tech	Advisor vehicle technology	AVT-1	Case 1 Focus-group session	22-11-2023
11	DMOD	ETC	CoELog	Researcher	R-1	Case 1 Focus-group session	22-11-2023
12	DMOD	MatlogCo	Department of Tech	Group of maintenance engineers	DoT-1	Case 2 Focus-group session	6-12-2023
13	DMOD	13th Light Brigade	MSU	Commander MSU	CMSU-1	Case 2 Interview	11-12-2023
14	DMOD	13th Light Brigade	MDR-group	Commander MDR-group	CMDR-1	Case 2 Interview	11-12-2023
15	TCR	Mobility, Secondary vocational education level 3		Senior teacher	ST-1	Case 1 Interview model development	30-1-2024
16	ANWB	CoE Knowledge & Development		Coordinator technical courses	CTC-1	Case 1 Interview model development	2-2-2024
17	DMOD	COMMIT	DO-MAINT	Project manager	PM-1	Case 3 Interview	21-3-2024
18	DMOD	ETC	STM	Instructor	I-2	Model validation	4-3-2024

Table 1.1: Overview of interviews and focus-group participants

1.6 Research outline

In this section, the structure of the research is outlined. Chapter 2 delves into the current maintenance policy, concept, and organization of the RNLA. Following this, chapter 3 provides an overview of emerging technologies expected to impact mechanics in the upcoming 5 to 10 years. This chapter underscores the crucial need to understand the implications of these TIs on mechanics.

Moving forward, chapter 4 discusses the objectives of the proposed solution, developed in collaboration with the CoELog. This chapter corresponds to the second step of the DS research methodology as proposed by Peffers et al. [4], directly addressing SRQ2.

Subsequently, chapter 5 conducts a review of the literature, laying the scientific foundation for the impact analysis instrument. Through this exploration, SRQ3 is addressed.

Chapter 6 focuses on the initial design of the impact model, representing the third step of the DS research methodology outlined by Peffers et al. [4]. This design is formulated based on predefined solution objectives, design criteria, and insights obtained from existing impact assessment literature. Furthermore, this design undergoes validation through interviews with normsetters (N-1, N-2, and N-3).

In chapter 7, the previously outlined design is put to the test using two distinct cases: electrification of armoured vehicles and the impact of increased data usage within maintenance operations. Recognizing the multidisciplinary nature of impact analyses, stakeholders from various disciplines were interviewed to provide input for the model, as detailed in Table 1.1.

Chapter 8 critically evaluates the processes employed in the initial two case studies in collaboration with CoELog. Subsequent improvements to the impact model are derived from feedback obtained from external parties (ST-1 and CTC-1) and enriched with additional literature substantiation, particularly from the Technology Impact Method (TIM) method described in subsection 5.1.3.

Chapter 9 demonstrates the redesign of the impact model in a third case study concerning the digitalization of the inspection work card.

Upon completion of the model design and evaluation process, chapter 10 engages in a comprehensive discussion of research findings and their implications.

Finally, chapter 11 culminates in the provision of management recommendations derived from the research outcomes.
This process has also been visualized in Figure 1.2.

Chapter 2

RNLA Maintenance Policy, Concept, and Organization

This chapter serves to elucidate the current maintenance policy, concept, and organization of the RNLA, aiming to furnish the reader with a contextual understanding of the maintenance framework within which this research has been conducted. Initially, an introduction of the most relevant maintenance terms used by the RNLA is presented. Subsequently, the chapter delves into an exposition of the maintenance policy. Building upon this policy, the RNLA has devised a comprehensive maintenance concept tailored to encompass peacetime operations, missions within the lower spectrum of violence, and large-scale combat scenarios. In adherence to the guiding principles delineated in the policy, the RNLA has engineered a maintenance organization that is both efficient and effective. Finally, the chapter sheds light on the roles within the WSM, offering insight into the end-users of the instrument developed in this research.

2.1 Terms and definitions

In this section, the relevant maintenance terminology is presented in Table 2.1. These terms serve as the foundational vocabulary for understanding the maintenance framework discussed throughout this research.

2.2 Maintenance policy

Due to the hazardous environment in which the RNLA assets will be deployed, a high rate of availability is key requirement in the procurement process. Therefore, reliability and maintainability are two main criteria. To realize a high rate of availability, the guiding principle of maintenance is that unserviceable equipment should be repaired as far forward as operationally possible and technically feasible (Repair forward). Preparing for missions while staying in barracks, maintenance capacity will always be available in the neighborhood of the units to support. In case of (exercises to train for) large-scale combat operations, specific selected maintenance capacity will be deployed as close to those units as possible.

2.3 Maintenance concept

Depending on the complexity of a repair, it will take more or less time, more or less spares, more or less high value tools and more or less technical skills. Therefore the maintenance concept has four different maintenance levels, which are described in Table 2.2
At this moment level 1 and 2 generally are mentioned as Organic Level Maintenance (OLM). Level 3 has been called ILM and level 4 is known as Depot Level Maintenance (DLM).

Term	Description
Maintenance	All actions taken to retain equipment in or to restore it to specified conditions until the end of its use, including inspection, testing, servicing, modification(s), classification as to serviceability, repair, recovery, rebuilding, reclamation, salvage and cannibalization.
Maintainability	The ability to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance.
Preventive maintenance	Systematic and/or prescribed maintenance intended to reduce the probability of failure.
Corrective maintenance	Maintenance carried out after fault recognition and intended to restore equipment to a state in which it can perform a required function. Within NATO and consequently RNLA several types of corrective maintenance haven been recognized.
Modification maintenance	The part of maintenance aimed at the permanent improvement of the operational usefulness, the safety, the reliability, or the maintainability of a certain type of equipment-piece.
Standard repair	In peacetime, maintenance focuses on the prevention and economical repair of technical faults in equipment. Repair procedures must reflect the statutory requirements of each nation including the host nation as regards safety, accident prevention and legal requirements for use of the equipment. Such 'full' or 'standard' repairs will generally comply with approved standards set by those responsible for designing and/or supporting the equipment.
Expedient repair	Repair to restore an equipment to a specified condition by non-conventional and/or improvised means [21]. There are two types: 1. An improvised, non-conventional repair that is of sufficient engineering quality and robustness to be considered as permanent, so allowing the continued use of the equipment, and does not require subsequent replacement. This repair must meet any legal and safety requirements (type 1). 2. An improvised, non-conventional repair that is considered only temporary in nature, allowing the equipment to complete the immediate mission or task, before being replaced by a conventional repair. This repair should meet the agreed legal and safety requirements (type 2).
Battle Damage Repair (BDR)	Essential repair, which may be improvised, carried out rapidly in a battle environment in order to return damaged or disabled equipment to temporary service.

Table 2.1: The most relevant maintenance term described by the RNLA [22]

Maintenance level	Description
Level 1	The system can be restored by the user, with the tools, consumables and procedures prescribed at subunit level. These will tend to be simple tasks, including the replacement of knobs, bulbs, road wheels and batteries or rebooting computers.
Level 2	The system can be restored by maintenance personnel, using the tools, spares, consumables and procedures prescribed at unit level. These will be more involved but straightforward tasks, which require a degree of diagnosis and technical competence. Repairs might include the replacement of spares or sub-assemblies, tuning, alignment and welding.
Level 3	The system can be restored by maintenance personnel using tools, spares, assemblies and procedures prescribed for use in mobile workshops. These will be more involved and time-consuming activities, which may require special tools, facilities and highly trained maintainers. Examples might include the replacement of major assemblies, the repair of sub-assemblies, optical alignment and limited manufacture of mechanical components.
Level 4	The system can be restored by maintenance personnel using special tools and test equipment in static workshops operated by the maintainer or Supplier. Such repairs would tend to be complex and may take a considerable period of time. They might encompass complete rebuilds, the replacement of component parts, calibration and manufacture under controlled conditions.

Table 2.2: The four different maintenance levels used in the RNLA maintenance concept.

2.4 Maintenance organization

Each RNLA unit (company level) has a so called MDR. The commander is responsible for advising level 1 maintenance, will focus on level 2 maintenance, might execute less complex level 3 maintenance and is the special maintenance advisor of the unit commander. Each brigade has a maintenance company consisting of several MSUs specifically designed to deliver equipment support (level 3) to each specific brigade unit. If desirable/necessary and possible, during exercises, missions and/or operations those MSUs or elements of it can and will be deployed as close as possible to the unit to be supported. Level 4 maintenance will be executed in static workshops either military or civilian. In a MDR group specific military personnel has been classified to execute limited maintenance tasks foreseen. In the MSUs of the brigade maintenance company three types of mechanics are active: vehicle technician, electric technician and weapon system technician. All three receive a special education and will improve their skills by executing both preventive and corrective maintenance while staying in the barracks or supporting training exercises.

2.5 Characteristics of the army mechanic

Traits of a military mechanic differ significantly from their civilian counterparts. In the RNLA, these mechanics serve dual roles, not only as technicians but also as soldiers, operating in more varied and less predictable environments. Primarily, their focus lies on military duties rather than mechanical tasks. Their loyalty prioritizes their unit, relegating their role as mechanics to a secondary duty. Consequently, they dedicate fewer annual hours to mechanical work compared to civilian mechanics.

2.6 Sustainment during lifetime cycle

The RNLA distinguish three kinds of systems: A, B and C. A-systems are face-determining systems for the DMOD. The A-systems could also be described as 'the main weapon systems'. A-systems are complex in configuration and are usually quite heavy. The A-systems are meant to fulfill a prominent function in an armed conflict. B-systems form a larger group of military systems that are not directly face-determining for the DMOD. However, they do contribute to the projection of air, sea, and land power. The complexity of these configurations can range from simple to complex systems. C-systems do not contribute to the projection of air, land, and sea power. C-systems often fulfill a supporting role. When introduced in the organization maintenance history of A- and B-systems will be collected and necessary measures will be taken to secure the desired/requested availability. On a regular basis at DMOD level, represents of the standard authority, the maintenance organization and the units using A- and or B-systems come together in a consultation meeting: the so called WSM team. During those consultation meetings all kind of issues will be discussed in order to keep availability at the highest rate possible and prepare maintenance if necessary, for instance midlife update maintenance to implement new technologies. [23]

2.6.1 Weapon System Management roles

A WSM-team consists out of 4 people: (i) the chairman, (ii) normsetter, (iii) maintainer, and (iv) user.

The chairman coordinates the processes between the normsetter, the maintainer, and user within all phases of the life cycle.

The normsetter is responsible for establishing standards aimed at improving safety and cost-effectiveness of the system. This involves considering the functional requirements and availability needs communicated by the user. The normsetter also oversees the compliance with the standards and may suggest deviations from the standards if necessary. Furthermore, the normsetter monitors and updates technical and usage standards, monitors technical and economic lifespan, manages the system and ILS plans, and more.

The maintainer is responsible for the readiness of the system and controlling the maintenance. The maintainer follows the instruction provided by the user and the normsetter. In addition, the maintainer is responsible for the operational budget and carries out maintenance activities outside the operational environment, administers the performance contracts, and supports the user and normsetter.

The user monitors the usage of the system and its operational life, performs maintenance during missions and operational exercises, manages the operational budget, and also supports the maintainer and normsetter. [23]

Chapter 3

Identification of the Key Technological Innovations

In this chapter, SRQ1 is answered. First, an overview of all TIs that will likely have an impact on the RNLA mechanic is provided. These TIs are then elaborated in section 3.1 and section 3.2. The list of upcoming TIs underlines the necessity of having a grip on the future and knowing what the consequences of a TI for the mechanic will be. This list also serves as a reference in subsequent chapters for selecting TIs to develop and implement within the impact model.

In this research, a TI is defined as the "creation and application of new or improved technologies, tools, systems, and processes that bring about significant advances or breakthroughs in various fields" [24]. Using this definition, a selection of TIs with a potentially significant impact on the RNLA mechanic is created. The selection is based on the technological readiness in the upcoming 5 to 10 years, the relevance to ground-based military systems, the estimated impact that it will have on maintenance management, and their relevance to the maintenance tasks of the mechanic himself. The technologies are mostly inspired by technology trend-lists/vision statements of the DMOD [25, 5, 26, 27], research pilots/projects of the DMOD (found on the internal innovation website of the DMOD: innovatie.mindef.nl), and external technology impact vision statements [28, 29].

An overview of the relevant TIs is displayed in Figure 3.1. This selection of TIs is still a global vision, and it is uncertain whether its impact on the RNLA mechanic will be significant. However, the overview provides a basis for selecting a TI on which an impact analysis can be performed [12]. These TIs are selected as a global technological trend, but are not yet defined concretely. For example, Extended Reality (XR) can be applied in several methods. It can be used to assist the mechanic during their education/training [30, 31, 32, 33], but it can also be used as a tool in the field to let an expert support the mechanic remotely with difficult tasks [34, 35]. Therefore, this overview is to be used as a basis for the selection of a TI which can then be worked out more elaborately.

Furthermore, the TIs can be integrated within the organization in different manners. Firstly, innovations that affect the system itself, such as the transition of diesel motors to electric motors, are only affecting newer systems that will be built in the future or current systems that will be modified. However, a TI also can affect the tools of the mechanic. This means that it does not necessarily affect one system, but it can be relevant for the work practises of the mechanic on multiple systems, e.g. the use of 3D-printing, or XR.

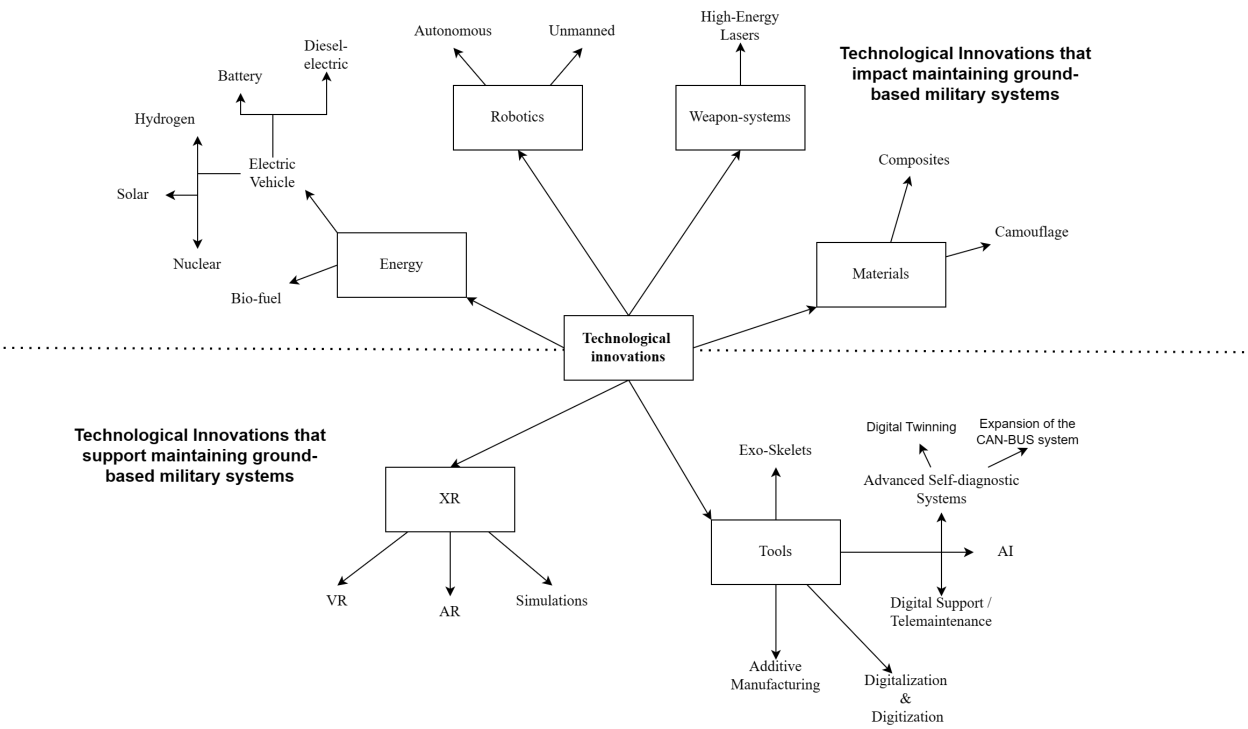

Figure 3.1: Overview of the different innovation categories

3.1 TIs that impact maintaining the ground-based military systems

In this section, the first part of SRQ1 is answered. The identified TIs that will have an impact on the maintenance of the ground-based weapon systems are elaborated upon. This means that these technologies will only be implemented by the RNLA when acquiring new equipment or when the existing equipment receives a modification update. The technologies identified in this section are: electrification of the drive train, RAS, High-energy lasers (HEL), and composites.

3.1.1 Electric vehicles

The share of Electric Vehicles (EV)s in the Dutch vehicle fleet is growing [28]. The European Parliament has decided that in 2035 no more new Internal Combustion Engine (ICE) vehicles powered by diesel or gasoline are allowed to be sold within her borders [36]. This policy is one of many, that forces the country to make the transition from fossil fuels towards clean energy. As the number of EVs will grow, and the number of ICE-vehicles will decrease, the RNLA is posed with a challenge; namely, the maintenance of the ICE vehicles in the future. As the RNLA purchases her assets for a long life cycle, it might mean that in the future there will be less mechanics specialized for the diesel ICE, as the industry is transitioning towards EVs.

Furthermore, even though at the moment most of the assets of the RNLA are diesel powered, the DMOD is working on solutions to become less dependent on fossil fuels in 2050 [26]. Electrification and hybridisation of vehicles/platforms are one of the main developments within the energy transition [25]. This electrification will not only affect the procurement of new assets, but also the supply parts and the technical knowledge for repair and maintenance [37].

There are several types of EVs. An electric vehicle requires two features: "(i) The energy source is portable and electrochemical or electromechanical in nature, and (ii) traction effort is supplied only by an electric motor" [38]. However, besides EVs there are also hybrid electric vehicles (HEVs). HEVs generally use an ICE in conjunction with one or more electric machines for propulsion [38]. In this research EVs are differentiated into 3 types, namely: (i) battery electric vehicles, (ii) hydrogen fuel cell (HFC) vehicles and (iii) hybrid vehicles.

Battery electric vehicles

The first category is battery electric vehicles. In this type, the energy of the vehicle is stored within a battery-pack for energy delivery upon demand [38]. Disadvantages of battery-electric is the limited energy density of the battery-packs, which causes the vehicle to have a lower range when using the same volume of space [39]; as depicted in Figure 3.2.

Hydrogen fuel cell vehicles

Hydrogen offers another solution for the transition towards zero emissions. Wind and/or solar power produced at contingency bases could power electrolyzers to produce hydrogen [39]. Hydrogen (combined with oxygen) is used to power the fuel cell, which then produces electricity through a chemical reaction [38, 40]. The electricity produced is used to power the electric vehicle.
An important advantage of fuel cells compared to batteries is that the refueling of hydrogen can be much faster than battery refueling in an electric vehicle [40].
A study carried out on US Army vehicles showed that currently commercial hydrogen fuel cell technology does not have the theoretical capability to deliver the same amount of operational capabilities as fossil fuel tracked vehicles [39]. However, they also show promising increases in operational capabilities with the expected developments within the hydrogen technology sector. The results of this study are depicted in Figure 3.2.

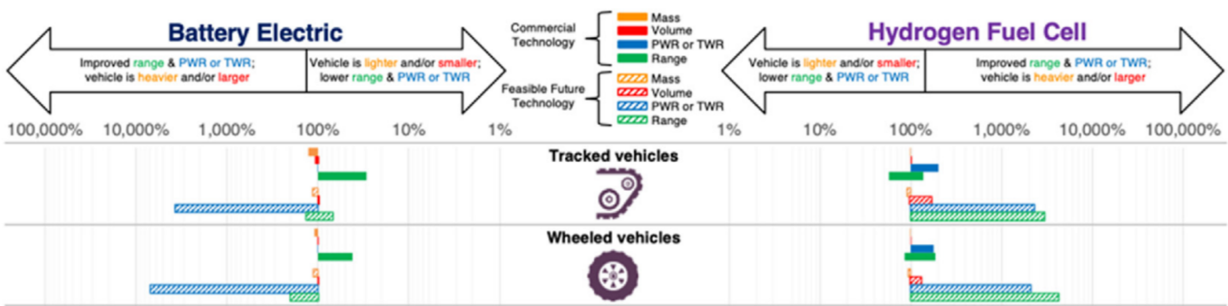

Figure 3.2: Feasible characteristics of Battery EVs and Hydrogen Fuel Cell EVs are compared to existing ICE vehicles upon conversion with equal or improved overall vehicle power to weight ratio (PWR). Solid bars represent commercial technology. Hatched bars represent future feasible technology suggested by the literature. [39]

Hybrid vehicles

The hybridization of military vehicles has been identified as one of the most important developments in the energy-transition by the Defense Technology Exploration report in 2020 [25]. This is because hybrid vehicles offer numerous advantages, such as the better fuel economy, more volumetric design flexibility, more silent operation capability, lower thermal signature, and the capability to produce a higher amount of electric power generation [41, 42].

3.1.2 Robotic & autonomous systems

Unmanned Aerial Vehicles (UAVs) have become an essential feature of land operations. This technology has been widespread and is used by the military's of almost all countries [43]. The armed conflicts initiated by the Arab spring in 2011, the fighting in Nagorno-Karabakh in 2020 and the conflict currently going in

Ukraine have demonstrated the significance of these UAVs [44].
Not only the aerial variant of unmanned vehicles have shown to be of significance in military operations, similar growth is expected to occur in other unmanned systems, such as the Unmanned Ground Vehicles (UGVs) [44, 45]. Besides UAVs and UGVs, there are other variants of unmanned systems which also have been deployed in military operations. These include robotic ground platforms (RGPs), unmanned surface vessels (USVs), and unmanned underwater vessels (UUVs), as well as unmanned weapons and surveillance systems (UWS) [46]. However, as the scope of this research is limited to ground-based military vehicles, this section will focus on UGVs.

The RNLA is currently also exploring the opportunities of UGVs [47]. For example, they are testing the effectiveness of the MilRem vehicle, which is shown in Figure 3.3. This remote controlled vehicle is intended for multiple tasks in areas such as transport, reconnaissance or combat operations [48]. The reason for testing the UGVs is because they offer numerous advantages. First of all, unmanned vehicles allow the operator to control the vehicle from a distance, and can therefore avoid harms way in certain operations. For example, "the UGVs delivered to Ukraine are being used to clear areas from anti-tank mines as well as unexploded ordnances (UXOs), transporting equipment to areas that are not accessible with conventional vehicles or where the risk of losing that equipment is high; However, the most important benefit comes not from avoiding the loss of equipment but the loss of life." [49]

Figure 3.3: The MilRem is a remote controlled vehicle currently tested by the RNLA [48]

3.1.3 High Energy Lasers

Already in 2004 the potential of integrating electric solid-state HELs as primary armament on ground vehicles has been recognized [50]. And currently a lot of research is going into the development of lasers for military operations [51]. The high power laser beams can be used to hit a target over hundred of miles with good precision and accuracy [51]. A weapon-class HEL uses a focused spot of light to inflict thermal damage at the surface of the target. An example of a HEL system developed by Rheinmetall is shown in Figure 3.4. Unique characteristics of HEL are:

- speed of light delivery [50, 51]
- not affected by gravity [50]

- extreme precision [50, 51]
- lethal and non-lethal capabilities [50]
- low cost-per-kill [50, 51]
- deep magazines [50]
- capacity to engage multiple targets with fewer moving mechanical parts [51]

There are several types of lasers, each with their own unique characteristics:

- chemical laser [51]
- solid state laser [51]
- free electron laser (FEL) [51]
- fiber laser [51]
- liquid laser [51]

The RNLA has also identified the development of HELs as a relevant TI [25]. Therefore, the RNLA is currently working on a project concerning HEL weapon systems, which can be mounted on ground based vehicles [52]. Regarding maintenance, there is still little to be found about the maintenance of military HEL (on ground-based systems. However, the US Army has reported encountering certain challenges, resulting in the deployment of four HEL systems to the Africa Command area of responsibility. This is attributed to the necessity of having multiple systems available, as it essentially requires three units to ensure operational readiness [53].
The skills expected of RNLA mechanics are presumed to primarily revolve around maintaining optical systems free from moisture using nitrogen gas, along with proficiency in diagnosing malfunctions within the electric power supply.

Figure 3.4: An example of a HEL module on the Boxer Infantry Fighting Vehicle [54]

3.1.4 Composite materials

Military vehicles operate in environments that most civilian vehicles will never encounter. Military vehicles require protection against ballistic threats, mine protection, IED protection, signature protection, protection from shaped charges, and protection for military operations in built-up terrain [55].

Therefore, defense companies as Rheinmetall combine various elements within their armor, such as steel, ceramic composite systems, liners and other advanced materials. The greatest challenge is to equip vehicles with the maximum possible protection while keeping its weight at a minimum. Materials such as individually coated aramid, high performance polyethylene and glassfibre are used to create a versatile armour. Against higher threat levels, these materials can also be combined with ballistic ceramics for optimum security and optimum mobility [55]. In Figure 3.5 the composite armour of a Boxer fighting vehicle is highlighted and shown.
Also, the DMOD has started a Defense Technology Project in 2021 to do a feasibility study to make the mission-module of the Boxer vehicle completely of a glass-fiber composite, with as goal to save weight while keeping the same functionalities [56]. This in turn will have a great influence on repairs or modifications to the chassis, as the properties of glass-fiber composites are significantly different from those of armoured steel.

Figure 3.5: The composite armour of a Boxer Infantry Fighter Vehicle [55]

3.2 TIs that support maintaining ground-based military systems

In this section, the second half of the answer to SRQ1 is provided. This is the part of the TIs that will have an impact on the support for the maintenance of ground-based weapon systems. These TIs essentially function as a tool to support the maintenance of existing or new ground-based military systems. The technologies identified in this section are: XR, telemaintenance, AM, AI and digitalization/eMaintenance.

3.2.1 Extended Reality

XR is a concept that covers all combining real and virtual elements, such as Augmented Reality (AR), VR, and Mixed Reality (MR). The XR field is developing fast, and the naming conventions are not yet fixed [57]. For this research, the terminology will be defined as follows:

VR creates a virtual world using 3D computer technology, which has physics and simulation features, and where the (human) operator's sense perception are linked through sensors and actuators to give a fully immersive and presence sensation [58]. An example of a VR system are the VR-glasses where the operator can only see a screen.

AR aims to integrate digital visual data (e.g. text, graphics, images, videos, and 3D visual objects), audio content, and other external stimuli into a real-world space [58]. AR therefore combines reality and additional material in the same space.

Applications of XR in maintenance

XR can be used in several manners within the maintenance sector. First of all, it can be beneficial for service technicians in their education [30, 31, 32, 33, 59]. XR can provide an environment in which the mechanic can be introduced to work on a system, without the risk of damaging the system. It also provides the ability to be introduced to the system without requiring an (potentially) expansive physical asset to be available. In addition, XR-technology allows us to show more information about the system in an interactive manner.
Furthermore, XR can help to make system maintenance easier/simpler, as the instruction can be visualised [34, 35]. This in turn might allow the mechanic to be trained more generally, and then be able to maintain a higher variety systems, as he or she is required to know less by information by heart. An example of this application is the Virakle software-platform, 'which allows the layman to do the work and be immediately productive' [60].
However, a potential risk with XR-technology is that the RNLA operates in harsh environments and must do so with as little equipment as possible. This means that the equipment might not always be available or usable under these conditions. Especially when a stable network connection with a sufficiently large bandwidth is required.

3.2.2 Telemaintenance

Telemaintenance is a general term used for maintenance processes that are performed remotely. Telemaintenance can be seen as the collection of these processes. More specific terms are better applicable to practice, these terms are: telemetering, telecontrol, telemonitoring, telerepair, telediagnose, teleassistance, and telemanagement [61]. Each of these specifics telemaintenance process will briefly be explained:

Telemetering

Telemetering is about the sending of measurement values from an asset to a remote location through use of wiring, radio waves or another form of communication. Telemetering is mainly used for consumables, such as gas, water and electricity [61]. However, it can also be used for vehicles. A requirement to apply telemaintenance is for the vehicle to be equipped with an on-board diagnostics systems and a CAN-BUS [62]. Most of the modern armies are currently taking the step towards monitoring their land vehicles in real time. The telemetry is closely connected with the logistics systems of the army, so the vehicle data can be processed and evaluated. Modern systems used for monitoring the vehicles provide complex information about the vehicles status. This information can be used for workshops specialists, command and management, logistic support, etc., in order to make better decisions for their operations [62].

Telecontrol

Telecontrol is about operating an asset through communication. The commands that causes an asset or installation to perform a tasks are given from a remote site. Telecontrol allows an operator to control an asset from a central location, which then also makes it possible for an operator to control several assets at once [61].

Telemonitoring

Telemonotoring is about supervising one or more assets from a distance through the monitoring of consistency of parameters. Telemonotoring allows a supervisor to guard the working status of an asset from a central position. This allows for a more efficient deployment of operators because they can monitor multiple systems at the same time [61].

Telerepair

Telerepair is about remotely repairing unusable parts, components, and/or a collection of components. Telerepair is mainly used in software-based repairs. Faulty software in remote sites can be emulated on hardware at a maintenance centre. Here, the software can be checked and modified and then reinstalled at the remote site [61].

Telediagnosis

Telediagnosis is about the execution of constructed measurements with as special goal to detect measurable faults in assets from a distant. The diagnosis can be made at the headquarters after the measured results are sent [61].

Tele-assistance

Tele-assistance are activities led by an expert (or team of experts) from a headquarters which are executed by 'less-skilled/less-specialised' personnel on an asset locally [61]. Besides the use of tele-assistance in operations, it can also be used for educational purposes. For example, an instructor can remotely assist a student which is stationed within a MSU, instead of needing to drive a complete distance. The utilization of tele-assistance can involve the use of AR or VR glasses, as elaborated upon in subsection 3.2.1.

Telemanagement

The last form of telemaintenance is telemanagement. Telemanagement is about the use of automated maintenance systems that are controlled through data using configurations, company hours, maintenance tasks, spare parts, and the procurement of these spare parts, defects, costs, and safety of an asset or collection of assets. [61]

Relevant Telemaintenance Concepts

For maintenance work done by (army) mechanics, the integration of several telemaintenance concepts will most likely have a larger impact than others. The telemaintenance concepts that will most likely have a larger impact on the mechanic are telerepair, telediagnosis, and tele-assistance.
Telerepair will have a larger impact because it could mean that failures in the future do not need to be repaired on-site by the mechanic. However, it will require a mechanic with enough expertise to repair certain problems from a distance. Telediagnosis can also have a significant impact on the mechanic, as a big part of reparations is first diagnosing why the system fails. If the diagnosis can be done automatically or from a distance, this could greatly influence how a mechanic can prepare for a reparation, especially in the military context. Lastly, the tele-assistance concept is also something that could potentially have a great influence on the job of a military mechanic. This is because it can allow a mechanic to receive information from an expert from a distance, meaning that the mechanic requires less specific knowledge about a technical system as this can be provided by the expert.
It is important to note that the telemaintenance techniques also pose a non-negligible problem/risk, as the assets of the RNLA should not send (sensitive) data during operations (with the exception of combat-communication). This is partially because the data contains sensitive information about the use of the assets during operations, but also because the sending of data can potentially give away its position. Furthermore, a stable network connection with sufficient bandwidth is a mandatory requirement for telemaintenance techniques, but it will most likely not (always) be available on the battlefield. Therefore, the RNLA mechanic at OLM and ILM must be able to still perform his duties without this technology.

3.2.3 Additive manufacturing

AM is defined as "an innovative manufacturing technique in which objects are created layer-by-layer, opposed to conventional manufacturing, which removes pieces from a solid piece of material" [63]. Compared to

conventional manufacturing processes, AM allows for "a substantial reduction of dedicated tooling requirements and setup costs, and thus enables more flexible production of various parts with the same machinery" [64]. This is especially relevant for military and humanitarian operations, as they require a robust and well managed supply chain. For these types of operations, the financial aspects are often not the driving factor, but advancing the efficiency of operating troops [63].
The DMOD has also identified AM as a key TI in its defense technology exploration report from 2020 [25]. In the RNLA, there are numerous projects where the feasibility of AM in a military context is, has been or will be tested. In Mali, 3D-printing has already been used by the RNLA to print several items, such as holders for navigation systems and phones, brackets to attach weapons to vehicles, and cart wheels used by the mechanic to 'slide' under the vehicles [65]. Another example is the AM Container Operational Purposes, which is a project by the DMOD to test the use of 3D-printing in an operational context [66].
Also in the industry, the potential of AM in a military context has been identified. Rheinmetall, one of the main suppliers of Defense materiel for the RNLA, has developed a mobile production container to utilize the advantages of 3D printing, which is to be used for the mobile production of spare parts in BDR [67, 68]. An image of this container is shown in Figure 3.6.
Despite the advantages, the use of AM in a military context also face numerous challenges. Producing a part can still be time-consuming, which is not always available. Also, the data needed to produce the parts is often not available. This is partially because the manufacturers of the parts often do not want to provide this data (for free), as it is valuable intellectual property and the printing of parts will result in less profit margins in selling spare parts to its customers.
The impact of AM on mechanics within the RNLA will depend on how the organization utilizes this technique. It is unlikely that the RNLA will directly undertake the design of these products, as it requires significant time and expertise in engineering parts and operating AM machinery. The task of printing parts will not be challenging, given the largely automated process. Therefore, the primary role of RNLA mechanics in AM will likely involve post-processing the printed parts [69]. Since most parts may have a rough texture due to the printing process or the need to remove supports, RNLA mechanics may need additional post-processing skills and knowledge to effectively utilize this technology. The mechanic should also be able to check for visual defects in 3D printed parts, and specific training is expected for this competency [69].

Figure 3.6: The Mobile Smart Factory for the battlefield, presented by Rheinmetall [68]

3.2.4 AI within maintenance

Artificial intelligence (AI) has undergone rapid evolution in recent decades, leading to its implementation in various domains. Already in 1996, the advantages of utilizing an AI-based diagnostic system for the Abrams

tank were identified. Showing that for both senior and junior mechanics the AI-based system yielded positive results. Overall, the mechanics demonstrated a 96% increase in their ability to efficiently diagnose the engine[70]. In the current landscape of the maintenance branch, AI also emerges as a valuable tool. In a literature review conducted by D. Scaife, several findings regarding the application of AI to enhance Predictive maintenance (PdM) were highlighted [71].
The first finding suggests that AI offers the potential for remote monitoring of facility system conditions. This capability enables real-time surveillance and analysis, facilitating early detection of potential issues. The second finding underscores the role of AI in data interpretation, providing awareness for facility management professionals, leaders, and stakeholders. AI-powered analytics enable informed decisions regarding investments, system repairs, and data-driven responses to equipment operations. The final finding in the reviewed literature suggests that integrating AI into facility operations technology within the facility management program can enhance facility system uptime. By leveraging AI algorithms for predictive analytics and proactive maintenance, organizations can minimize downtime and optimize operational efficiency. [71]

When considering the utilization of AI within the RNLA, numerous projects are currently active or have been executed to explore and test AI applications. One such project involves the development of a transition document for PdM within RNLA, which delves into leveraging sensor data to render maintenance more predictable. Moreover, AI plays a significant role in the Maintenance Decision Support & Simulation (MaDeSi 2.0) project. Here, AI can be used to aid in the development of databases, algorithms, and decision support systems, enhancing the overall maintenance processes.

In the context of the mechanic's workfield, AI presents significant opportunities [72], particularly within the realm of diagnosis. AI has the potential to revolutionize fault diagnosis processes, potentially reducing the workload for mechanics and expediting problem-solving procedures.
By leveraging AI-powered systems, mechanics can benefit from advanced diagnostic tools capable of analyzing complex data patterns to identify potential faults or problems in machinery or vehicles. These AI systems can process large volumes of data from various sensors and sources, enabling faster and more accurate fault detection compared to traditional methods.
Moreover, AI-based diagnostic systems can provide insights and recommendations to mechanics, guiding them through troubleshooting procedures and suggesting appropriate solutions based on the identified issues. This can streamline the diagnostic process, allowing mechanics to address problems more efficiently and effectively. Overall, AI holds great promise in enhancing diagnostic capabilities within the mechanic's field, potentially improving efficiency, reducing downtime, and ultimately leading to better maintenance outcomes.

3.2.5 Digitalization/eMaintenance

One of the major developments of the past decades, is the increase use of smart and connected devices. This trend can be referred to as digitalization, the Internet of Things (IoT), or Industry 4.0 [73]. "Digital maintenance or eMaintenance can be described as the area of maintenance where technology is used to provide decision support for operations and maintenance, through the application of advanced information technology" [73].
EMaintenance is globally made up of Intra-Net, Extra-Net, and Inter-Net parts. These parts are built up from lots of different e-technologies, including sensors, signal analysis, hand-held computers, the use of the Internet and data, etcetera [74, 75].
Also within the RNLA, ditigalization has been implemented in the past decade. For example, the integration of the DO-MAINT platform, which is essentially a digital version of the inspection-list.
The adoption of these electronic measures has profound implications for maintenance professionals. Basic ICT skills have become essential to perform maintenance tasks successfully, both in the electronic and mechanical domain. As a result, mechanics are required to be able to use digital tools and technologies. [28]

3.3 Overview of TIs

In this chapter, a selection of TIs is made that will likely have a significant impact on the RNLA mechanic. This selection of TIs is divided into 2 categories; The first category is the selection of TIs which have an impact on the maintenance of the systems; this selection is elaborated upon in section 3.1. The second category is the selection of TIs which have an impact on supporting the maintenance of the system; This selection is elaborated upon in section 3.2. The selection of the TIs is based on the following aspects: their technological readiness in the upcoming 5 to 10 years, their relevance to ground-based military systems, the estimated impact that it will have on maintenance management and their relevance to the maintenance tasks of the mechanic. The technologies are mostly inspired by technology trend-lists/vision statements of the DMOD [5, 25, 27], research pilots/projects of the DMOD (found on the internal innovation website of the DMOD: innovatie.mindef.nl), and external technology impact vision statements [28]. The selection of technologies has also been validated in interviews with N-1, N-2, N-3, TCR-1, CTC-1, and I-2.
An overview of the discussed TIs is shown in Table 3.1, this selection will provide input for the case studies used in the design of the impact model.

Selection of TIs	
Impact on maintenance:	**Impact on supporting the maintenance:**
EVs	XR
RAS	Telemaintenance
HEL	Additive manufacturing
Composite materials	AI
	Digitalization/eMaintenance

Table 3.1: Overview of the different TIs discussed in this chapter

As explained in section 1.5, the goal of this research is to assist the organization in providing insights into the impact of TIs on the RNLA mechanics by developing a tool or instrument to improve the understanding of these impacts. In the following chapters, this tool will be designed and demonstrated, which consequently should help answer the main RQ.

Chapter 4

Objectives of the Design

In the following chapters, a impact model is designed that should help answer the main RQ. The model will be designed using the DS research methodology, which is explained in section 1.5.
In this chapter, the design objectives are established, as should be done according to the second step of the DS research methodology of Peffers et al., which is highlighted in Figure 4.1 [4]. These objectives form the foundation for the impact model, upon which the initial version is designed in chapter 6. Through the delineation of design objectives and criteria, the answer to SRQ2 is provided.

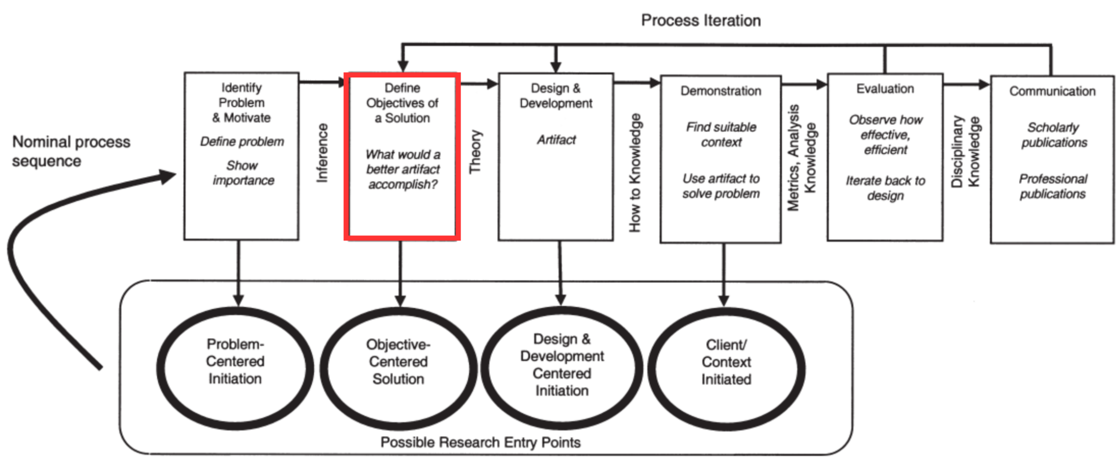

Figure 4.1: The solution objectives step, highlighted in the design science research methodology process model from Peffer et al. [4]

As outlined in section 1.4, the primary objective of this research is to aid the CoELog (which advices the normsetter), in ensuring the future readiness of mechanics at all maintenance levels. This will be achieved by developing and designing an instrument to assist in identifying TIs, determining their impact, and selecting appropriate skills and capabilities to ensure the maintenance of all systems in the future. In doing so, the RNLA can carry out its tasks effectively.

4.1 Objectives of the solution

In order to assist the organization in creating a vision of what the mechanic in 5 to 10 years will look like, for each TI the solution should:

- show how the professional maintenance tasks of the mechanic change for each maintenance level (OLM,ILM, and DLM).

- show the impact on the maintenance workload of the TI.
- show what tools & equipment the mechanic needs to be able to operate/use to maintain the systems. This includes hand tools, workshop equipment, digital tools, and tools required for educational purposes.
- show at which (physical) location the mechanic can maintain the TI.
- determine what prior education is required by the mechanic to be able to maintain the TI.
- determine the (preferable) competences that the mechanic should possess.
- determine the mindset, attitude, and/or beliefs of the mechanics towards the TI.

The objectives of the solution are determined in collaboration with the CoELog, the literature described in section 5.1, and the Integrated Logistic Support (ILS) handbook [76].

4.2 Design criteria

Furthermore, there are also several design requirements based on the needs and desires of the CoELog to make it a useful model. These design criteria are inspired by the design criteria used in the Lifetime Impact Identification Analysis (LIAA) from Ruitenberg et al. [10], and the design criteria have been established through several discussions with an expert of the CoELog (R-1).

1. The model should show how to collect the information;
2. The model should show how to produce a clear (and useful) overview of the potential impact of a TI on the mechanic of the RNLA.
3. The model should show how the RNLA can use the impact analysis to make their mechanic more future-proof.
4. The model should focus on the intermediate future upcoming 5 to 10 years.
5. The model should be workable in the organizations situation; therefore, the model should be rigorous and relevant.

4.3 User of the impact model

When new techniques or technologies are identified by the RNLA, there are various manners in which this comes back into the organization. The identification of new technologies and the manner in which they are purchased/integrated within the organization are 2 different things. The relevance for both of these tasks are described in this section.

Identification of TIs

The identification of new technologies is an ongoing process involving multiple different departments within the DMOD. The CoELog is one of the departments responsible for keeping an eye on technological developments regarding logistics. Therefore, the impact model developed within this research is especially relevant for the CoELog, as they have to take into account the impact of future technologies on the RNLA mechanic.

Implementation of TIs

The integration of new technologies can happen in various different manners. For example, new techniques (and thus new technologies) can be involved when A- or B- system are purchased by the RNLA. In the acquisition of these new systems, it is also important to take into account the (potential) impact on the mechanic. This is one of the tasks that fall (partially) under the responsibilities of the CoELog. There are roughly 2 area's of expertise for which the commander of the CoELog is responsible, namely:

1. Acquire logistic equipment usable for ground-based operational logistic action, fitting within the doctrine/ground-based action.
   In other words: looking after the future users of logistics resources

2. To make sure that the ILS aspects/resources are set up properly. This allows to keep the readiness of the assets on an acceptable level while keeping the costs at a minimum.

Especially the second task is relevant for the impact model developed in this research. This is because this task includes making sure that the mechanics are able to maintain the systems when they become operable.

In short, the impact model is designed to be used by the CoELog to help determine possible impacts on the mechanic and to set a vision regarding his or her training & education, as the time frame of the model is defined to be 5 to 10 years. This information is eventually passed through to the (relevant) normsetter, who is then responsible for coping with the identified challenges. The specific role of the normsetter has been described in section 2.6.

In this chapter, the objectives of the solution were established, design criteria were defined, and the intended user of the impact model (to be designed) is elucidated. Collectively, these components address SRQ2. The following chapter will focus on gathering and reviewing the theoretical foundation necessary to design the impact model. This theoretical groundwork, combined with the objectives outlined in this chapter, will guide the initial design phase of the impact model.

Chapter 5

Literature Review

In this chapter, the literature behind the impact assessment methods of this research is discussed. Four different impact analysis methods that are relevant to this research' context are described. In doing so, SRQ3 is addressed: "Which tools/instruments are available to identify the impact of both types of TIs and successfully cope the challenges?".

5.1 Impact models

Technology can indirectly influence human capital, as new assets are designed, this can also result in different task demands [77]. However, technology can also affect the development of human capital, such as the support of personnel with e-learning [16]. Because the implementation of innovations almost always plays an important factor in the success of a company, it is important to identify potential & risks of technologies to adequately anticipate technological developments [12]. For this, risk or impact assessment tools can be used.

As mentioned in section 1.3, there are already numerous different tools available that can help predict the impacts of technologies on organizations [10, 12, 13, 14, 15, 78]; however, most of them focus on jobs that are not necessarily relevant to mechanics [19, 79, 80], do not focus on specific job disciplines [13, 14, 16, 15, 78], or focus on macro-level impacts instead of micro-level impacts [10, 12].
Despite this challenge, four different methods for impact assessment were found to be relevant and are described in this section. These methods will in turn provide the foundation for an impact analysis instrument in the next chapters.

5.1.1 10 Aspects of change from Prosci

The first method discussed is Prosci's framework, which is "a framework that enables change practitioners to remind, focus, dissect, and document the individual's journey" [81]. The focus of this model is to determine how changes, such as the implementation of a new product, impacts an individual in their job. For this, the model has created 10 aspects to consider when determining the impact of change. These aspects are: processes, systems, tools, job roles, critical behaviours, mindset/attitudes/beliefs, reporting structure, performance reviews, compensation, and location [82]. An overview of these change aspects is shown in Table 5.1.

5.1.2 Lifetime Impact Identification Analysis

Ruitenburg has developed the LIAA method, which is used to gain a deeper insight in the remaining lifetime of an asset by identifying possible lifetime impacts. The LIAA incorporates the technical, economic, compliancy and commercial perspectives on the asset. [10]
As the LIAA focuses on the technical impact on the lifetime, not all aspects can be used. However, the method provides a useful framework for collecting the information and determining the impacts in a structured manner.

Aspect	Definition	Example
Processes	The actions or steps taken to achieve a defined end or outcome	Steps in the client engagement process and actions taken to capture data in a cloud-based CRM system
Systems	A combination of people and automated applications organized to meet a set of objectives	The introduction of a new cloud-based CRM solution to manage and analyse client interactions and data throughout the customer lifecycle
Tools	An item or implement used for a specific purpose; can be a physical object such as mechanicals tools or a technical object such as a web authoring tool or software program	A conversion tool to move data from one CRM solution to another one mapping data as needed
Job Roles	A description of what a person does including competencies essential to performing well in that job capacity	The client services role responsible for engaging directly with clients
Critical Behaviors	Vital or essential response of an individual or group to an action, environment, person or stimulus	The actions of a client services associate based on client needs expressed including engagement with other team members to collaborate on solutions
Mindsets/Attitudes/ Beliefs	Mental inclination, disposition or frame of mind reflected in behaviors	The transition for a transactional mode of financial services engagement to one built on relationships with the mindset of improving client retention and advocacy
Reporting Structure	The authority relationships in a company or organization; who reports to whom	The move from regional sales teams to a global
Performance Reviews	The process and indicators of how performance is measured and assessed relative to objectives	The introduction of specific client retention and advocacy objectives for client services associates
Compensation	Amount of the monetary and non-monetary pay provided in return for work performed	The commission structure and bonus plan for client services associates
Location	A physical geographical place that provides facilities for a stated purpose	The consolidation of all client services associates to one floor of the building

Table 5.1: Overview of the 10 aspects of change by Prosci [82]

The steps of the LIAA method are: (i) asset selection, (ii) collection of general asset information, (iii) discussion of the asset in expert sessions, (iv) writing the lifetime impact report, and (v) evaluation. The steps taken by Ruitenburg et al. are shown in Table 5.2.

5.1.3 Technology Impact Method

TNO, an organization that does independent not-for-profit research, has developed a method called the TIM, which can be used to determine the concrete changes of function and jobs by new technologies [16]. For example, the TIM has been used to determine the impact of technology on the tasks, skills and quality of the work of electric- and maintenance mechanics [83].

In the TIM thinking framework the analysis-steps are divided into four blocks, namely: (i) technology, (ii) product/service, (iii) organization of the work, and (iv) human capital. An overview of the steps is shown in Figure 5.1. Furthermore, in the following sections is described how the TIM can be conducted. Several data-collection methods are described in the 4 steps, depending on the nature and need of the information types. The methods are selected based on the experience of what the TNO organization found to be most useful in their researches [16].

Technology

In the block of technology, the method focuses on technologies that can be implemented in the upcoming 5 years. The reason for this time-frame is that these technologies are often already available at frontrunner companies, or there are prototypes available. Because of the time horizon, the uncertainties of technologies with a time horizon of 10 or more years are reduced. Also, the time horizon of 5 years is deemed to fit the perceptions of many clients and the strategic choices they make about technology; But also the knowledge of stakeholders and experts that participate fit better to the 5 year time horizon. [16]
For this block in the TIM, it is important to understand the technologies that will become available in the foreseeing future, and how they will affect the work and tasks in an organization or sector. To gain that insight, the user can conduct interviews with (internal/external) technology experts from knowledge institutions, suppliers, industry organization or social partners. During the interviews it is important that the interviewer is very clear about the scope (time horizon and selected functions), and that the social, economical, and legal

Phase		Description	Main activities
0.	Adaption of the framework	Adaptation of the four types of lifetime impacts to the situation of Liander	- Interviews with experts on the four different lifetime perspectives (8 experts, interviews of around 1h) - Study of company documents (annual reports, strategy, etc.)
1.	Asset selection	Selection of a particular type of switchgear	- In close consultation with the researchers, the manager of Asset Management has selected this asset
2.	Collection if general asset information	Collection of general information on the particular type of switchgear and the population characteristics	- Study of company documents (e.g. policy documents related to this type of switchgear) - Collection of information stored in databases (e.g. age, numbers, maintenance data, cost data) - Company visit to see the asset in function and to the fault analysis team - Interviews with experts on this type of switchgear (3 different experts, at least 1.5h per expert)
3.	Discussion of the asset in expert sessions	Collection of information on the four types of lifetime impacts using expert sessions	- A first expert session lasting for 2 hours (5 experts present, representing all 4 types of lifetime impacts) - Additional study of company documents and information in databases - Analysis of failure and financial data - A second expert session, lasting for 1.5 hours (3 experts available, one different from the first session)
4.	Writing the Lifetime Impact Report	Structuring and summarizing the information into a Lifetime Impact Report	- Wrap up of all the information collected, identify the lifetime impacts and report these in a structured way - Consultation with two experts on the asset
5.	Evaluation	Evaluation of the Lifetime Impact Report with the experts	- Consultation with 2 experts on the asset - One expert session lasting for 1 hours (6 experts present)
6.	Reflection on the method for LIAA	Evaluation and reflection on the LIAA with the experts involved	- Consultation with 2 experts on the asset - One expert session lasting for 1 hours (6 experts present) - Critical reflection and discussion by the researchers

Table 5.2: Description of the development of the LIAA provided by Ruitenburg et al. [10]

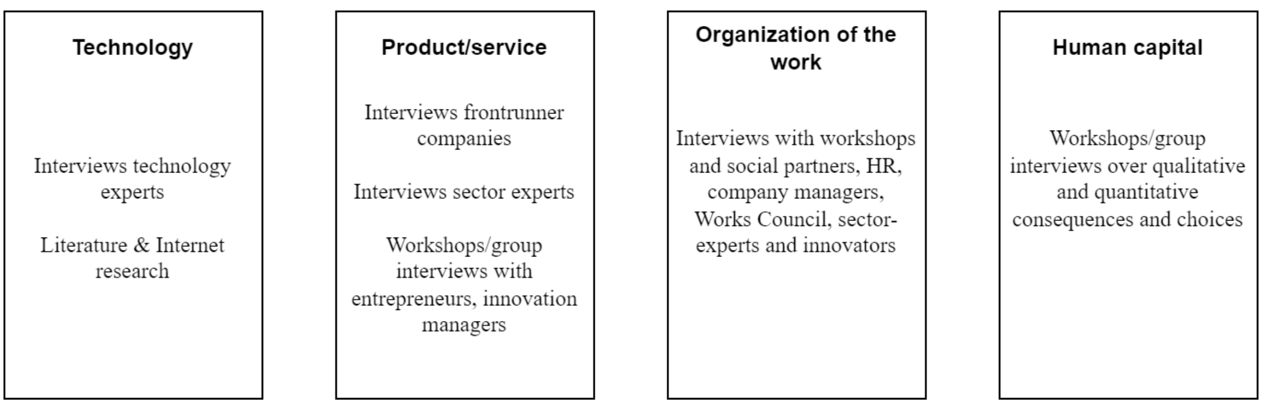

Figure 5.1: Schematic overview of the Technology Impact Method (TIM) approach with corresponding research methods [16]

constraints are also taken into account. Not all technological possibilities will take place. In addition, one can study literature (grey and scientific) and possibly consult data sources on investments in the technology. It is important to relate these technologies directly to the functions of the work-process of which the impact is predicted. So for this research: What technologies are most relevant for a mechanic of the RNLA and how are these technologies involving in the upcoming 5 years? In this way, the exploration does not become too

broad. [16]
Also mentioned in this method, is that for technologies which are completely new tech-experts, innovation managers, employees and teamleaders from the primary process in a workshop can be brought together to explore the applications. Another sidenote which is mentioned in this method, is that when using trend-reports or tech-lists, the reader needs to be aware that the substantiation behind of these reports or lists are often lacking. The reason for this is that the methods in which these reports are created is often not mentioned; And in addition, the parties also bring their own interests to the table when outing certain knowledge to the outside world. [16]

Products & Services

After understanding the relevant technologies, the uses analyses the significance for the organization's products and services. To this end, the user can again interview with technology experts, frontrunner companies and social partners, as well as with individuals from strategic departments or innovation (R&D) departments of their own organization. [16]

Organization of the work

The new products and services offered have implications for the organization of the work. The work organization is about the organization of work processes, and the role of new technology in it. This is about dividing the tasks between people and the new technology (think about automation of certain tasks). Through interviews with the works council, employees, team leaders, and the person responsible for innovation; it is possible to estimate how the organization of the work will change. For example: which tasks are appearing or disappearing, and what new competences are required by the personnel? [16]

Human capital

The human capital issues follow from the analysis of work organization. In this step, there is specifically looked at how individual tasks set change and what it means for the required competences and the quality of the work (mental and physical load, variety, challenge, etc.). For instance, certain technologies can lead to a different demand of personnel. Also, different educational levels can be required of the personnel due to the technological changes. These questions can be analysed by HR-managers, line managers, and work council/employees in workshops. This can lead to insights into qualitative and quantitative HR issues. [16]
Even though this subject is described separately, the human capital analysis can be conducted simultaneously with the organization of the work assessment. This is partially because the same stakeholders and experts are involved in these steps. Furthermore, it is possible to conduct group-interviews instead of workshops for these steps. The advantage of the workshops is that a relatively large amount of people can be questioned and that these people can also discuss together, which also allows them to build upon each others or exchange alternative perspectives. The advantage of the interviews is that they are easier to organize and that the researcher can go more into depth (on underlying reasoning and beliefs). [16]
When a job is taken as a starting point, a job profile of the future is established with a description of tasks and competences. There can also be argued what the changes of tasks will mean for the quality of work for these jobs (autonomy, challenge, mental and physical load). With this, organization can strengthen their HR recruitment and development policies. Certain human capital issues can, however, also lead to adaptation of the technology used or work processes. For instance, technology can be tailored to a specific user group; Or task packages can be deliberately widened to provide sufficient variety for employees. It is thus an iterative process in which the balance between different interests has to be continuously evaluated; in doing so, the components technology, products/services, organization of work, and human capital need to be constantly tuned. [16]

5.1.4 Human Factors Effect and Analysis

Sheikhalishahi et al. has developed the Human Factors Effect and Analysis (HFEA) method, which can be used for analyzing human factors in maintenance tasks. It aims to identify and reduce human errors in maintenance activities. The method involves several steps:

1. Identifying and categorizing human factors: Decision makers can use brainstorming sessions, literature surveys, cause and effect diagrams, historical data, and cognitive maps to identify potential human errors in the maintenance department. They can also refer to existing human factors categories and models proposed in the literature.

2. Evaluating human factors risks: Once the related human factors and risks are identified, they need to be evaluated to determine the most crucial human risks. Ideally, data should be accessed to quantify human factors risks. However, if data is not available, expert judgment can be used to compare and prioritize human errors severity. Multi-criteria decision-making methods like the analytical hierarchy process and analytic network process can be applied.

3. Assessing risk acceptability: Decision makers need to decide whether the risk associated with each human factor is acceptable or not. If the risk falls outside the tolerable limit, risk control methods should be employed.

4. Implementing risk control methods: Two categories of risk control methods are used in the literature-preventive and recovery risk control methods. Preventive risk controls aim to prevent human errors from occurring, while recovery risk controls focus on mitigating the consequences of human errors. Decision makers should prepare a list of potential preventive and recovery risk controls and evaluate them.

5. Cost-benefit analysis: Decision makers should compare the cost of implementing each risk control method to the expected savings in order to find the most cost-effective solutions.

Following the HFEA method, organizations can improve system reliability, reduce unexpected incidents and accidents, and enhance overall maintenance performance by addressing human factors and reducing human errors. In the case study conducted by Sheikhalishahi, the critical human factors identified include procedure usage, fatigue, knowledge and experience, and time pressure. [29]

5.1.5 Overview impact models

An overview of the aspects/perspectives of the different methodologies is provided in Table 5.3. It is evident that each tool incorporates different elements or disciplines to assess the impact of technology. In the subsequent chapter, the initial design of the impact model will be formulated by integrating the relevant impact elements of these diverse methods.

Methodology	**TIM [83]**	**Prosci [81]**	**LIAA [10]**	**HFEA[29]**
Impact aspects or perspective	Technology Products/service Organization of the work Human capital	Processes Systems Tools Job roles Critical behaviors Mindset/attitudes/beliefs Reporting structure Performance reviews Compensation Location	Technology Economy Commercial Compliancy	Procedure usage Fatigue Knowledge and experience Time pressure

Table 5.3: Overview of the impact aspects/perspectives of different methodologies

Chapter 6

Design & Development

In this chapter the initial 'artifact' is designed. Several impact models and integration books are combined into one initial design of the impact model. This is the design & development step of the DS research methodology process from Peffers et al., which is explained in section 1.5 and highlighted in Figure 6.1 [4]. The initial design should assist in finding an answer to the main RQ. After constructing the initial design based on the literature, it was validated through interviews with the normsetters (N1, N2, N3).

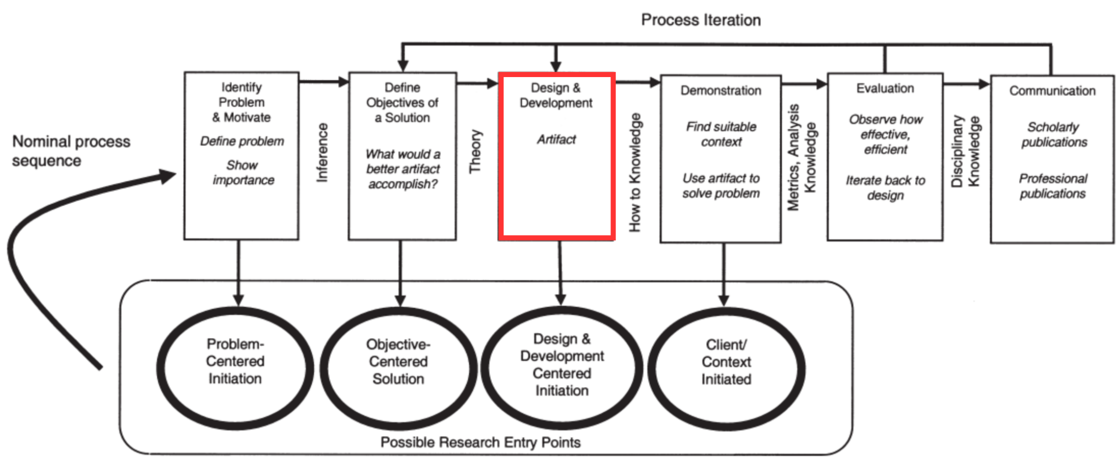

Figure 6.1: The design & development step, highlighted in the design science research methodology process model from Peffer et al. [4]

In order to start the research, an initial design of the impact model is first created based on a combination of the different methods. Several methods are used and combined, since each method covers a part of the solution. Therefore, by combining the relevant aspects of each method, it will assist in providing a solution to the specific problem of this research. The initial design is based on the ILS handbook [76] and the 10 aspects of change impact model from Prosci [81]. The ILS handbook shapes the policy in the field of WSM for DMOD, and therefore provides the relevant impact elements on how a TI is integrated within the maintenance organization. The Prosci model is "a framework that enables change practitioners to remind, focus, dissect, and document the individual's journey" [81]. This framework is used because it provides the relevant aspects regarding general changes on work by technology.

The items chosen from the ILS handbook were selected based on their relevance to the RNLA mechanics [76]. This implies that elements related to effects on the logistics supply chain, for instance, were not incorporated into the designed artifact. However, considerations such as required training and the selection of maintenance tasks accompanying a new asset at each maintenance level were taken into account. The impact elements

derived from both the ILS handbook and the Prosci model are summarized below [81, 76]. Moreover, they are combined into an overview of the initial impact analysis model in Figure 6.2.
Elements selected from the ILS handbook [76]:

- Maintenance tasks [76]
- Support equipment [76]
- Manpower & personnel [76]
- Training & training support [76]
- Facilities [76]

These ILS elements were selected as they are essential in determining how a TI will be implemented, which is necessary to determine the impact of a TI. Without these elements, it will be very challenging to properly estimate the impact on the job of the mechanic, as there will be too many uncertain factors.
Elements selected from the Prosci aspects of change model [81]:

- Processes [81]
- Systems [81]
- Tools [81]
- Job roles [81]
- Critical behaviours [81]
- Mindset/ Attitudes/ Beliefs [81]
- Organization structure [81]
- Compensation/rewards [81]
- Location [81]

These Prosci aspects were selected, as they provide an elaborate overview of the impact aspects that a mechanic is confronted by each day. In turn, these aspects help to meet the second design criterion, which is described in section 4.2.
Based on these elements, the following initial design is formed and displayed in Figure 6.2.

6.1 Impact elements

6.1.1 Maintenance tasks

The first element mentioned by the ILS handbook is the maintenance planning [76]. This element is about the arrangement of all maintenance tasks. The maintenance planning is the first element taken into account in the ILS handbook and is the most important element because all the other elements are derived from the maintenance planning [76]. Among other things, maintenance planning provides an 'action plan' for each Configuration-item (CI).
However, for this impact model, the maintenance planning is mostly related to determining the maintenance tasks that the mechanic has to perform on each maintenance level. Therefore, this element is referred to as "maintenance tasks". The maintenance tasks are defined into 4 different categories based on the user instruction for parts maintenance [84]. These 5 categories of maintenance are: (i) preventive maintenance, (ii) corrective maintenance, (iii) Battle Damage Repair (BDR), (iv) expedient repair, and (v) modification maintenance. These maintenance types are defined in section 2.1.
In this element, it is also important to consider which specialization of mechanic (vehicle-, electrical-, or weapon system technician, see section 2.4) has to operate or maintain the new TI. It can also be concluded that a new specialization category should be added; For example, if mechanics who are mostly specialized in

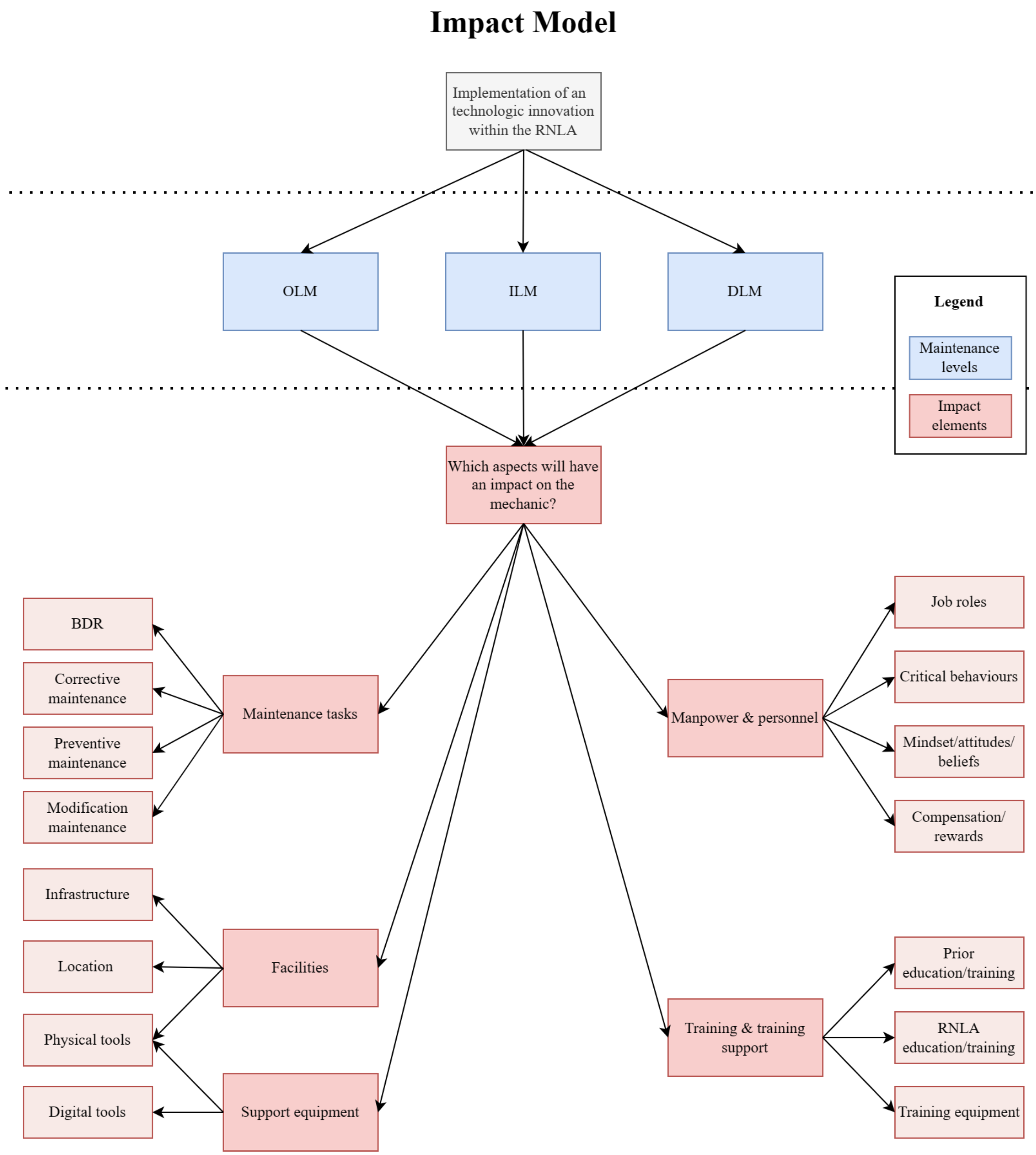

Figure 6.2: Initial design of the impact model based on the aspects of the ILS handbook [76] and the Prosci model [81]

software programming are required to maintain new assets digitally, it might be necessary to have a 'digital maintenance' specialization branch for the RNLA mechanic.
Furthermore, a possible increase or decrease in workload should also be taken into account in this element. To determine the impact of a TI on the maintenance tasks, the following questions should be answered:

- How are the maintenance tasked affected? What maintenance tasks can/should be done per maintenance level?

- How does the maintenance change? This is with respect to BDR, expedient, corrective, preventive, and/or modification maintenance.
- Are the specializations of the mechanic affected? Regarding the vehicle -, electrical-, and weapon system specializations.
- How does the workload of the maintenance operations change?

6.1.2 Facilities

Another important element is the impact on the facilities required to work with a new technology. This element is mostly based on the ILS handbook, but the location sub-element is also discussed in the Prosci model [76, 81]. The first subcategory here is the infrastructure required. For example, hydrogen-powered vehicles require a different type of fuel storage than diesel vehicles. The mechanic should then be able to operate the equipment of this new type of fuel storage. Another example of infrastructure could be the required digital connection for tele-assistance, in which the mechanic has to be able to communicate over a distance with a colleague.
The next subcategory is location. Due to the mission of the RNLA, the mechanic has to be able to operate in most weather conditions anywhere in the world. Therefore, it is important to consider the impact on the location where the mechanic has to operate or maintain the TI. For example, it might become harder to operate the XR equipment in a wet/rainy environment. The OLM and ILM mechanic should be able to work outside in a mobile repair shop [7], therefore the XR equipment might not be functional all the time. However, for the DLM mechanic this should not be a problem. The last subcategory of facilities and the first subcategory of support equipment are the physical tools. This category has to determine the effect of the TIs on the tools that are required. The tools in this subcategory are tools that are part of the facility, such as heavy-duty lift cranes. The physical tools that are not part of the facilities element, are taken into account in the support equipment element. The tools of the facility can also affect the mechanic, as he or she needs to be able to operate these tools in order to perform certain maintenance actions. To determine the impact of a TI on the facilities, the following questions should be answered:

- What infrastructure is required for the new TI?
- How does the TI affect the location of the maintenance operations?
- What physical tools need to be installed in the facilities? And how does this effect the mechanic in terms of training and licensing?

6.1.3 Support equipment

The support equipment element is about the changes in physical and digital equipment that is required to maintain the new TI, and is based on both the ILS handbook elements and the Prosci model elements [76, 81]. This could mean for example that a crane would be required to lift components of the TI. However, it could also be the use of software which might be necessary to read out certain data. In this impact element, it should also be taken into account what the new support equipment means for the training and licences of the mechanic.

6.1.4 Training & education

The next impact element is training & education. Here, the aspects of how the mechanics should, can be, and are trained is taken into account. It should also be checked if the current education that the mechanics receive before they join the RNLA still matches with needs of the RNLA. This means it should be checked if the education provided by the RNLA and the Regional Education Centre (REC)s cover all the needs, or if there is unnecessary overlap. To determine the impact of a TI on both the support equipment, and the training & education, the following questions should be answered:

- What physical/digital tools are needed to maintain the TI? And how does this effect the mechanic in terms of training and licensing?

- What education, and training does the mechanic require to operate or maintain the TI? And should/can this be insourced or outsourced?
- When insourced, what type of equipment/materiel is required to support these trainings?

6.1.5 Manpower & personnel

The manpower & personnel element contains several sub-elements, namely: job roles, critical behaviours, mindset/attitude/beliefs, and compensation/rewards. These elements are based on the Prosci model [81]. This element focuses on the social impact of a TI on the maintenance personnel, and also what is required by them to be able to successfully implement a TI within their work. To determine the impact of a TI on both the manpower & personnel, the following questions should be answered:

- How does the job description of the mechanic change?
- What type of critical behaviours are required by the mechanic to handle this TI?
- What is the mindset of the mechanic towards this TI?
- Does the implementation of the TI affect how the mechanic values his or her work? For example, in a financial sense and/or in job evaluation.

Impact element	**Question nr.**	**Assisting questions to determine the effect of TIs on the mechanic**
Maintenance Planning	**1**	How are the maintenance tasked affected? What maintenance tasks can/should be done per maintenance level?
	2	How does the maintenance change? This is with respect to BDR, expedient, corrective, preventive, and/or modification maintenance.
	3	Are the specializations of the mechanic affected? Regarding the vehicle -, electrical-, and weapon system specializations.
	4	How does the workload of the maintenance operations change?
Facilities	**5**	What infrastructure is required for the new TI?
	6	How does the TI affect the location of the maintenance operations?
Support (equipment and training/education)	**7**	What physical/digital tools are needed to maintain the TI? And how does this effect the mechanic in terms of training and licensing?
	8	What education, and training does the mechanic require to operate or maintain the TI? And should/can this be insourced or outsourced?
	9	When insourced, what type of equipment/materiel is required to support these trainings?
Manpower & Personnel	**10**	How does the job description of the mechanic change?
	11	What type of critical behaviours are required by the mechanic to handle this TI?
	12	What is the mindset of the mechanic towards this TI?
	13	Does the implementation of the TI affect how the mechanic values his or her work? For example, in a financial sense and/or in job evaluation.

Table 6.1: Questions to answer in order to determine the impact of TIs on the RNLA mechanic

6.2 How to use the impact model

In this section is described how the model can be used, in order to analyse the impact of a TI on the mechanic of the RNLA. Firstly, the TI has to be identified, then information must be collected regarding the TI, after which interviews and expert sessions can be held. Using the information retrieved from the interviews and focus-group session, an impact analysis report can be written. In the last step of the model, the results should be discussed with the participants to make sure that the information is processed and interpreted correctly. An overview of the model usage steps is shown in Table 6.2. After the second, third, fourth, and fifth step it can be concluded that there is insufficient information, the decision can then be made to go one or more steps back to make the impact analysis more complete. This process is also visualized in Figure 6.3.
An important note is that the impact model is intended as exploratory research on the expected impact of technology to the organization insights to make informed strategic choices about technology. Additionally, as

technology evolves and the impact analysis is based on assumptions, it is important to periodically re-evaluate the results of the impact analysis. This re-assessment should occur every few years, depending on the nature of the TI and its implementation.

Phase	Description	Main activities
1. Selection of the TI for the case	Selection of the TI.	- In this step the TI is selected for which the impact analysis has to be carried out. - Identify the TI, it is possible to couple a relevant asset to this TI.
2. Information collection	Thoroughly describe the TI in terms of physical characteristics, function, current state of technological readiness, advantages/disadvantages of the TI, and relevant policies.	- Study of company documents - Initial interviews with experts - Identify relevant stakeholders
3. Discussion of the case with experts	Collection of information through individual interviews and group sessions with experts.	- Individual interviews with experts - Focus-group session with experts - Possibly conduct questionnaires
4. Writing of the Report	Structure and summarize the information input from the experts.	- Wrap up of all the information collected and identify the impacts. - Combining the results in a structured overview/report.
5. Evaluation	Evaluation of the impact analysis report.	- Validate the results of the impact analysis report with the participants.

Table 6.2: Description of the usage steps of the impact model

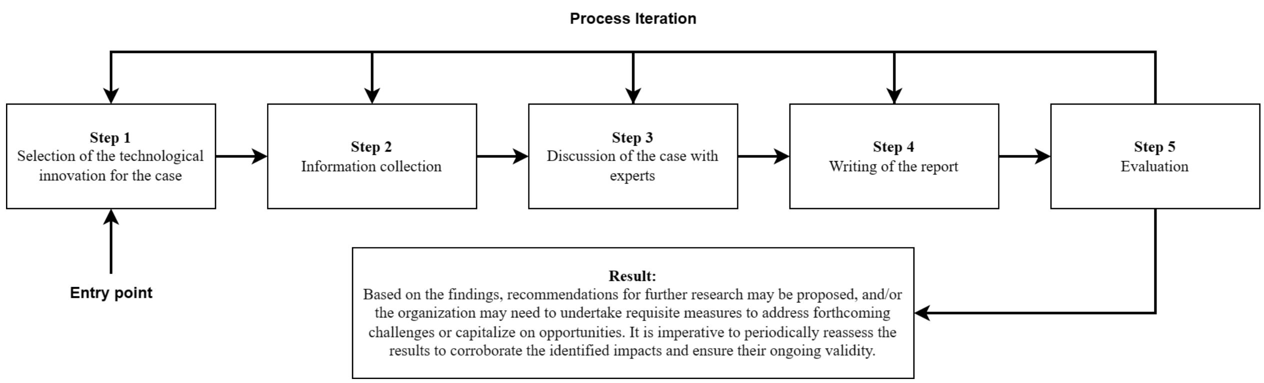

Figure 6.3: A visualisation of the usage of the impact model

1. TI selection

As first step of the impact analysis, the TI needs to be selected for which the impact analysis must be performed. In chapter 3 several potential TIs are already discussed that can be used for the impact analysis model. The TI can for example be: the use of electrical drivetrains in armoured vehicles, the use of composites in the vehicle structure, or a tool such as the use of VR-glasses to apply tele-assistance. It is important here that the case on which the model is applied is clearly defined. This prevents confusion during the process and ensures that the participants during the interviews and expert sessions are talking about the same case. The TI can be selected based on their (military) relevance, technological readiness, or their overall estimated impact on the maintenance tasks. Furthermore, a relevant asset can be coupled to the TI to use the model.

2. Information collection

After the TI has been selected, it must be thoroughly described in terms of physical characteristics, function, current state of technological readiness, advantages and/or disadvantages that the TI brings, and relevant policies. This step is important as it gives a basic understanding of the TI and also allows to create a 'level playing field' among the experts [10].
When collecting the information, a selection of experts or relevant organizations can be made. For this, there

are several relevant groups of people that can be relevant to take into account and retrieve information from.

Firstly, there are the mechanics of the RNLA, who are working with the assets that are currently operational in the RNLA. An advantage of this group is that they know the setting in which they have to maintain the systems and do have relevant experience with current systems. However, a disadvantage is that it is likely that they have no experience with the new TI as the goal of the impact analysis is to look at systems that are not yet operational (within the RNLA).
Secondly, there are the (maintenance) managers of the WSM, from which the functions are described in section 2.6. This group is responsible for asset management and can provide valuable information on the organizational impact of implementing a new TI. A potential disadvantage might be that they probably do not have experience with the TI, as the TI is not yet operational in the organization, as explained before.

Thirdly, it can be possible to collect information from research projects. The DMOD has a wide range of research projects that are often carried out in partnership with external organizations. An example of one of these projects is the E-Fennek project, which is used for the first case in this research and is described in section 7.1. The advantages of these projects are that experts have a lot of knowledge regarding the TI, a risk however is that not all research projects focus on the practical maintenance aspects which impact the RNLA mechanic. It can also be that if a research project is external, the experts might have less knowledge of the military environment that the OLM and ILM mechanics might find themselves in.
Additionally, it is possible to find information from the civilian industry. There are several companies and organizations that also have maintenance operations similar to the RNLA from a technical point of view. For example, to look at the impact on the OLM mechanic, it can be relevant to look at road services such as The Royal Dutch Touring Club ANWB. This organization provides road assistance when a vehicle breaks down, finding ways to get the vehicle up and running as quickly as possible. An organization like ANWB might already be aware of technologies that are still in the future for the RNLA, such as electrification of the vehicle drive train.
In addition to ANWB, manufacturers or maintenance workshops might also provide relevant information on the impact of TIs on the RNLA mechanic. For example, Scania is responsible for most of the maintenance of the Scania Gryphus which is currently operating within the DMOD. This means that they also have to train and educate their mechanics to be able to operate on the new systems.

Fourthly, equipment manufacturers, the regional education centers and the STM can also provide relevant information with regard to the impact of TIs on the mechanic, especially in their education. This is because equipment manufacturers, such as Scania, also often provide vehicle-specific training. The RECs and the STM also have to ensure that their mechanics are kept up to date with the latest developments in the industry.
An overview of the potential sources of information that can be used for the impact analysis is provided in Figure 6.4.

It is also noteworthy that in this stage it may become apparent that the case or TI has not been adequately defined or has been incorrectly selected. At this juncture, it is possible to initiate an iteration back to the first step of the process.

3. Discussion of the case in expert sessions and interviews

ThInterviews and the focus group session form the core input of the impact analysis. In the focus group sessions, experts from different disciplines are brought together so they can exchange information, interact, and discuss the impacts of TIs that they consider to be relevant. The potential disciplines or backgrounds of experts are explained in the previous section and are shown in Figure 6.4
The interviews and focus group sessions are structured as follows: Firstly, the case has to be discussed, so it is clear to the participant(s) how the TI is defined. Then, each impact element is tackled in the following order:

1. Maintenance tasks

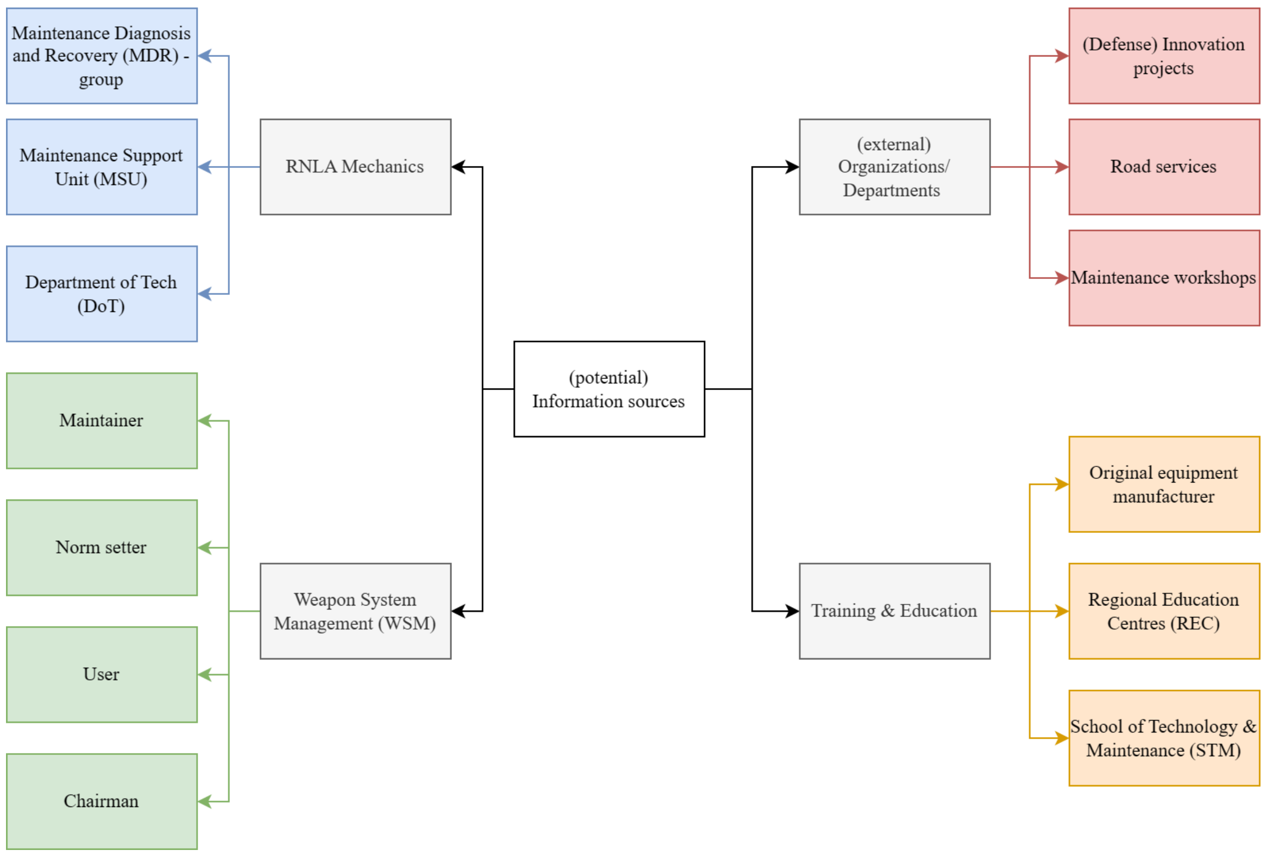

Figure 6.4: For illustrative purposes, the diagram provides an overview of potential information input sources that can be utilized for conducting the impact analysis

2. Facilities
3. Support equipment
4. Training & support
5. Manpower & personnel

It is especially important to start with the impact elements related to the maintenance tasks, as assumptions are made here which can influence the answers of the next questions. After each impact element is discussed and the belonging questions (see Table 6.1) are answered, the experts are able to make remarks or comments. These comments can be about the impact analysis, but also about the progress of the interview.

During the discussion, it may become evident that additional information sources are necessary to enhance the analysis. Consequently, it might be deemed appropriate to iterate back to one of the preceding two steps in the process.

4. Writing the Impact Analysis Report

In this step the impact analysis report is written. The answers of the focus-group, interviews, and of the information collection step are combined and formed into a complete overview. The answers can be shortly summarized into the diagram in Figure 6.2 to provide a brief overview of the complete impact analysis. Also suggestions/advises can be included in the impact analysis report on how to mitigate potential problems or utilize opportunities that the TI might bring.

5. Evaluation

In this step, the answers found in the impact analysis can be re-evaluated with the participant(s), and made sure that the right conclusion are drawn. It can also provide the participant(s) to add new information to the report, or to determine that the current analysis does not provide sufficient answers/is not sufficiently substantiated.

Chapter 7

Initial Design Demonstration

In this chapter, the design of the initial impact model is demonstrated using 2 different cases. In the first case, the impact of a battery-electric drive train is analysed. In the second case, the impact of the increasing amount of data and sensors used in the vehicles is analysed. The step taken in this chapter is the demonstration step from the DS research methodology, and is depicted in Figure 7.1.

The selection of the TIs for the case studies is based on their feasibility. This is because it was found to be difficult, if not impossible, to compare the impacts of different TIs, as they have different natures and it is still uncertain how they will be implemented within the RNLA. Therefore, it was not deemed possible to simply select the TIs that were assumed to have the most impact.
The first case, which is about electrification, has been selected as it represents a change in the system, allowing for validation of the model in this context.
The second case, which deals with the increasing use of data and sensors in vehicles, will also focus primarily on the diagnostics of recently acquired assets within the RNLA. This choice enables the validation of the impact model for TIs in this context.
Both of these case studies were also selected because there would be sufficient knowledge and resources available.

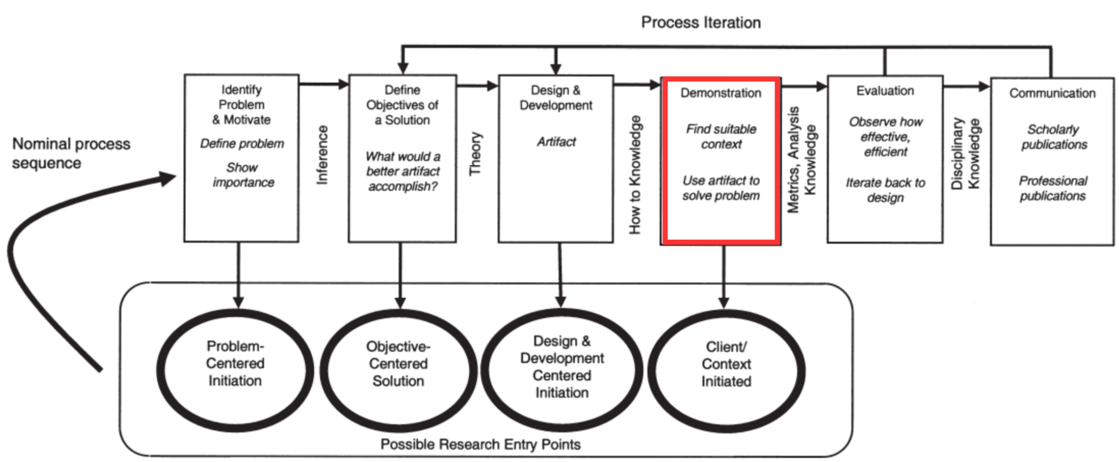

Figure 7.1: The demonstration step, highlighted in the design science research methodology process model from Peffer et al. [4]

7.1 First case: electrification of armoured vehicles

In the first case, the impact of electrification of the drive train (of armoured vehicles) on the RNLA mechanic is assessed. The reason for choosing this TI is because it represents a significant change in the system. Consequently, electrification will likely have a significant impact on the mechanics work, making it a suitable case to test and demonstrate the initial model. Furthermore, as explained in subsection 3.1.1, it is not unlikely that the RNLA will add armoured EVs to its arsenal in the upcoming future. For this case, the E-Fennek project is taken as a sample case. The E-Fennek project started in 2018, and the goal of the project is to convert a light armoured wheeled vehicle to an electric-powered variant. The first objective of the project is to investigate to what extent the technology is mature for the integration of an electric drive system into current weapon systems, using the Fennek as a use case [85].
The Fennek is an armoured reconnaissance vehicle, which is relatively light and small compared to other armoured vehicles. This is because, in the operational context, the Fennek should be as undetectable as possible. The vehicle is required to operate quietly with low heat radiation, and to be as small as possible.
The second objective of the E-Fennek project is to evaluate the use of an electrically powered weapon system in operational action. Despite the existence of the technique, integrating it into existing weapon systems poses a challenge [85].
The objective of the case study in this research is to determine the impact of the electric drive train of the E-Fennek that it will have on the RNLA mechanic.

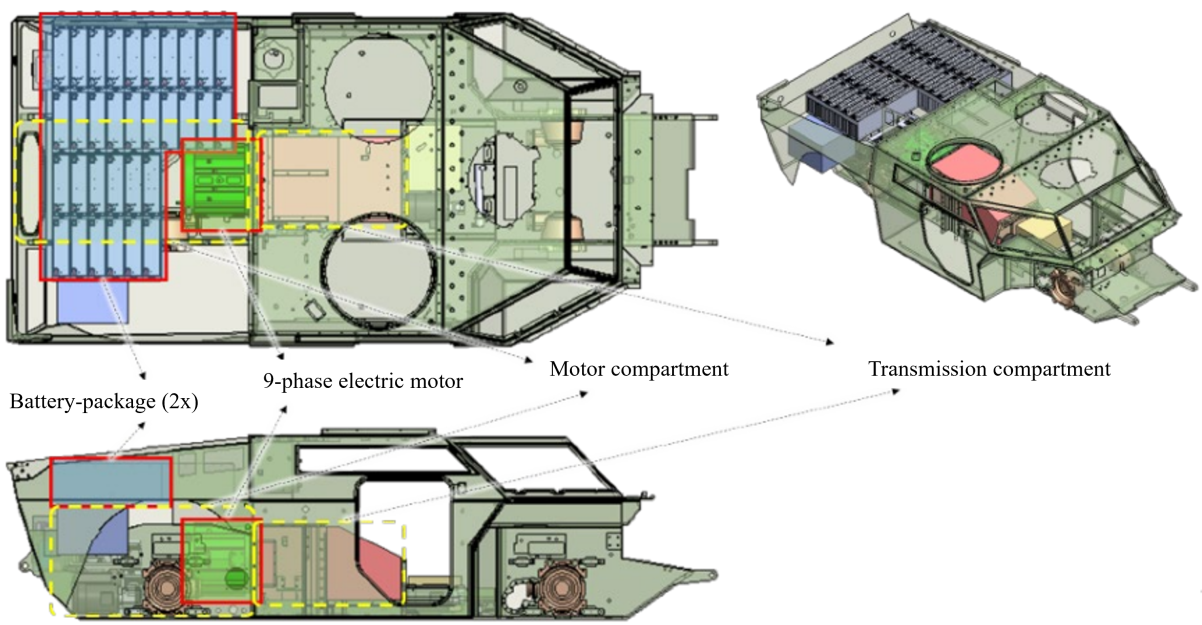

Figure 7.2: A CAD Drawing of the E-Fennek with various components from the electric drive train [85]

7.1.1 Information collection

In this section, background information about EVs and its relevant maintenance aspects are provided. First, some (technical) background information about EVs is provided.
Afterward, some aspects of NEN9140 are explained. The NEN9140 is an important standard that many organizations in the Netherlands use to safely perform EV maintenance. The NEN9140 information will also provide input for the impact analysis.

EV systems

As described in subsection 3.1.1, there are several types of electric vehicles. The E-Fennek is currently powered by a large battery pack, therefore it is a full electric battery EV. However, the battery pack can also be replaced by a smaller battery pack combined with an ICE used as a electric generator, a fuel cell, a microjet-generator or possibly by the upcoming M-Star generator (nuclear-powered) [85].
For the case study, the scope is defined by the E-Fenneks current configuration, namely as a full-electric battery EV. The drive train of this type of EVs consists out the following main components: (i) battery packages, (ii) DC-DC converter, (iii) motor controller, (iv) electric motor, and the (v) charger [86]. In Figure 7.2 can be seen where several of these components are located in the vehicle.

Maintenance on EV systems

Compared to ICE-vehicles, EVs are more reliable and require less maintenance [38, 39]. In battery EVs, there are less moving parts, which results in less wear and therefore less maintenance costs [87].
The maintenance for the motor also depends on the type of electric motor (AC type vs DC type). Currently most electric motors are of type AC, due to the size and maintenance requirements making DC motors obsolete [38]. Brush wear is the main cause of high maintenance in DC motors [38].
Furthermore, because in a full electric vehicle the operation is controlled by microprocessors, it lends itself to the use of a Health and Usage Monitoring System (HUMS). Based on the provision of data from the HUMS, the EV would be capable of implementing reliability centered maintenance [88].

NEN9140

The introduction of EVs introduces new risks, which can lead to serious damage and injury if handled incorrectly. The High-voltage (HV) electric circuits generally contain several hundreds of volts, which can be life-threatening. Therefore, it is essential that the mechanics and service technicians possess the right knowledge on how to work safely on hybrid and electrically powered vehicles. These safe-working practices are specified in the NEN9140 [89].
For the impact analysis, a large part of the answers required for the model can be found in this standard. Therefore, for each element the relevant section of the NEN9140 norm is provided (due to copyright protection, no quotations are given).
It is important to note that the NEN9140 is not required by law; however, if the organization decides to not follow this standard, they should carefully consider the implications of non-compliance and take appropiate measures to mitigate the risks if they choose not to follow the standard. Therefore, for the remainder of this paper, we will assume the NEN9140 as requirement.

NEN9140 roles

The NEN9140 norm defines several roles with regards to safely working on EVs, namely: layman, EV instructed person, EV skilled person, EV work planner, and lastly the employer (in Dutch: "leek", "voldoende-onderricht persoon", "vakbekwaam persoon", "werkverantwoordelijke", and "werkgever" respectively). The layman has no experience or training specifically regarding the maintenance EV. The EV instructed person is sufficiently instructed in executing tasks with known, limited electric hazards of EVs and is able to recognize these electric hazards and take precautions. [89]
The EV skilled person has a relevant education making him or her able to acknowledge and prevent hazards from electricity. The EV skilled person is also directly responsible for safety in respect of work that may present electrical hazards when working on EVs.
The EV work planner is a person designated and directly responsible for safety regarding work that may create electrical hazards when working on EVs. The EV work planner must have at least the knowledge of a EV skilled person. [89]
Lastly, the employer is the person directly responsible for working safely on the EVs. The person installation manager, as referred to in NEN3140 from which this standard is derived, as such has no comparison with the scope of this norm, NEN9140. For this reason, the installation manager is split into the person employer and owner. The employer can also be a delegated person on behalf of the employer. Furthermore, parts of the

Impact element	Sub-element	Information	Section of the NEN9140 [89]
Operational maintenance	BDR	BDR activities to the HV-system are not compliant to the NEN9140 norm. The surroundings are not up to the criteria, as it can be an instable workplace in a humid environment.	6.3; 6.101.3
	Corrective maintenance	-	-
	Preventive maintenance	-	-
	Modification maintenance	-	-
Facilities	Infrastructure	Spot which are susceptible to electric dangers have to be marked.	4.5
	Location		6.101.3
	Workplace equipment		
Tools & equipment	Physical tools	Tools, aids and (personal) protective gear must comply with the international, European or national norms. Examples of these tools with the relevant specific norm is provided in the NEN9140. These tools have to be inspected regularly according to NEN3140 and A2:2018.	4.6
	Digital tools	-	-
Manpower & personnel	Job roles	Several electrical operations are described by the NEN9140, and for which level of certified mechanic this should be executed.	5
	Critical behaviours	-	-
	Mindset/attitudes/beliefs	-	-
	Compensation/rewards	-	-
Training & training support	Prior education/training	The mechanic requires a specific trainingprogram to develop the competence of EV skilled person and EV instructed person.	6.3.2
	RNLA education/training	-	-
	Training equipment	-	-

Table 7.1: Information input from the NEN9140 norm [89]

employers responsibility may be delegated on an as-needed basis to, for example, a supplier or manufacturer. [89]

7.1.2 Discussion of the case with experts

For the electrification case, several experts within the organization of the DMOD where interviewed and a focus-group session was held. As for the case it was possible to collect information through a pilot program of the E-Fennek, it makes sense to involve the people working on the project. Therefore, an initial interview was conducted from which a range of potential participants followed. The list of person to involve:

- A maintainer from WSM
- A chairman from WSM
- A vehicle technology advisor from the department of Tech
- A representative of EV maintenance at ILM: maintenance advisor of RAS-unit
- A representative of KI, from the department of Mobility & Energy
- A representative of CoELog

The participants were selected from several disciplines based on their knowledge of working with EVs and their position in order to represent as many of the information sources that were explained in section 6.2. However, for the focus-group session it was also important that the group did not become too large so it would still be possible to involve everyone in the discussions. To summarize, the participants of this case study were from the following disciplines:

- Mechanic from MSU

- Mechanic from Department of Tech (Dutch: Afdeling Tech) (DoT)
- Maintainer from WSM
- Chairman from WSM
- Defense innovation project

After a selection of potential participants required for the case study was made, they were contacted. Due to scheduling and limited amount of time, the maintainer and maintenance advisor of the RAS-unit were unable to join the focus-group session. Therefore, an individual interview was conducted and the answers summarized to represent them at the focus-group session.
Furthermore, the other focus-group participants were provided a questionnaire so the answers could be evaluated before-hand and the answers that diverged the most could be receive more attention during the focus group session.

7.1.3 Impact analysis report

The results of the case study are summarized in Table 7.2, and a visualisation of these results within the impact model is shown Figure B.6. The green letters represent a positive impact, the red a negative impact, and the orange letters represent an impact which is not definitively positive or negative. The complete impact analysis report can be found in Appendix B.

Topic	**Impact element**	**Summary of the results**
Maintenance tasks	BDR	BDR cannot be used on the High-Voltage system due to safety constraints. The other systems are unaffected.
	Corrective maintenance	Less.
	Preventive maintenance	Less.
	Modification maintenance	Same.
Facilities	Infrastructure	The applicability varies depending on the battery type (LFP vs NMC). However, the addition of charging stations and storage locations for batteries is necessary. Specific requirements are outlined in NEN9140 section 4.5.
	Location	The working conditions are outlined in NEN9140. However, engaging in activities related to the HV-system in the field will likely not meet safety regulations.
Support equipment	Physical tools	The required tools for safety are described in NEN9140 section 4.6. They contain among others: isolating gloves, isolated tools and voltage indicators.
	Digital tools	Not specifically.
Manpower & personnel	Job roles	New tasks are de-energizing the vehicle, handling diagnostic tools and perhaps a piece of programming. These tasks are handles by the qualified personnel, defined as the skilled person (in Dutch: Vakbekwaam persoon) in NEN9140.
	Critical behaviours	The mechanic needs to be aware of the dangers of HV-systems. Accuracy, caution and knowing what you are doing is crucial! Both for the mechanics and his colleagues safety.
	Mindset/attitudes/beliefs	”Unknown is unloved”; However, the mechanics are generally ’enthusiastic’ about new material. The most important thing is that they see the electric vehicles are really becoming operational.
	Compensation/rewards	A cleaner workplace due to less oils/dirt might be appreciated, but the complexity of the electric systems perhaps not. Eventually it is important that recognition is not only in salary, but also in accreditation of their education within the industry.
Training & training support	Prior education/training	For the NEN9140 course certification, the knowledge of at least a BAT (in Dutch: Bedrijfsautotechnicus) is required. This is a level 2 education in the Dutch vocational schooling system.
	RNLA education/training	To work on electric vehicles, mechanics must undergo a NEN9140 certified course.
	Training equipment	A TABBY can serve as an excellent demonstration vehicle for educational purposes. It provides mechanics with a safe platform to learn the basics of electric vehicles.

Table 7.2: A short summary of the impact analysis results of the second case

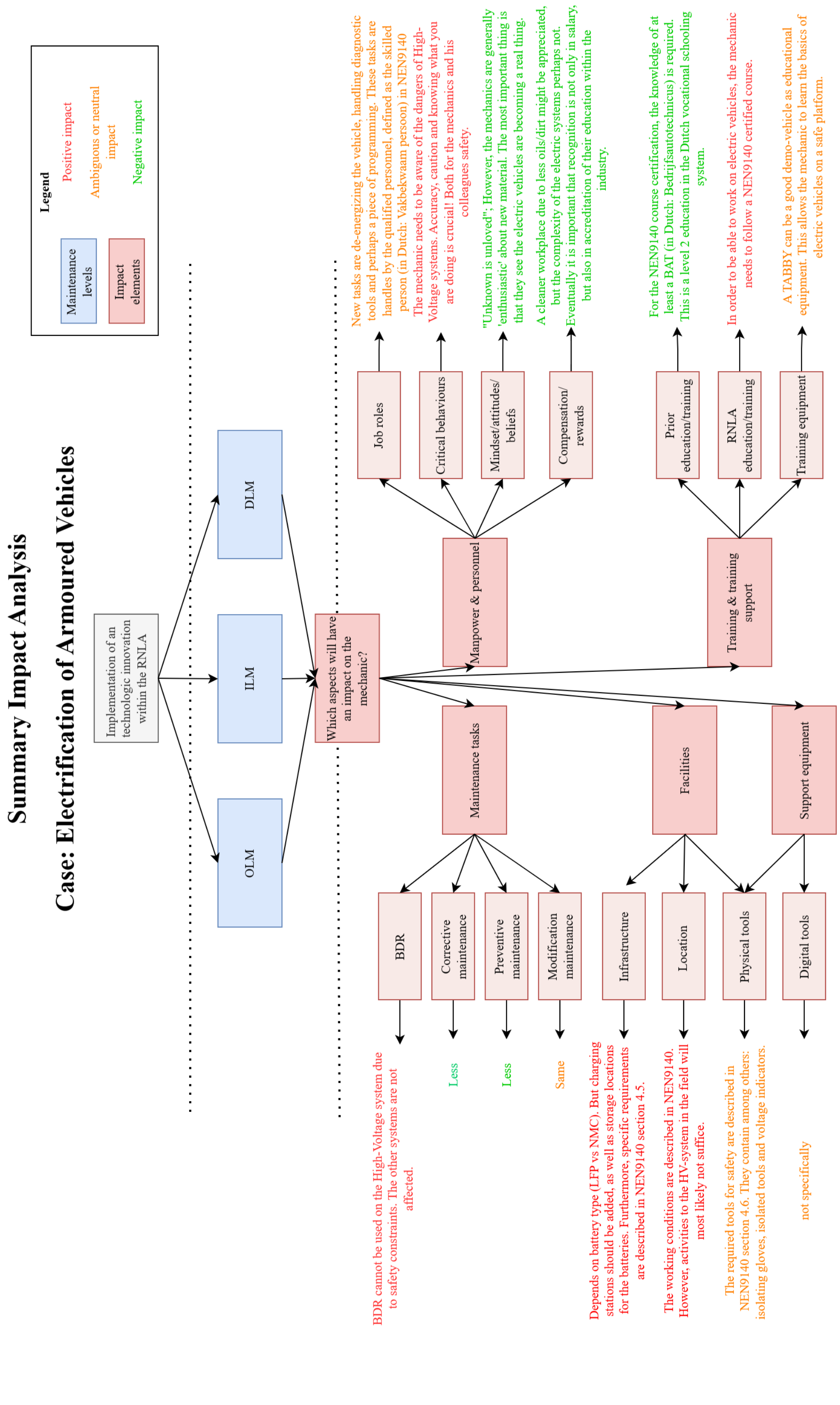

Figure 7.3: A complete overview of the summarized impact analysis of case 1

7.1.4 Evaluation

After writing the impact analysis report by combining input sessions (interviews & focus-group session), the participants received the report to validate or make changes. In this case, no changes were made to the input from the sessions.

7.1.5 Recommendations based on case study

This section delves into the risks and opportunities discovered during the case study analysis, which lead to recommendations for the organization. The risks & opportunities follow from the impact analysis report. These recommendations follow from the impact analysis report.

Limitations to maintenance operations in the field

The organization must address limitations with respect to maintenance operations in the field, primarily in terms of safety and practicality. Given safety constraints, particularly with respect to compliance with NEN9140 standards, it is imperative to strategize approaches for conducting field maintenance operations. As outlined in the report, the use of BDR or other forms of repair in the field currently poses feasibility challenges due to safety concerns. Hence, it is recommended to explore alternative methods for field repairs. Furthermore, the large size of the EV toolkit presents practical challenges during field operations. Therefore, it is advisable to conduct research aimed at enhancing the toolkit's portability and usability in field environments.

Opportunities

EV present several opportunities, e.g. in their ability to offer advanced self-diagnostic systems compared to traditional ICE-vehicles. This advancement has the potential to reduce the required skill level of mechanics and alleviate workload demands.
Another advantage of EV is their anticipated lower maintenance workload, attributed to the simpler design with fewer moving parts.

EV expert

Considering the unique features of EVs and their evolving technology, it may be beneficial to explore the concept of an EV expert within the organization. In other domains, electrical engineers with specialized expertise already play a role, such as on a Navy vessel or at a military camp. Thus, it is worth considering how a similar concept can be adapted for EV maintenance.

7.2 Second case: increase in data within maintenance operations

The second case focuses on the increased use of data within maintenance operations. The increased use of data within automotive systems is one of the certain changes in the next 15 years, according to a research carried out by a cooperation of BOVAG, Innovam, OOMT, and the RAI Association [28]. Software and connected car-applications provide a lot of information about the vehicle and of the users. This allows the vehicle to predict their maintenance requirements, and allows the transition towards PdM. "Reading out cars on the spot in the workshop, will soon no longer occur" [28].
This is an important trend that occurs in the civil sector. It is important to note that this does not necessarily mean that it will also take place in a military context. However, the systems used by the RNLA are often based on a system designed for the civilian industry, e.g. the Scania Gryphus, which is essentially a civilian Scania truck from the XT series that had some design modifications to adjust it to a military environment. Therefore, trends from the civil industry are likely to be relevant for military systems as well.
In short, the increased use of data within maintenance is an important trend that also significantly changes the mechanics' work. For this reason, it is selected as TI for the second case study.

7.2.1 Information collection

One of the major contributors of the use of data within maintenance operations is because of the development and expansion of the CAN-BUS systems. A CAN is a serial network that facilitates the passing of information between Electronic Control Units (ECUs) [90]. The CAN-BUS provides improved vehicle diagnostics, less complex design of electronic circuit controls, and advanced implement management [90]; CAN-BUS also allows for high precision in machinery performance and logistics information, which help to estimate the operational cost and projected size in downstream operations. The specific measurement of other metrics, including fuel consumption, engine load, and average operating speed can also help supply chain managers maximize field and transport efficiency, while designing overall equipment solutions at a lower cost [90]. CAN-BUS systems also play an important role in telematics, as it helps in the communication of large quantities of data which is eventually converted into valuable information for end users [90].
One of the significant impacts of CAN-BUS technology is the transition from voltage-based control to data-traffic-based control of specific components and systems. Consequently, diagnostic procedures have undergone substantial changes compared to conventional electric systems. As modern vehicles integrate various sensors, actuators, and multiple control units, a more precise diagnostic approach becomes imperative. The traditional method of fault isolation proves less effective, necessitating an alternative with a more comprehensive fault description [91].

7.2.2 Discussion of the case with experts

For the second case, mostly maintenance personnel within the RNLA has been interviewed, to get a perspective of what they already see happening in their job due to the increase of data within the systems. The mechanics from OLM, ILM, and an instructor of the STM have been interviewed individually. For the DLM, a group session has been held with several of the maintenance managers. To summarize, the participants of this case study were from the following disciplines:

- Commander of the MDR-group
- Commander of the MSU
- Maintenance managers of the DoT
- Instructor of the STM

7.2.3 Impact analysis report

The results of the case study are summarized in Table 7.3, and a visualisation of these results within the impact model is shown Figure 7.4. The complete impact analysis report can be found in Appendix C. The green letters represent a positive impact, the red a negative impact, and the orange letters represent an impact which is not definitively positive or negative.

Topic	**Impact element**	**Summary of the results**
Maintenance tasks	BDR	This can become a problem, as sensors and electronics are sensitive equipment and can sometimes require computers which are currently not always available in the field.
	Corrective maintenance	The integration of sensors facilitates the shift towards predictive and condition-based maintenance, resulting in reduced reliance on corrective maintenance. However, it can also complicate corrective maintenance procedures. Errors in the CAN-BUS, for instance, may be challenging to rectify without the necessary equipment such as spare parts and laptops, consequently increasing the time spent addressing faulty system errors.
	Preventive maintenance	The proliferation of sensors and data enables the transition towards predictive maintenance for some components, leading to either reduced maintenance requirements or more effectively planned maintenance schedules.
	Modification maintenance	Not discussed.
Facilities	Infrastructure	In combat operations, there's no distinction. However, in certain contexts, a data connection might be necessary to enable the producer to monitor the system or for updates.
	Location	No difference.
Support equipment	Physical tools	Computers/laptops are required to read out the systems. Additionally, cables are required.
	Digital tools	Each computer system necessitates specific software. The manner of usage may vary depending on the system.
Manpower & personnel	Job roles	"From mechanic towards detective"
	Critical behaviours	Computers can be more sensitive systems, demanding discipline from the mechanics. Additionally, mechanics must maintain their knowledge and skills, highlighting the importance of internal motivation and curiosity.
	Mindset/attitudes/beliefs	This differs a lot per generation. However, at the MDR-group, 2 types of mechanics are noticed. 1. The mechanics who are eager to learn. 2. The mechanics who are reluctant to learn, as they are overwhelmed by the complicated systems.
	Compensation/rewards	It is crucial to ensure that mechanics retain the sense of capability to identify and resolve problems independently. They should not merely perform tasks from a checklist and send away malfunctioning equipment without attempting to diagnose and address the underlying issues.
Training & training support	Prior education/training	For a proper CAN-BUS training, at least a level 3 vocational education in vehicle-mobility (In Dutch: EBAT) is required as prior knowledge.
	RNLA education/training	A CAN-BUS training is recommended.
	Training equipment	Not specifically.

Table 7.3: A short summary of the impact analysis results of the second case

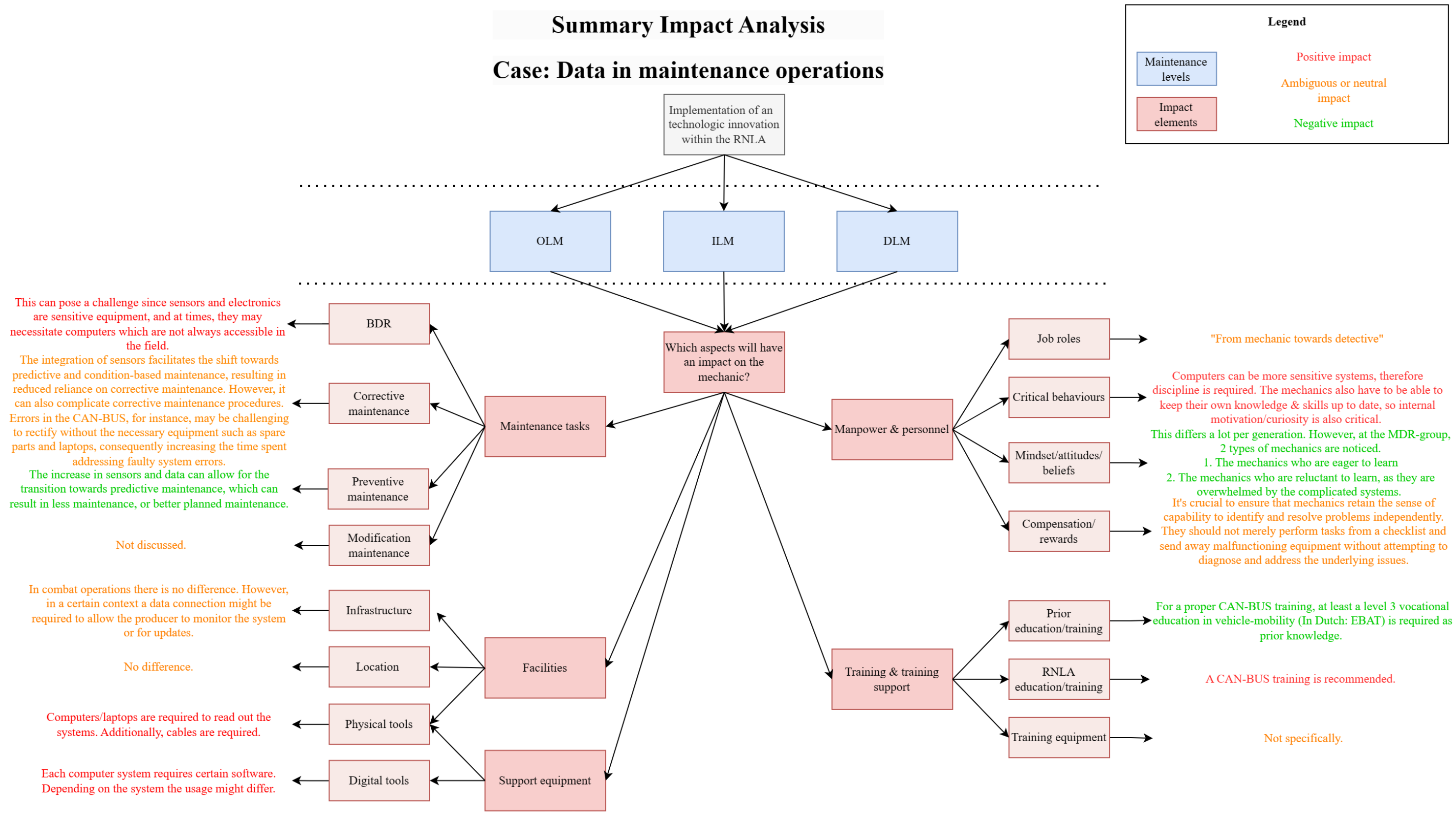

Figure 7.4: A complete overview of the summarized impact analysis of case 2

7.2.4 Evaluation

After the impact analysis report was written by combining the answers from the input sessions (interviews & focus-group session), the participants were send the report in order to validate or make changes. In this evaluation step no changes to the impact analysis were found necessary.

7.2.5 Recommendations based on case study

A primary conclusion drawn from the case study is the challenge posed by the increase of components and systems within the CAN-BUS, rendering diagnosis increasingly complex for mechanics. The increasing complexity of systems, coupled with the sensitivity of sensors, exacerbates the difficulty, compounded by the lack of availability of computers at OLM, negatively impacts the availability of materials during operational breakdowns.

Despite the current complexity introduced by the expansion of CAN-BUS systems, there is potential for improvement. As articulated by one respondent, "If you give the mechanics a more goal-oriented training, it delivers more knowledge, experience, and insight about CAN-BUS systems. Then you can do a more in-depth diagnosis, and get a diagnosis easier and faster in 9 out of 10 times" (CMDR-1). Hence, my foremost recommendation is to ensure mechanics are adequately trained in the new (digital) diagnostic methodologies.

Moreover, it is imperative to equip mechanics with the requisite (digital) tools and ensure their availability in field environments. Additionally, leveraging the CAN-BUS presents opportunities to explore novel techniques like PdM or various forms of telemaintenance. However, it is essential to tailor these approaches to the specific operational context of the RNLA.
In the subsequent chapter, the impact model process is evaluated. This evaluation is then used to improve the design of the impact model.

Chapter 8

Design Evaluation

In the previous chapter, the initial design of the impact analysis model has been demonstrated using two different cases. In this chapter, the process and results of these case demonstrations are evaluated. This corresponds to the fourth step of the DS research method from Peffers, which is explained in section 1.5 and depicted in Figure 8.1 [4].

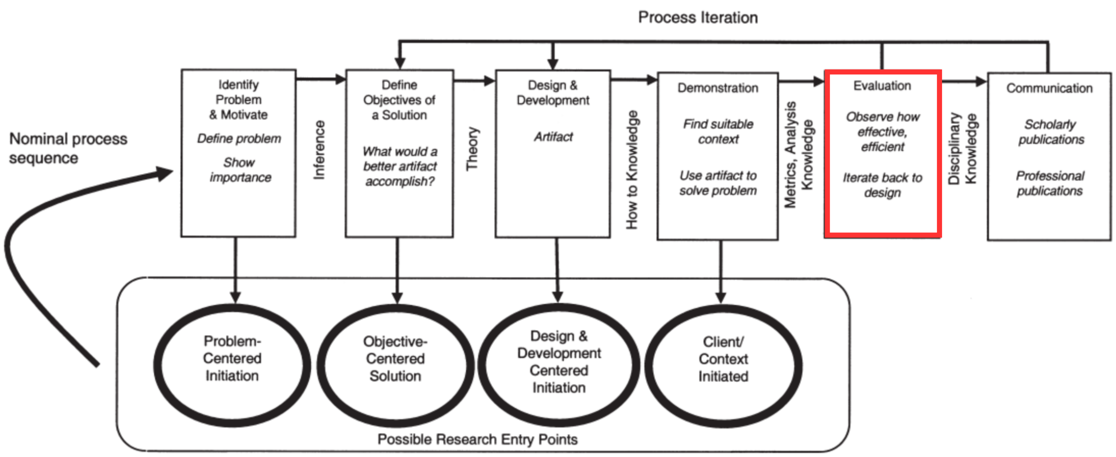

Figure 8.1: The evaluation step, highlighted in the design science research methodology process model from Peffer et al. [4]

8.1 Evaluation of the cases

8.1.1 Evaluation of the first case

After developing the impact analysis report on the first case, the process and the result have been analysed. By evaluating the steps taken to create the impact analysis, the design of the impact model can be improved. In the evaluation, several things came to light; therefore, in this section, the demonstration process of the first case is evaluated per step.

Step 1: Selection of the TI

Selecting the TI In this step, the task at hand was to identify a relevant TI that could potentially be implemented within the next 5 to 10 years, with a significant projected impact on the mechanics of the RNLA. Comparing various TIs proved challenging due to the uncertainty surrounding their potential effects. Therefore, the case about electrification of armoured vehicles has been selected based on the assumption that the impact on the mechanic would be significant, as the mechanical drive train of the system would be (almost) completely changed. Furthermore, considering the evolving policy landscape shaped by the European Parliament within the automotive sector, the integration of armoured EVs into the RNLA is increasingly plausible [36].

Step 2: Information collection

Defining the TI Secondly, defining the appropiate TIs proved challenging due to the uncertainties surrounding future technolgical advancements. For instance, crucial details such as the specific battery types, integration methods, interchangeability, charging procedures, and maintenance protocols remain uncertain. To mitigate this uncertainty, the E-Fennek, an existing prototype, was selected as representative vehicle for the analysis. While the E-Fennek serves as a valuable starting point, which provided some footing during the interviews and focus group session. It is essential to acknowledge that the impact analysis is dependent on the assumptions made during the TI definition phase. Thus, periodic re-assessment of these assumptions is crucial for maintaining the validity of the analysis.

Implementation within the organization In addition to technological uncertainties, assumptions regarding the integration of the TI into the organization's logistics pose significant challenges. Interviewees were asked to provide insights into which components of the electric drive train would require maintenance or repair and where these activities would take place within the organization. This task is complex and dependent on various factors, such as the availability of time, materials, and people who are adequately trained to perform these maintenance activities. This is especially relevant within the dynamic operational environment of the RNLA.

Step 3: Discussion of the case with the experts

Use of focus-group session & interviews The focus-group session and interviews provided clear and useful answers for the case. Also the possibility to engage in a discussion is a big advantage of the collaborative session. However, one of the disadvantages is that it is challenging to get all participants together in the same time and place, especially in a focus group session with many participants. Also, a risk of inviting too many experts to the session is that not everyone gets the chance to contribute to the discussion as some participants might be more present than others. Furthermore, as the topics were now mostly discussed in the focus-group session by participants who work together more regularly, it was found that their answers are more overlapping than the participants who did not co-operate on a regular basis.

Lack of input from outside of the organization The focus-group session for the first case involved mainly people within the organization. However, especially regarding EVs, there is a lot of information in the civil industry as well. Furthermore, the representation from the educational institution was missing, as it was not yet specifically clear how well the current education of the mechanic is sufficient for maintaining EVs during the focus-group sessions. Therefore, after evaluation, an interview was conducted with the ANWB and TCR to get more insight from the civil industry.

Step 4: Writing of the report

Presentation of the results The results are currently described into an impact analysis report, as this allowed for more detailed answers. The answers are formulated in sentences because, due to the nature of the answers, it is not possible to quantify them. Consequently, it is not possible to produce an accurate and brief depiction of the results that can show the general results at a glance. However, a very briefly summarized version is presented in an overview and a table, to still provide a readable and short representation of the results.

Step 5: Evaluation

Difficult to build an advice/recommendation Because the technology is still far away, it is not sure yet how it will be implemented within the organization, and if it would be implemented at all. This makes it challenging to make concrete advice for the organization. However, the model in its initial state does allow to identify risks associated with implementing armoured EVs within the maintenance organization. Such as the problems with regards to BDR, doing maintenance in the fields, and the required knowledge by the mechanic.

Difficult to identify specific skills & education Initially, there was no input from the RECs or other school institutions, this made it difficult to determine if the current education of the mechanic would be sufficient. Therefore, this was one of the aspects in the impact analysis reports that had to be investigated further. Also, it was found difficult to determine the specific skills of the mechanic as this element was discussed later during the interviews and focus group session than the 'tasks' of the mechanic.

Evaluation of the usage steps of the impact model

The usage steps of the model were found to be effective, as there were no major problems caused by following these steps. The steps also helped to find some footing for creating the impact analysis for the case in a structured manner.

Evaluation of impact analysis report

In collaboration with the CoELog, the results of the case study are evaluated against the objectives of the solution and the design criteria, as depicted in Table 8.1 and Table 8.2 respectively. It is noteworthy that the majority of input originated from participants within the organization, thereby potentially limiting the diversity of perspectives. Furthermore, it was observed that the education domain was not adequately considered in the analysis, suggesting a potential area for further exploration and refinement in future iterations of the study. The evaluation will be used in chapter 8 to evaluate the impact model and make improvements.

Solution objectives:	**Input:**
show how the professional maintenance tasks of the mechanic change for each maintenance level (OLM,ILM, and DLM).	Partially. The skill changes required by the mechanic are not clearly provided.
show the impact on the maintenance workload of the TI.	Insufficient, this is seperate from the EVs. Other TIs are simultaneously of influence on the mechanics tasks & skills.
show what tools & equipment the mechanic needs to be able to operate/use to maintain the systems. This includes hand tools, workshop equipment, digital tools, and tools required for educational purposes.	Insufficient. Digital tools (/the self-diagnosis) system cause a change, but the model does not show this clearly.
show at which (physical) location the mechanic can maintain the TI.	Sufficient.
determine what prior education is required by the mechanic to be able to maintain the TI.	Insufficient. It is not clear where and when the mechanic needs to learn programming.
determine the (preferable) competences that the mechanic should possess.	Sufficient.
determine the mindset, attitude, and/or beliefs of the mechanics towards the TI	Partially, but the input for the results mostly come from within the organization. Therefore, there is still a lack of input from outside the organization.

Table 8.1: Evaluation of the results of the first case study with regard to the solution objectives.

Design criteria	Input
The model should show how to collect the information;	Sufficient, but perhaps input from technology experts themselves are missing.
The model should show how to produce a clear (and useful) overview off the potential impact of a TI on the mechanic of the RNLA.	Sufficient, in table format.
The model should show how the RNLA can use the impact analysis to make their mechanic more future-proof.	Insufficient.
The model should focus on the intermediate future upcoming 5 to 10 years.	Insufficient. The model should make the distinction between three levels: the situation now, the situation in 5 years, and the situations in 10 years.
The model should be workable in the organizations situation, therefore the model should be rigorous and relevant.	The steps of the model are clear. However, the results of the case study do not yet show a definitive answer, and the information regarding required skills is not fully complete.

Table 8.2: Evaluation of the results of the first case study with regard to the design criteria.

8.1.2 Evaluation of the second case

In this section, the process and results of the second case are evaluated. The lessons learned and identified from the the second case are described in this section, this is done per step of the impact model.

Step 1: Selection of the TI

Selecting the TI For the second case, the increased use of sensors in the ground-based vehicles have been selected as TI. This is because it has been identified as one of the major changes for the mechanic in the initial interviews, and also because this change has been identified as one of the major developments in the civil automotive industry [28]. The major challenge in this step was the difficulty in accurately defining this TI. This is because the research looks at the impact of these changes in the upcoming 5 to 10 years, meaning that these changes are not 'active' in the current fleet of the RNLA and that it is not yet certain how it will develop in the future.
The TI is also quite broad, as there are many sensors in a military system and not each sensor addition has the same impact on the mechanic's job. Hence, delineating the TI posed a challenge. Opting for the inclusion of only one type of sensor presented difficulties, as its addition alone might not yield a significant impact for a thorough analysis. Moreover, focusing solely on one sensor type risked rendering the case study overly specific, potentially hindering the creation of a general view of the impact.

Step 2: Information collection

Difficult to collect information As stated in the evaluation of the previous step, it was not possible to select a specific system (or system component) as a 'case scenario' due to it being to specific for an impact analysis of future systems. This made it harder to gather information about the impact of the TI. As, for example, if a specific CAN-BUS system would have been selected, it is not sure that the CAN-BUS will be used in that configuration in the future. And even though the principal of the CAN-BUS will be the same, in the usage there are a lot of differences between which brands (concluded in the focus group session, DoT-1). Especially in relation to the transparency of the manufacturer with its users it is important which brand/asset is selected.

Step 3: Discussion of the case with the experts

Use of group- & individual interviews For this case, both group and individual interviews were held. The reason for not using a focus-group interview with participants from different parts in the maintenance organization was because of the limited time to plan these interviews. Therefore, individual interviews and a group interview were held with DoT, to still provide input for the cases. The interviews still provided good input for the case study; however, because no specific component/system was selected for the case study, the participants encountered challenges in answering certain questions.

Lack of input from outside the organization The input from the interviewees came from within the organization. As mainly mechanics from the RNLA were interviewed, it helped to get a good view of the practical impact on the job. It also allowed to bring problems to the light that are currently being experienced by the RNLA mechanics. However, since these mechanics work in the operational domain and therefore only work with currently active materiel, the experience is mostly limited to systems that are currently being used by the RNLA (or systems that have been used in the near past). Especially when looking at systems that will be active in the future, it might also be beneficial to include frontrunner companies pilot projects to create a vision of what new assets will bring to the table.

Step 4: Writing of the report

Presentatifon of the results The results are described in an impact analysis report. Here, the same feedback is applicable as mentioned in the previous case study; namely, as the results are not quantifiable, it is not possible to produce an accurate and brief depiction of the results that can show the general results at a glance. However, a very briefly summarized version is presented in an overview and a table to still provide a readable and short representation of the results.

Step 5: Evaluation

In collaboration with the CoELog, the results of the case study are evaluated against the objectives of the solution and the design criteria, as depicted in Table 8.3 and Table 8.4 respectively. The evaluation of this case is very similar to the first case, as the same impact model design is used. Also in this case, one of the main points is the lack of insights in which competences to acquire, and the input from outside of the organization.

Solution objectives:	**Input:**
show how the professional maintenance tasks of the mechanic change for each maintenance level (OLM,ILM, and DLM).	Not yet clear how the competences change.
show the impact on the maintenance workload of the TI.	Insufficient. Other TIs are simultaneously of influence on the mechanics tasks & skills.
show what tools & equipment the mechanic needs to be able to operate/use to maintain the systems. This includes hand tools, workshop equipment, digital tools, and tools required for educational purposes.	Insufficient. Digital tools (/the self-diagnosis) system cause a change, but the model does not show this clearly.
show at which (physical) location the mechanic can maintain the TI.	Sufficient.
determine what prior education is required by the mechanic to be able to maintain the TI.	Insufficient. It is not clear where and when the mechanic needs to learn programming.
determine the (preferable) competences that the mechanic should possess.	Sufficient.
determine the mindset, attitude, and/or beliefs of the mechanics towards the TI	Partially, but the input for the results mostly come from within the organization. Therefore, there is still a lack of input from outside the organization.

Table 8.3: Evaluation of the results of the second case study with regard to the solution objectives.

Design criteria	**Input**
The model should show how to collect the information;	Sufficient, but perhaps input from technology experts themselves are missing.
The model should show how to produce a clear (and useful) overview off the potential impact of a TI on the mechanic of the RNLA.	Sufficient, in table format.
The model should show how the RNLA can use the impact analysis to make their mechanic more future-proof.	Insufficient.
The model should focus on the intermediate future upcoming 5 to 10 years.	Insufficient. The model should make the distinction between three levels: the situation now, the situation in 5 years, and the situations in 10 years.
The model should be workable in the organizations situation, therefore the model should be rigorous and relevant.	The steps of the model are clear. However, the results of the case study do not yet show a definitive answer, and the information regarding required skills is not fully complete.

Table 8.4: Evaluation of the results of the second case study with regard to the design criteria.

8.1.3 Evaluation of the model

In conclusion of the first two case studies, two significant challenges emerged. Firstly, both case studies revealed the inherent difficulty in definitively defining the required skill sets. This complicates the task of determining how organizations can proactively educate their mechanics to effectively address these TIs. This challenge is compounded by the uncertain trajectory of technological developments. As the manner in which technologies evolve and are implemented (within the RNLA) remains uncertain, robust recommendations for anticipation become exceedingly challenging, if not impossible to formulate.

Moreover, the model does not adequately account for the simultaneous combination of different TIs. As multiple TIs develop simultaneously, they impact each other in the future. For instance, EVs necessitate distinct skills and tasks, which are, in turn, influenced by the evolution of self-diagnosis systems. This interplay between TIs can potentially mitigate problems associated with the complexity of automotive systems. However, it also makes the task of providing reliable advice significantly more challenging, given the multitude of factors that influence changes in job roles.
Lastly, the model encompasses numerous impact elements, each briefly addressed. These elements themselves are often influenced by a myriad of different'subfactors', adding layers of complexity to the problem. Consequently, crafting reliable advice to anticipate future developments becomes a formidable endeavor.
In essence, the evaluation underscores the complexity and uncertainty inherent in predicting the impact of TIs within the RNLA industry. While the model provides a framework for analysis, its effectiveness is constrained by the dynamic and interconnected nature of technological advancements and their implications on job roles and skill requirements. Thus, while valuable insights can be gleaned, the model's capacity to provide definitive guidance for proactive measures remains limited.

8.2 Redesign of the impact model

As described in the steps by Peffers et al., the evaluation is iterated back to the design using the DS research methodology [4]. After careful consideration, it was decided to return to the design & development phase and redesign the impact model using the lessons learned from the first two cases. This step in the DS methodology is shown in Figure 8.2.

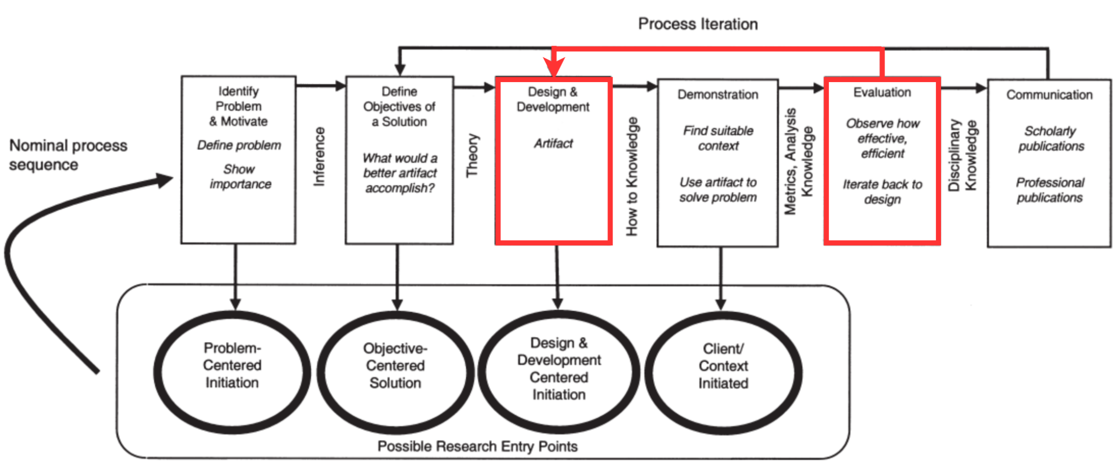

Figure 8.2: The design iteration made using the design science research methodology process model from Peffer et al [4]

8.2.1 Design improvements

From the evaluation of the first two cases, it was found crucial to use a specific and well-defined case study in order to obtain the right information from the participants. Without a proper definition of the case study, it

becomes more challenging for the participants to provide useful answers, and it also leads to more divergent responses. Furthermore, one of the conclusions is that the impact model required more scientific literature to support it.
Another part of the feedback given by the CoELog, is that the selection of the TI has been based on literature research from within the organization. The impact analyses performed do not take into account the need to cooperate with external organizations, such as regional schools or industry maintenance workshops. Therefore, in the design iteration, it is decided to take these new aspects into account and also focus more on the external information.

Adapting literature from TIM

One of the design improvements is to provide a better substantiation from the literature. Therefore, the TIM has been introduced and certain impact elements of the TIM are integrated into the impact model. The TIM has also been applied by the TNO to analyse the impact of future technologies on the tasks, skills, and quality of the work regarding electric-, and maintenance mechanics. In turn, the lessons learned from the research of the TNO are implemented within the redesign of this model [92].

Comparing the TIM to the impact model. Before design improvements are made, the initial impact model is compared to the TIM. The first notable difference is that the TIM divides the impact analysis in 4 different aspects: technology, product/service, organization of the work, and human capital (as described in subsection 5.1.3).

Another difference between the initial impact model, and the TIM, is that the TIM method focuses on the TIs of the upcoming 5 years. This is because technologies that will be broadly applied in 5 years, are often already used by front-runner companies or there are prototypes available [16]. Therefore, in future applications of this research's impact model, it might also be relevant to reduce the time horizon to 5 years. In doing so, it will provide more clarity to the case study participants and also helps to define the development/implementation of the TI.

Another relevant study, is the application of the TIM on the maintenance mechanic in the agrifoods and the electrician from the energy network management. In this research, the TNO started with defining a generic function profile of the mechanic [92].
This is something which is difficult for the RNLA, as the army mechanics operate on multiple maintenance levels, with each individual mechanic also often having a unique training path (as explained in section 2.4). However, in some specific cases, it can be useful to start by creating a general function profile of the army mechanic.

Adding TIM's job quality aspects. The TIM method also takes into account aspects related to the quality of the work the mechanics do [16]. These aspects are important because they directly influence not only the mechanic's tasks but also how the mechanic experiences the job. Therefore, these aspects are integrated as impact elements in the redesign of this research's impact model.

Adding risks & opportunities to the analysis

One important thing missing from the initial solution, is that the model missed an explicit presentation of the important risks & opportunities that are impaired by the impact analysis. Therefore, the representation of the new impact model allows more explicitly mentioning of important risks & opportunities.

Input from external sources

As mentioned in the evaluation of the first 2 cases, all interviewees were from inside the organization. This means that the view is restricted and the 'outside views' are not taken into account. Therefore, an interview has been conducted with a regional vocational school in Rotterdam, the TCR. In this interview is discussed which TIs they identify, and how they change their education to anticipate on these TIs. The mechanics at the RNLA all have a prior education which is followed at one of these regional schools. Therefore it is

important to make sure that the education that is given by the regional educational centers does not overlap or have too big of a knowledge & skills gap with the education provided by the RNLA.
Also an interview with the Centre of Excellence (CoE) for Knowledge & Development of the ANWB has been held. At this CoE they train the future mechanics of the ANWB. These mechanics have tasks which can be described as the MDR-mechanics of the civil sector. As the civil sector already has to deal with innovations such as EVs a lot more than the RNLA, it is interesting what lessons they have learned for their mechanics. The input of how the ANWB deals with TIs can therefore provide fresh insights to compare to the insights from this research.

Order of steps

One of the lessons learned from the first two cases and from the TIM, is that it is important to define how a TI will implemented into the maintenance organization before determining the impact factors of the work. Therefore, in the redesigned impact model, the inital step during the interviews and focus group sessions is to explicitly state how the TI is assumed to be implemented within the organization. This allows for easier reevaluating the validity of the impact analysis as the TI is developing.

8.2.2 Redesigned impact model

In Figure 8.3, the new design of the impact model is displayed. As can be seen, the aspects of the TIM method has been integrated within this design. The key improvements to the impact model are summarized in Table 8.5.

	Key improvements
1.	Defining the tasks & skill changes more explicitly. This improvement is depicted by the green elements in Figure 8.3.
2.	Addition of the impact elements regarding job quality from the TIM. The job quality elements are elaborated upon in section 8.2.2.
3.	The addition of the risks & opportunities overview in the impact analysis report.

Table 8.5: Overview of the key improvements in the revised model

The usage steps of the impact model remain the same as explained in section 6.2 (and summarized in Table 6.2), this is because the steps of the model are deemed to be effective based on the author's experience in the first 2 cases.

Job quality impact element from TIM

The job quality element is added to the elements of the impact model, based on the TIM method [16, 92]. By job quality is meant the characteristics of the work itself, and not of the job holder [16]. The important sub-elements of the research are: mental strain, autonomy, difficulty & development opportunities, social & functional support, variation in tasks, and physical strain. These sub-elements are elaborated further in the following paragraphs.

Mental strain: the job contains a balance of control options and tasks demands to make the time pressure and amount of work manageable. [92]

Autonomy: the job contains independent control options, e.g. regarding determination of work order, work pace, work quantity, work quality and regulation interventions. The job contains technology that supports the worker in performing the work, and not just tracks work performance as a management information tool and as a steering tool (e.g. for work assignments). [92]

Difficulty & development opportunities: the job contains tasks with learning opportunities and challenge to learn. [92]

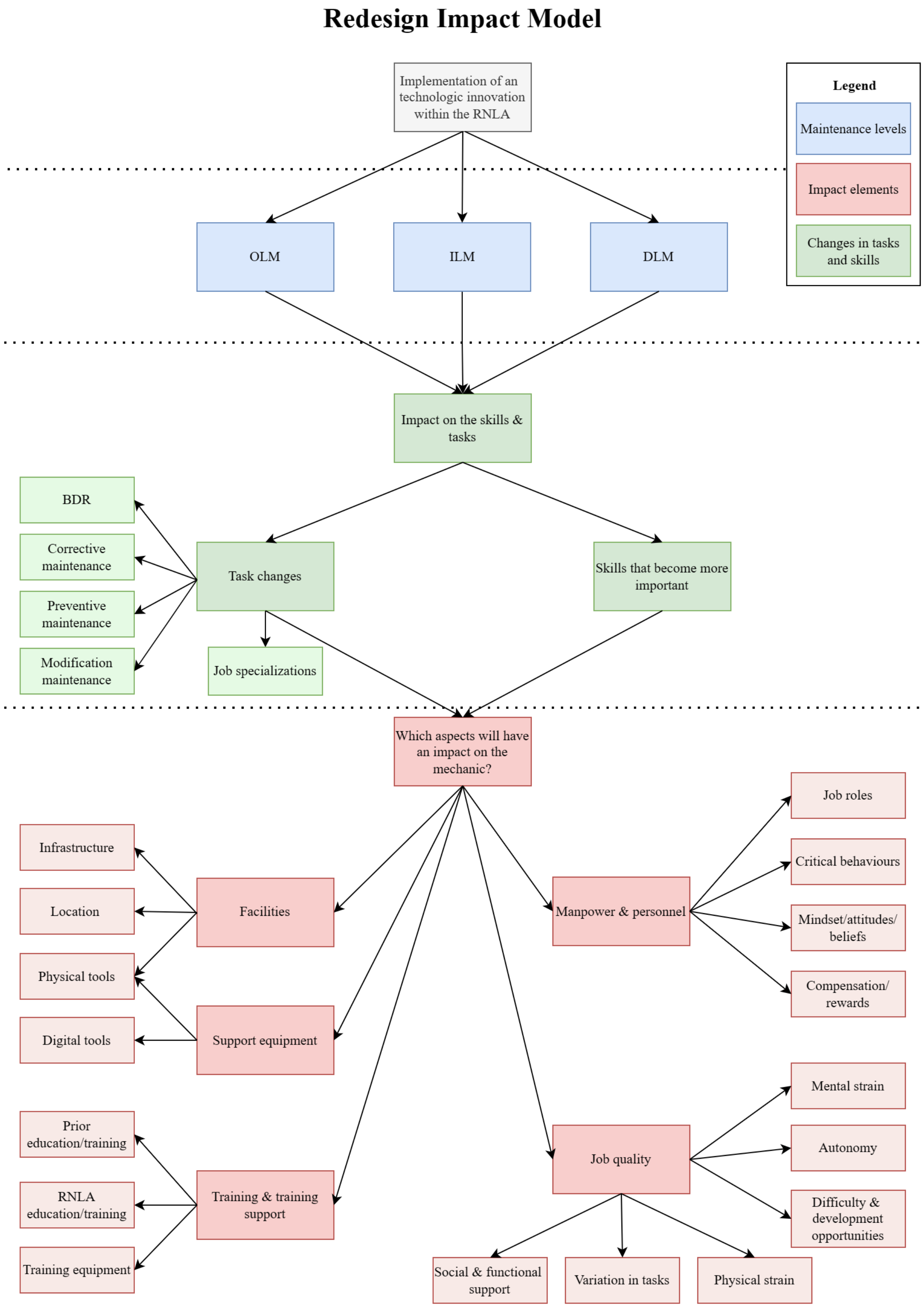

Figure 8.3: The redesign of the impact model after evaluation of the first 2 cases

Social & functional support: the job includes opportunities to contact and seek the help of others, and is not an isolated function or workplace. [92]

Variation in tasks: the job contains as few monotonous and repetitive short-cycle tasks (both cognitive and physical) as possible; furthermore, the sets of tasks are as coherent as possible. [92]

Physical strain: the job contains opportunities to recover from physical strain or to prevent physical overload through the presence of ergonomic aids and being able to take of breaks and rest and recovery time. [92]

Interview questions

An overview of the questions (after the design iteration) to ask during the interviews and focus-group sessions is shown in Table 8.6. The questions regarding changes in tasks & skills (questions 1, 2, and 3) are determined more specifically in the start of the interview (or perhaps during earlier interviews), so in further input sessions it is clear which assumptions are made about the implementation of the TI. Furthermore, the questions with regard to job quality are added.

Impact element	Question nr.	Assisting questions to determine the effect of TIs on the mechanic
Changes in tasks & skills	**1**	Which tasks & skills are added, become more important, or disappear for the mechanic due to technological development? Distinguish between OLM, ILM, and DLM.
	2	How does the maintenance change? And does the maintenance workload herewith increase or decrease? This is with respect to BDR, expedient, corrective, preventive, and/or modification maintenance.
	3	Are the specializations of the mechanic affected? Regarding the vehicle -, electrical-, and weapon system specializations.
Facilities	**4**	What infrastructure is required for the new TI?
	5	How does the TI affect the location of the maintenance operations?
Support (equipment and training/education)	**6**	What physical/digital tools are needed to maintain the TI? And how does this effect the mechanic in terms of training and licensing?
	7	What education, and training does the mechanic require to operate or maintain the TI? And should/can this be insourced or outsourced?
	8	When insourced, what type of equipment/materiel is required to support these trainings?
Manpower & Personnel	**9**	How does the job description of the mechanic change?
	10	What type of critical behaviours are required by the mechanic to handle this TI?
	11	What is the mindset of the mechanic towards this TI?
	12	Does the implementation of the TI affect how the mechanic values his or her work? For example, in a financial sense and/or in job evaluation.
Job quality		**How does the job affect the following job quality aspects:**
	13	mental strain
	14	autonomy
	15	difficulty & development opportunities
	16	social & functional support
	17	variation in tasks
	18	physical strain

Table 8.6: Questions to answer in order to determine the impact of TIs on the mechanic (in redesigned impact model)

Chapter 9

Demonstration of the Redesign

In this chapter, the redesign of the impact model from subsection 8.2.2 is tested using a small impact analysis with regards to the digitization of the mechanic. This is the second demonstration step from the DS research methodology from Peffers et al. [4], as depicted in Figure 9.1. This step is executed after a design iteraiton, which is described in subsection 8.2.2.

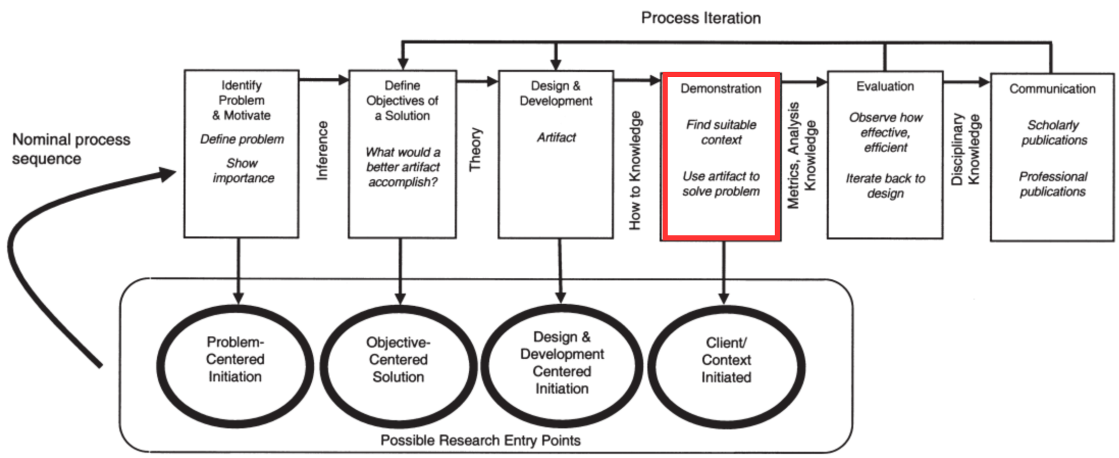

Figure 9.1: The demonstration step (performed after an iteration is made in the DS process), highlighted in the design science research methodology process model from Peffer et al. [4]

9.1 Third case: digitization of the inspection work card

9.1.1 TI Selection

For the third case, the use of the DO-MAINT platform is selected as new innovative technique for the RNLA. The reason for selecting the DO-MAINT platform is because it is expected that this platform will have a relatively small but noticeable impact on the mechanics of the RNLA, and therefore it would be possible to use this TI to test the redesign of the impact model in the limited time available for this research.
DO-MAINT is a digital platform on which the papers of the inspection lists can be filled in digitally by the users. So, it is a platform which replaces the paper inspection-list. The platform offers support for inspection-lists for OLM, ILM, and DLM. DO-MAINT also offers the possibility to digitalize for example detail-, and count-lists. DO-MAINT can be used for all ground-based (military) systems, so for A-, B-, C-, and D-systems & assortment. The DO-MAINT app works on devices coupled to the network of DMOD (both on MULAN and Mobile Device Management (MDM) of the DMOD. [93]
Currently, the platform has been in use for almost 3 years. The platform was developed by a project team

in collaboration with JIVC in order to make maintenance and checking of the status of the equipment easier and more efficient. [94]

9.1.2 Information collection

Users of the DO-MAINT platform

The DO-MAINT platform has defined 4 different roles for personnel that uses the platform, namely [93]:

1. Inspector: user of the materiel/the person who performs the inspections.
2. Sample taker: the person who is carrying out the sampling.
3. Maintainer: The one who performs the maintenance within his/her own unit.
4. Map manager: the person who creates and manages the inspection lists.

Within the DO-MAINT platform, the maintainer role is the most relevant for the mechanic. The tasks that the maintainer should be able to do within the DO-MAINT platform are:

- Full inspections
- Separate defects
- Separate measuring points
- Suggestions
- Perform sample test
- Overwrite action points
- Dashboard maintenance
- Overview of inspection developments
- Concept M-notifications in SAP
- Measuring points in SAP
- Provide visual feedback of defects & measuring values
- Maintenance configuration
- Provide feedback

Advantages and disadvantages of the digitization within maintenance

Advantages of the DO-MAINT platform, as listed in the hand-out for the maintainer [95]:

- User-friendly: "for the user, by the user"
- Digital entry (add photos of defects) & processing
- Always up-to date inspection list
- Extensive (visual) support per inspection point
- View details of previous maintenance
- Overview of 'ongoing' and 'submitted' inspections
- Overview of -observed- particularities in inspections
- Insight into maintenance history - via Mulan
- Greatly reduced processing steps
- Readable and extensive feedback from Inspectors/Samples
- Substantial time savings
- Less error-prone processing of data
- Clear overview
- The users have to deal less with paperwork

However, there are also disadvantages impaired with using a digitized version of the inspection work card.

- To use the digital version, you have to have a network connection with the DMOD
- If the RNLA mechanic gets used to the digital version, he might not have the skill or knowledge (anymore) to use the 'traditional paper version' properly when in an operational setting (where the DO-MAINT app is often not available).
- To make the transition to using the DO-MAINT platform, employees have to be willing to change their way of working.

9.1.3 Discussion of the case with expert(s)

For this case, only one person was interviewed. This was mainly due to the limited amount of time available in this research. The person interviewed was a project leader of the DO-MAINT program.

9.1.4 Impact analysis report

The results of the case study are summarized in Table 9.1, and a visualisation of these results within the impact model is shown Figure 9.2. The complete impact analysis report can be found in Appendix D. The green letters represent a positive impact, the red a negative impact, and the orange letters represent an impact which is not definitively positive or negative.

Topic	**Impact element**	**Summary of the results**
Tasks & skills	Task changes	No significant changes. However, the potential for integrating new features into the app opens up various tasks within the job, such as the addition of visual aids.
	Skill changes	A basic understanding of mobile device usage is necessary, although no specific skills are required. "The process should become easier, as there is more guidance in the activities that need to be performed."
Facilities	Infrastructure	An operational internet connection is imperative since an offline version is not currently available. As long as this condition is satisfied, the potential work locations remain unchanged.
	Location	
Support equipment	Physical tools	Mobile devices/computers that are connected to the DMOD network are required.
	Digital tools	
Training & training support	Prior education/training	None.
	RNLA education/training	A brief training or introduction session is beneficial, focusing on navigating the documentation. This training is expected to last no more than half a day.
	Training equipment	None.
Manpower & personnel	Job roles	None.
	Critical behaviours	Be open to change.
	Mindset/attitudes/beliefs	While most individuals are satisfied, those who have been accustomed to working in the same manner for an extended period (25 - 30 years) are encountering more difficulties in transitioning to using the app.
	Compensation/rewards	"The job satisfaction should increase."
Job quality	Mental strain	No change.
	Autonomy	Autonomy is reduced as the app guides the mechanic step-by-step through the process.
	Difficulty & development opportunities	The process becomes easier, but consequently, it presents fewer challenges.
	Social & functional support	No change.
	Variation in tasks	No change.
	Physical strain	No change.

Table 9.1: A short summary of the impact analysis results of the third case

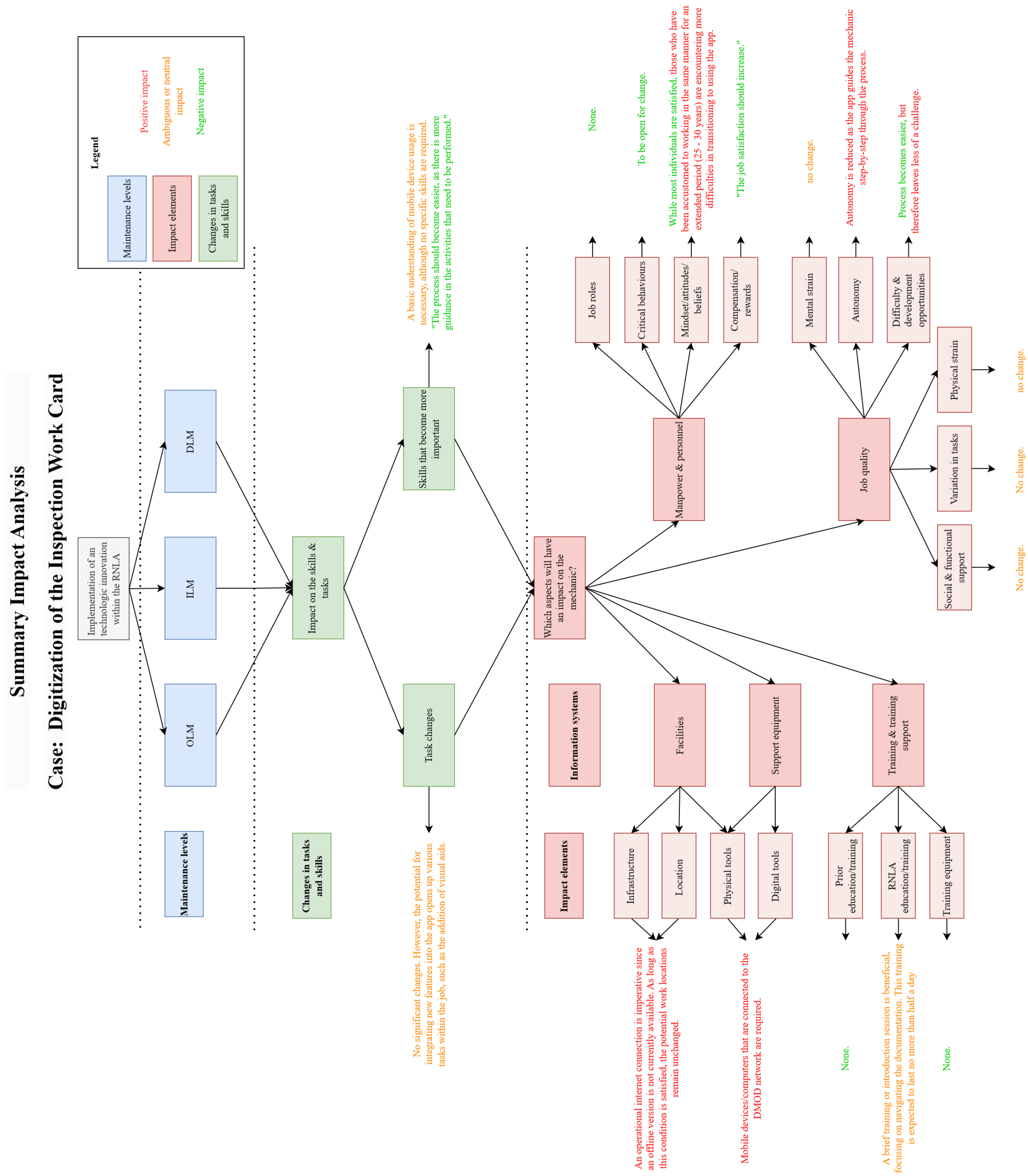

Figure 9.2: A complete overview of the summarized impact analysis of case 3

9.1.5 Evaluation

Upon completion of the impact analysis report, it was sent to the participant for feedback. Minor adjustments were made based on his input.
Subsequently, in conjunction with the CoELog, the outcomes of the case study were assessed against both the solution objectives and the designated design criteria. This evaluation, illustrated in Tables 8.3 and 8.4 respectively, indicated that unlike the first two cases, all solution objectives were achieved in the third case. However, certain issues persisted within the design criteria framework.
Notably, most impacts stemming from the DO-MAINT platform have already been addressed, owing to its active status; it is no longer in the implementation or development phase.

Solution objectives:	**Input:**
show how the professional maintenance tasks of the mechanic change for each maintenance level (OLM,ILM, and DLM).	Sufficient.
show the impact on the maintenance workload of the TI.	Sufficient.
show what tools & equipment the mechanic needs to be able to operate/use to maintain the systems. This includes hand tools, workshop equipment, digital tools, and tools required for educational purposes.	Sufficient.
show at which (physical) location the mechanic can maintain the TI.	Sufficient.
determine what prior education is required by the mechanic to be able to maintain the TI.	Sufficient.
determine the (preferable) competences that the mechanic should possess.	Sufficient.
determine the mindset, attitude, and/or beliefs of the mechanics towards the TI	Sufficient.

Table 9.2: Evaluation of the results of the third case study with regard to the solution objectives.

Design criteria	**Input**
The model should show how to collect the information;	Sufficient.
The model should show how to produce a clear (and useful) overview off the potential impact of a TI on the mechanic of the RNLA.	Sufficient, in table format.
The model should show how the RNLA can use the impact analysis to make their mechanic more future-proof.	Insufficient.
The model should focus on the intermediate future upcoming 5 to 10 years.	Insufficient. The model should make the distinction between three levels: the situation now, the situation in 5 years, and the situations in 10 years.
The model should be workable in the organizations situation, therefore the model should be rigorous and relevant.	The steps of the model are clear.

Table 9.3: Evaluation of the results of the third case study with regard to the design criteria.

9.1.6 Implications based on impact analysis

Based on the impact analysis, it can be concluded that the DO-MAINT platform does not significantly alter the job of RNLA mechanics, as their core tasks remain unchanged. Rather, it should be viewed primarily as a tool with heightened relevance during peace operations, where a stable connection to the DMOD network is essential for its functionality. Nevertheless, the platform introduces new possibilities, such as offering visual aids and facilitating a more structured process through its step-by-step guidance feature.
Despite the advancements brought by the platform, mechanics must still maintain proficiency in using paper inspection cards for fieldwork when internet connectivity is unavailable. Therefore, it is vital to ensure that this skill set is not overlooked or disregarded.

Chapter 10

Discussion and Implications

In this chapter, the main RQ is addressed and the results of this research are discussed. Subsequently, practical and theoretical implications are made. Lastly, recommendations are presented for future research.

10.1 Discussion

The main RQ is: ***"How can the Logistic Centre of Excellence (in the role of maintenance policy advisor) anticipate the impact of technological innovations in ground-based military systems on mechanics' work and support effective maintenance operations in the future?"***

In pursuit of answering this question, this research aimed to design and develop a (simple) model to help address this RQ. The designed model considers changes in tasks, skills, facilities, support equipment, training, manpower, and job quality. However, it has been concluded that the problem consists of numerous factors, many of which are beyond influence, prediction, and response.

In the development of this model, three different case studies have been performed. The first case study considered the electrification of armoured vehicles. The second case study looked at the increased use of data within maintenance operations, and the last case study focused on the digitalization of the inspection work card. The input for these case studies has been collected through individual interviews and focus group sessions with experts from multiple disciplines. These case studies have revealed the complexity of reality, making it challenging to develop a simple predictive model for the exact impact of technological developments on mechanics.
What has emerged from the research is the complexity of the problem. With myriad technological advancements, predicting their exact trajectory and implementation becomes unfeasible.

Given the inherent complexity and uncertainty of the future, and the uncertain manner in which TIs will be implemented within a (military) maintenance organization, the impact model cannot generate reliable predictions. However, the designed impact model enables an organization to structurally analyse the global impacts of TIs on its mechanics, showing its value in exposing possible risks and opportunities. In addition, the value of the impact model also lies in its multidisciplinary approach, which brings together information from different disciplines. This is especially the case for the focus group session, as the session allows the participants to directly share information and come to an overall impact analysis together.

Furthermore, one of the key findings of the case studies is that TIs do not necessarily make the mechanic's job easier. They often introduce additional complexities, particularly in a military context. This underscores the need to proactively assess the impact of new TIs related to the mechanic, allowing future problems to be mitigated and the exploitation of potential advantages.

In conclusion, the main contribution of the impact model lies in providing a framework that allows a maintenance organization to take the first step in preparing its mechanics for the future.

10.2 Practical implications

The impact model has been constructed to provide the CoELog an instrument that assists in identifying TIs, determining their impact, and select the appropriate skills and capabilities to support effective maintenance of all systems in the future. Although the impact model does not offer definitive solutions due to inherent uncertainties, it does prove helpful in identifying potential risks and opportunities. Such as the exposed limitations in the safety standards currently faced when maintaining/repairing EVs on the battlefield, or the additional (digital) skills required to diagnose the more technologically advanced vehicles. Identifying these risks and opportunities, in turn, assists the organization to proactively address challenges, explore solutions, provide advice to maintenance management, and potentially mitigate future issues.

Furthermore, the impact analyses performed are based on assumptions, highlighting the importance of periodically reevaluating their validity as technology evolves. This re-assessment should occur every few years, depending on the nature of the TI and its implementation.

It is also important to note that the manner in which the RNLA can anticipate these future impacts is not standard, as there are many different TIs, and each requires a different approach to these problems. Nonetheless, this research provides the first step to proactively anticipate changes in the work of mechanics. Therefore, the impact model facilitates the transition towards a more effective approach, wherein it is imperative that not only the mechanics adapt to technology, but also vice versa.

10.3 Theoretical implications

In section 1.3, the current state of research has been described. Here, it has been concluded that most (encountered) impact analysis models focus on the macro-level impacts of TIs. However, since the "human being" is one of the most important assets in asset management, it is crucial to take into account the impacts of TIs on the maintenance personnel. Therefore, this model stands out as one of the few that focuses on the micro-level impacts of technical roles, thus contributing to scientific knowledge by offering a unique method to assess the impacts of TIs on (army) mechanics in the near future.

Furthermore, this research also aligns with the recommendations of a recent study, which emphasizes the role of people in risk management within the asset management domain. The designed impact model addresses the qualitative aspects in risk management that were highlighted in the aforementioned study: know-how maintenance, role definition, proper training plans, and motivation on the team. [18]

10.4 Future research

The presented study can be regarded as an initial exploration into the impact analyses of TIs on military mechanics. It is important to exercise caution in interpreting the results, given the small sample size.
Therefore, further research endeavors could play a pivotal role in validating the model and examining whether the relevant impact elements have been adequately considered. By incorporating a broader spectrum of TIs, such investigations could facilitate a more comprehensive understanding of the impact of TIs on mechanics within military contexts. In addition, conducting a more thorough analysis of individual impact factors could further enrich comprehension.

Moreover, the application of the proposed impact model in other industries and in other working environments would be interesting. Such investigations could show the relevance of the impact model to other maintenance sectors.

Last, further research could explore the diverse potential users of the impact model. Although the model was initially designed for the CoELog in their role as maintenance advisors, the insights derived should ultimately inform normsetters. Therefore, further research could investigate how normsetters can utilize or integrate the impact model into their processes. Moreover, the impact model is also relevant to project researchers. They can explore its applicability to their specific projects, enabling them to consider the impacts at an early stage of their research.

Chapter 11

Management recommendations

This chapter provides recommendations for the RNLA based on the findings of this study. In the first part, general recommendations are discussed. In the second part, specific recommendations are presented based on case studies.

11.1 General recommendations

Validate the model

The first step should be to validate the impact model by replicating the research steps in multiple different cases. Given the time constraints during the initial phase of this study, interviews were limited to one or two participants per stakeholder group. To enhance the reliability and generalizability of the results, it is recommended to reach out to a broader range of experts from each stakeholder group in future validation efforts. This iterative process will help validate and refine the model, ensuring its applicability across diverse contexts within the RNLA framework.

Expand analysis to more TIs

To gain a comprehensive understanding of the skills required by the mechanic in the future, it is essential to extend the analysis to include a wider spectrum of TIs. The limited time frame of this study restricted the analysis to a selected few TIs. By conducting analyses on additional TIs, the RNLA can develop a more nuanced understanding of evolving skill requirements, considering the interdependencies and synergies that exist between different technological implementations. This expanded analysis will contribute to a more holistic approach to skill development within the RNLA workforce.
Recommended TIs to investigate, though not limited to, are: composites, telemaintenace, XR, hybrid EVs, RAS, HEL, AM, or AI.

Periodic re-assessment of impact analyses

As mentioned in section 6.2, it is crucial to periodically re-assess the impact analyses of TI within the RNLA framework. Regular reassessment, conducted every few years, will enable the RNLA to adapt to emerging technological trends and evolving skill demands. This proactive approach to impact analysis will facilitate timely adjustments to training programs and workforce development initiatives, ensuring the continued relevance and effectiveness of the RNLA's skill development strategies.

Balance technology and skill levels

A fundamental principle for the successful implementation of TI within the RNLA is to maintain a balance between technology and the skill level of mechanics. While technological advancements drive innovation within the industry, it is equally important to consider the capabilities and expertise of the workforce.
Therefore, my advice to the organization is to ensure a proper balance between technology and its mechanics.

Meaning that not only the mechanic has to adjust to new technology, but also vice versa. By adopting this approach, the RNLA can effectively leverage its workforce to maintain assets of the past, present, and future, ensuring operational effectiveness in a rapidly evolving technological landscape.

11.2 Recommendations based on case studies

First case: electrification of armoured vehicles

From the first case, it follows that addressing the limitations of EVs maintenance operations is crucial, primarily in terms of safety and practicality. It should be investigated how an army mechanic can still work safely on EVs in the field, without losing the ability to maintain or repair systems during combat operations. Furthermore, the relatively large size of the EV toolkit should also be reviewed, and a solution should be found to ensure that the size of the toolkit does not hinder the mechanic.

Despite these challenges, it is also crucial to recognize and capitalize on the opportunities presented by EVs. Relevant opportunities for mechanics include the expected reduction in maintenance workload and the potential for improved self-diagnostic systems. Especially utilizing the improved self-diagnostic systems of EVs is important, as the RNLA mechanic already has to face numerous different complex systems, this can reduce the problems associated with the maintenance education levels and time in the field.

Lastly, I recommend that the organization explore the concept of an EV expert within their operations. This individual should have specialized knowledge and skills related to EV maintenance and could play a pivotal role in ensuring safe and effective maintenance operations on the battlefield.

Second case: increase in data within maintenance operations

The main conclusion drawn from the second case study is that currently the use of CAN-BUS systems in vehicles complicates the diagnosis for mechanics. This complexity is exacerbated by the lack of computers available in the field and inadequate training. While this situation presents significant challenges, there are also opportunities for improvement.

A key recommendation from the second case study is to ensure that mechanics receive adequate training in new (digital) diagnostic methodologies. With better and more goal-oriented training, mechanics can diagnose issues easier and faster. However, it is essential to note that training alone may not be sufficient. The mechanic's effectiveness in diagnosing CAN-BUS issues also depends on having access to the necessary digital tools. Therefore, alongside training initiatives, it is crucial to ensure that army mechanics are adequately equipped with the digital tools required to diagnose modern vehicle systems effectively.

By addressing both training and equipment needs, organizations can help mechanics overcome the challenges associated with CAN-BUS systems and take advantage of the opportunities they offer for more efficient and effective vehicle diagnosis and maintenance.

Third case: digitization of the inspection work card

Based on the results of the third case study, there are no significant impacts associated with the DO-MAINT platform, as the 'technical' job does not change. Nonetheless, my recommendation is to ensure that the 'paper-skills' are not neglected during peacetime, and that the mechanic retains proficiency in both digital and manual (paper-based) procedures.

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Appendix A

Interview Questions

This appendix first makes a statement about the use of tools in this research. After, this section provides the interview questions asked during this research. Three different stages of interviews were held, resulting in 3 different question lists. Due to the semi-structured approach, these question lists form the basis of each interview. Follow-up questions were formulated, based on the interviewee's answers and role.

A.1 Use of tools/services in this research

During the preparation of this work, I used 'DeepL Translate' and 'ChatGPT3.5' to translate and refine the writing in the text. After using this tool/service, we thoroughly reviewed and edited the content as needed, taking full responsibility for the final outcome.

A.2 Initial interviews questions

- *What are the key TIs that will have a significant impact on the mechanic?*
- *What are important impact elements to take into account to in this research?*
- *Who are the important stakeholders to interview in order to get the information?*

A.3 Initial impact model questions

Impact element	Question nr.	Assisting questions to determine the effect of TIs on the mechanic
Maintenance Planning	**1**	How are the maintenance tasked affected? What maintenance tasks can/should be done per maintenance level?
	2	How does the maintenance change? This is with respect to BDR, expedient, corrective, preventive, and/or modification maintenance.
	3	Are the specializations of the mechanic affected? Regarding the vehicle -, electrical-, and weapon system specializations.
	4	How does the workload of the maintenance operations change?
Facilities	**5**	What infrastructure is required for the new TI?
	6	How does the TI affect the location of the maintenance operations?
Support (equipment and training/education)	**7**	What physical/digital tools are needed to maintain the TI? And how does this effect the mechanic in terms of training and licensing?
	8	What education, and training does the mechanic require to operate or maintain the TI? And should/can this be insourced or outsourced?
	9	When insourced, what type of equipment/materiel is required to support these trainings?
Manpower & Personnel	**10**	How does the job description of the mechanic change?
	11	What type of critical behaviours are required by the mechanic to handle this TI?
	12	What is the mindset of the mechanic towards this TI?
	13	Does the implementation of the TI affect how the mechanic values his or her work? For example, in a financial sense and/or in job evaluation.

Table A.1: Interview questions of the initial version of the impact model

A.4 Questions asked to external organizations

- *How do you identify the impacts of TIs on the mechanic?*
- *What technological developments do you foresee in the upcoming 5 to 10 years? And how do you anticipate these developments?*
- *What are important impact elements to take into consideration?*

A.5 Redesigned impact model questions

Impact element	Question nr.	Assisting questions to determine the effect of TIs on the mechanic
Changes in tasks & skills	**1**	Which tasks & skills are added, become more important, or disappear for the mechanic due to technological development? Distinguish between OLM, ILM, and DLM.
	2	How does the maintenance change? And does the maintenance workload herewith increase or decrease? This is with respect to BDR, expedient, corrective, preventive, and/or modification maintenance.
	3	Are the specializations of the mechanic affected? Regarding the vehicle -, electrical-, and weapon system specializations.
Facilities	**4**	What infrastructure is required for the new TI?
	5	How does the TI affect the location of the maintenance operations?
Support (equipment and training/education)	**6**	What physical/digital tools are needed to maintain the TI? And how does this effect the mechanic in terms of training and licensing?
	7	What education, and training does the mechanic require to operate or maintain the TI? And should/can this be insourced or outsourced?
	8	When insourced, what type of equipment/materiel is required to support these trainings?
Manpower & Personnel	**9**	How does the job description of the mechanic change?
	10	What type of critical behaviours are required by the mechanic to handle this TI?
	11	What is the mindset of the mechanic towards this TI?
	12	Does the implementation of the TI affect how the mechanic values his or her work? For example, in a financial sense and/or in job evaluation.
Job quality		**How does the job affect the following job quality aspects:**
	13	mental strain
	14	autonomy
	15	difficulty & development opportunities
	16	social & functional support
	17	variation in tasks
	18	physical strain

Table A.2: Interview questions of the redesigned version of the impact model

Appendix B

Case 1: Impact Analysis Report Electrification of Armoured Vehicles

This chapter contains the impact analysis report for the first case of this research, namely: the electrification of armoured vehicles. Each impact element is discussed and the results of the focus-group sessions, questionnaires and interviews are summarized here. In several of the subsections in this report, the analysis is subdivided into the different maintenance levels in order to take into account the different tasks associated with each maintenance level. To clarify here, the following assumption is made: the OLM is done by the mechanics of the MDR-group, the ILM is done by the mechanics of the MSU, and the DLM is executed by the mechanics of the department of Tech.

B.1 Maintenance tasks

B.1.1 Impact on the maintenance activities

In this section is discussed what electrification would mean for the components that have to be replaced. It is important to first determine which level of components should be replaced at which maintenance level as the following maintenance elements are influenced by this. For example, if determined is that it is only possible to exchange simple large components at the OLM and ILM, then the mechanics of these maintenance level will require less specific knowledge of the electrification than if they would have to be able to repair these elements on a deeper component level. The question asked to the participants is:
How does the electrification impact the activities? Which components must/can be replaced per maintenance level?

At OLM

The conclusion that followed from focus-group session is that the MDR-group is still able to execute tasks in the field, as long as the components are not part of the electric drive train. "So replacing a light bulb or a flat tyre is still possible" (KI-1). However, if a problem occurs such as the shutting down of the electric motor, the MDR-group will not be able to repair this. In that scenario, the vehicle has to be towed off or disconnected, depending on the construction of the vehicle. This is because the converter has to be able to absorb the electric energy that is being generated during the tow-operation. Usually this is not a problem around 15-20 km/h; However, at higher speeds the converter can become too hot, which can lead to fires or cause short circuit.
Besides that it is not deemed feasible to replace components in the field, because the operational setting does not comply with the NEN9140 norm, the MDR-group also has the task of diagnosing broken vehicles. The NEN9140 is not required by law; however, if the organization decides to not follow this standard, they should carefully consider the implications of non-compliance and take appropiate measures to mitigate the risks if they choose not to follow the standard. Therefore, for the remainder of this analysis, we will assume

the NEN9140 as requirement.
For EVs it is still possible to perform simple diagnoses, such as the checking if all connectors are still connected properly and if an interlock is open or not. However, truly performing maintenance tasks on the HV-system is not deemed feasible.
For the MDR-group, it is important that at least one person is present with an education of a level higher than layman regarding the NEN9140 norm. This is due to the risks associated with working around HV-components.

At ILM

At the ILM, the mechanics (so from the MSU) should be able to replace the Line-Replaceable Units (LRUs) of the electric drive train without opening them. So every HV-component, which are indicated by 'a yellow sticker with a lightning bolt', has to remain closed during the replacement. Examples of these LRUs are: Batterypacks, Battery Disconnecting Unit (BDU)s, motor-controllers, and chargers.

At DLM

The components that can be completely de-energized, or the components that are relatively simple, can be repaired at DLM. For example, a BDU can still be repaired by the department of Tech, provided proper factory training has been followed. Other components such as the DC-DC converter, motor controller, battery-box, electric motor, or charger has to be replaced and can eventually be repaired by the industry.

For example, there is a high risk associated with repairing battery packages. The exchanging of battery modules/-cells has to be done in a prepped room with people who know what they are doing. Furthermore, the exchanging of battery modules/-cells is only relevant to do internally if the turnover is high enough. This is because "you actually have to pre-select them to have the same internal resistance and the same age. In doing so, you then start putting together modules and later packages. And now, if I look at how it is done for a battery-chargesystem, I think in this moment where we're really sitting with too low numbers. Therefore it is better to outsource exchanging the battery modules/-cells to parties who do have those stocks, and that throughput" (KI-1).
Other components can still be diagnosed by the department of engineering, but the repair should probably be performed by the manufacturer or industry, due to the specialized equipment and knowledge required to handle the more complex parts.

B.1.2 Impact on the maintenance types

This section discusses the impact on the proportions between the maintenance types due to the implementation of an electrical drive train compared to the traditional diesel ICE. The question that was asked to the participants is:
How does electrification of the drive train change the maintenance tasks, regarding BDR, corrective, preventive and modification maintenance?

Regarding corrective and preventive

It is expected that there is less corrective and less preventive maintenance on EVs.
"You can see a number of things. You no longer have the oil from the diesel engine, so you no longer have sulphur in the system. There is also no fuel dilution oil, because there is no fuel dilution needed as there is no fuel. And that is the reason we have the maintenance-intervals. Also braking pads are used a lot less, so they will wear less because you brake using the electric motor." (KI-1)

Regarding BDR

BDR is about repairing components with the tools available in the BDR-toolkit. ”But I do not see anyone putting a piece of tape on a HV-cable.” (KI-1). A possibility for BDR can be to replace a cable in total, where the cable should be disconnectable at both sides with connector.

B.1.3 Impact on the specializations

Here the impact on specialization is discussed. Currently there are 3 main specializations for the mechanic, and it is important to determine for which specialization of mechanic the TI is of relevance. Therefore the participants were asked the following question:
”Do the specialization-directions of the mechanic remain the same, or should there come a new specialization direction? Also for which specialization is the TI of relevence?
Regarding specialization directions: the thrust is that the EV-mechanic is within the specialization of vehicle technicians. However, this mechanic will need a NEN9140 certified training to become qualified to maintain the systems. Furthermore, it is also suggested to add the role from work planner (as defined in the NEN9140).

An advice was also given during the focus-group session:
”As the RNLA we are only now looking at electric propulsion for a little bit. Within the navy, they are already doing this much more and they actually have a dedicated engineer walking around on board who can monitor that kind of thing, who can manage it. At the moment we do not have that in the RNLA, but we do have a sergeant-major in command who might be able to fulfil this role. That’s an idea to think about; Especially when you go on deployment, that you are sure that someone is walking around there who has expertise of electric drive-trains.” (KI-1)

B.1.4 Workload

The participants were also asked:
”Do you expect the maintenance load to become more or less? Does the amount of people required to execute the maintenance tasks change?
Regarding the diagnostics of EVs, the amount of time is expected to decrease. This is due to the good self-testing function of the E-Fennek. ”The system is not as complicated as everyone seems to think. The system has a very good self-diagnosis function, so you can figure out relatively fast what the problem is. So I expect that fault-diagnosis in an EV does not need to take a long time.” (KI-1). This is in line with the literature collected fromsection 7.1.1.
In the interview, the sergeant major of the RAS-unit also concludes: ”Less maintenance hours, of that I am convinced” (SM-1). This is also in line with the conclusion drawn in subsection B.1.2, which is that there would be a general decrease in corrective and preventive maintenance.

B.1.5 Overview maintenance tasks

The main impacts on the maintenance tasks, concluded from the focus-group session and interviews, are briefly summarized in Figure B.1.

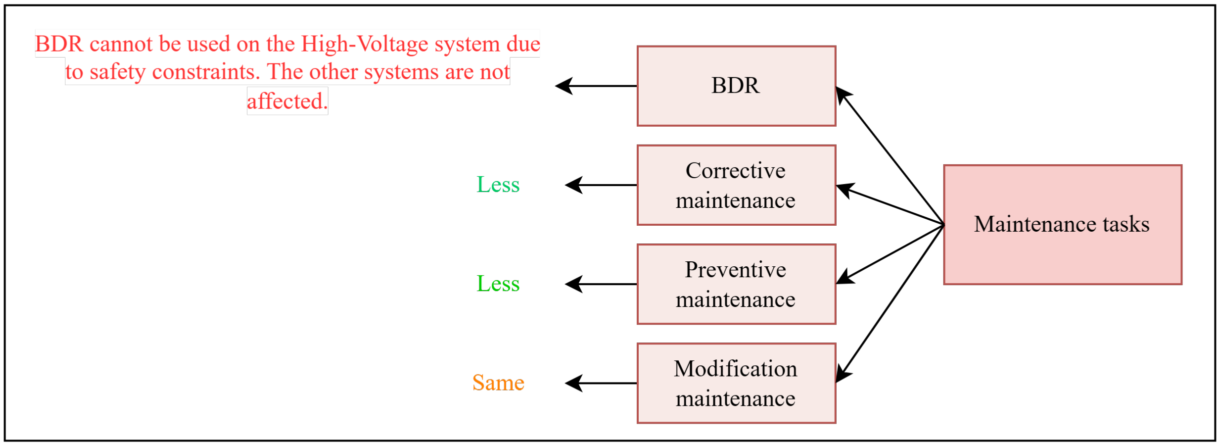

Figure B.1: Summarized overview of the impact on the maintenance tasks

B.2 Facilities

B.2.1 Infrastructure

Regarding the facilities, the participants were asked the following question:
What infrastructure is required to support EVs?
The infrastructure that is required depends on the battery type of the used asset. The E-Fennek uses a LFP battery, which can be charged inside. However, another type of battery could better be charged outside. "We use mostly LFPs; But if you take the Tesla battery, the NMC, then I would not dare to charge it indoors; That is due to the flammability of that stuff"(KI-1). Besides the specific components of EVs, there is also a set of general rules and demands described in the NEN9140.

B.2.2 Location

The setting in which the mechanics of the RNLA operate might also be affected by the electrification of the drive train. Therefore, the participants were also asked:
Does the location change on which maintenance can be carried out?
Here it was concluded that all the components with the exception of the HV-components can still be done as before the electrification. For activities around the HV-system, the NEN9140 norm applies. It is unlikely that the location in the field are able to hold up to this. "If I were sitting in the eastern Europe with the Fennek and it breaks down, the vehicle has to be moved to a space in which can be worked under proper circumstances before the repairs are carried out. I am not going to take the risk to work on the HV-system in the rain." (KI-1)

B.2.3 Overview facilities

The main impacts on the facilities, concluded from the focus-group session and interviews, are shown in Figure B.2.

B.3 Support equipment

B.3.1 Physical tools

To determine the impact of electrification on the tools & equipment, the participant were asked the following question:

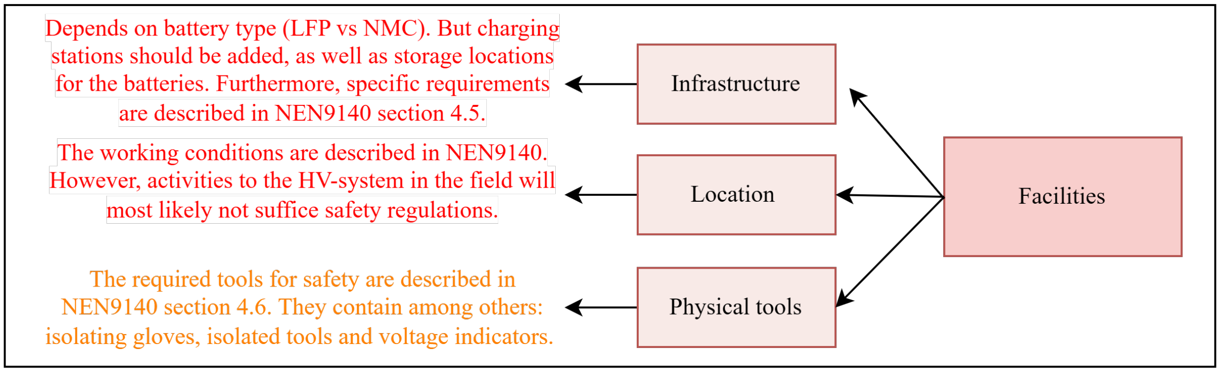

Figure B.2: Summarized overview of the impact on the facilities

What (new) physical tools should be available in the workshop? And does the mechanic require any licences or training to operate these new tools?
The toolkit for EVs are described in section 4.6 of the NEN9140 norm. The toolkit contains among others: isolating gloves, eye/face-protection, isolating plates, isolated tools, and more. To use these tools properly, the mechanic needs a minimum certification of an EV instructed person of the NEN9140 norm.
The mechanic will also need special tools provided by the manufacturer of the asset, that might be necessary to carry out certain activities. The specific EV tools are only necessary for operations/actions to the HV-system. This does mean that the tools required by the mechanic will depend on what maintenance actions are carried out at which maintenance level.
Also an important mention from the focus-group, is that a kill/safety -switch is required in the EV, especially because the DMOD operates in an uncontrolled environment. "The safety switch goes through the whole system. So through the tubes, the modules, the covers, everything. It is all connected in-series, so if you cut-off the system anywhere it shuts down." (KI-1). This does not necessarily mean that each specific component is de-energized.

B.3.2 Digital tools

Regarding the digital tools, the electrification of the drive train does not make a significant difference.

B.3.3 Overview support equipment

The main impacts on the support equipment, concluded from the focus group session and interviews, are shown in Figure B.3.

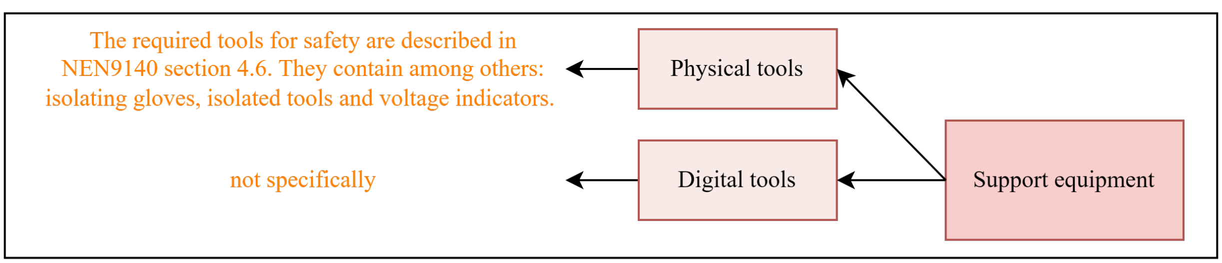

Figure B.3: Summarized overview of the impact on the support equipment

B.4 Manpower & Personnel

B.4.1 Job roles

To determine the change in job roles, the participants were asked:
how does the job description of the mechanic change? Who should be in responsible for maintaining the electric drive train?
From the focus-group followed: the new tasks of the mechanic of the RNLA are de-energizing the EVs, handling the diagnostic-equipment, and maybe a bit of programming in the system (KI-2). These tasks fall under the mechanic who is trained as the skilled person from the NEN9140 norm.
"Extra competences outside of the education are not required" (M-1).

B.4.2 Critical behaviours

The questions asked was:
"What concrete behaviour does the electrification require from the mechanic in the daily process? For example, does he or she have to be good with electrical engineering, or with a digital environment?
The most important conclusion that followed from the answers of the focus-group session and the interviews, is that working around EVs requires awareness of the dangers of HV-systems. Here: accuracy, caution and understanding what you are doing is very important. This is both important for the EV-mechanic, but also for his colleagues ("the laymen"). It is important to add: despite the dangers that HV-systems can bring, when using the proper procedures working with an EV does not need to be dangerous.

B.4.3 Mindset, attitudes and beliefs

To get an idea of the overall attitude of mechanics towards electrification, the participants were asked:
What is in your experience the attitude of the mechanics towards the electrification of armoured military vehicles?
The answer of the participants was similar, and it came down to: "unknown is unloved". Which means, that as the people get more experience with EVs, the more they will like it. There was also mentioned: "Everything that is new, that is awesome." (M-1)

B.4.4 Compensation rewards

Also to get an idea of how electrification might impact the mechanics appreciation of his job, the participants were asked:
What kind of influence do you expect electrification to have on the mechanics appreciation of his/her job?
The overall conclusion here: The appreciation depends on each individual mechanic. Also: "The mechanic will probably appreciate the EVs in terms of greasiness and dirtiness, however maybe not as much in terms of complexity of the systems." (KI-1). However, eventually the conclusion is that also financial compensation for working on EVs plays an important role. "As long as there is no fincancial compensation, they will not appreciate it as much. That is a problem within the DMOD" (KI-1).
Furthermore it is also important for the mechanic that the education and training are accredited by the industry.

B.4.5 Overview manpower & personnel

The main impacts on the manpower & personnel, concluded from the focus-group session and interviews, are shown in Figure B.4.

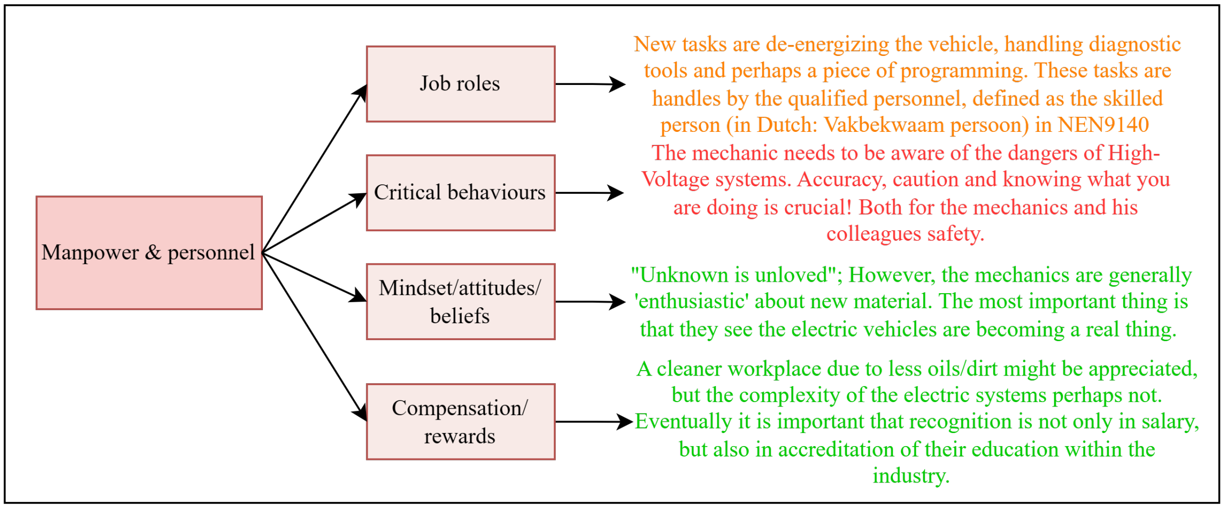

Figure B.4: Summarized overview of the impact on the manpower & personnel

B.5 Training & training support

B.5.1 Education/training

Before the mechanic starts their education at the RNLA, they generally have followed a secondary vocational education. After their prior education, the RNLA also educates and trains the mechanic based on the function that they will fulfil. The participants were therefore asked:
"What education & training does the mechanic require to work on EVs, and should this be given within or outside the RNLA?
The conclusion from the focus-group session: to be certified for working on EVs, the mechanic requires a NEN9140 certified education. There are several levels of certification defined in the NEN9140, these are described in subsection 7.1.1.
"If you would do the NEN9140-accredited training internally; I am not sure that the RNLA will do that, or if it is even a possibility, then you could introduce a basic electrical engineering module for the mechanics to make the transition more smoothly". (KI-2)

B.5.2 Training equipment

To assess if there would be required 'support materials' to give the proper training and education regarding EVs, the participants have been asked the following question:
"What materiel is necessary to support the training & education of the mechanics?
From the focus-group session followed that currently the "training is mostly theoretical" (KI-1). Therefore, a demonstration-vehicle would be of value. "We did the training ourselves. What I like, but that is personally, is if there is a physical vehicle in front of you. Then you can learn what an interlock looks like, and what it is like to pull a safety plug. That you can be sure that there will not be a current on the system when you de-energize it. But that is personally. I think a physical vehicle is of great value, especially compared to learning by just looking at a Powerpoint". (KI-2)
As a demonstration vehicle, a TABBY has been suggested in the focus-group session. "A TABBY is an electrically powered platform, without bodywork, and in the middle a batterypack of 80 Volts, a 3-phase motor, a motorcontroller, everything on-board. There you can just reach it, grab it and it is not dangerous."(KI-2)

B.5.3 Overview training & training support

The main impacts on the training & training support, concluded from the focus-group session and interviews, are shown in Figure B.4.

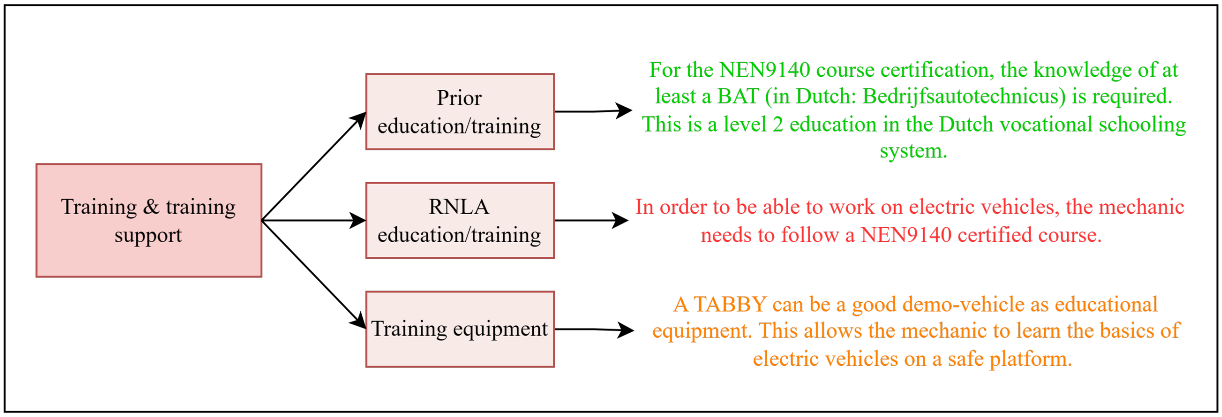

Figure B.5: Summarized overview of the impact on the training & support

B.6 Summary of the Impact Analysis of case 1

In Figure B.6 a complete overview of the summarized elements is shown. The green letters represent a positive impact, the red a negative impact, and the orange letters represent an impact which is not definitively positive or negative.

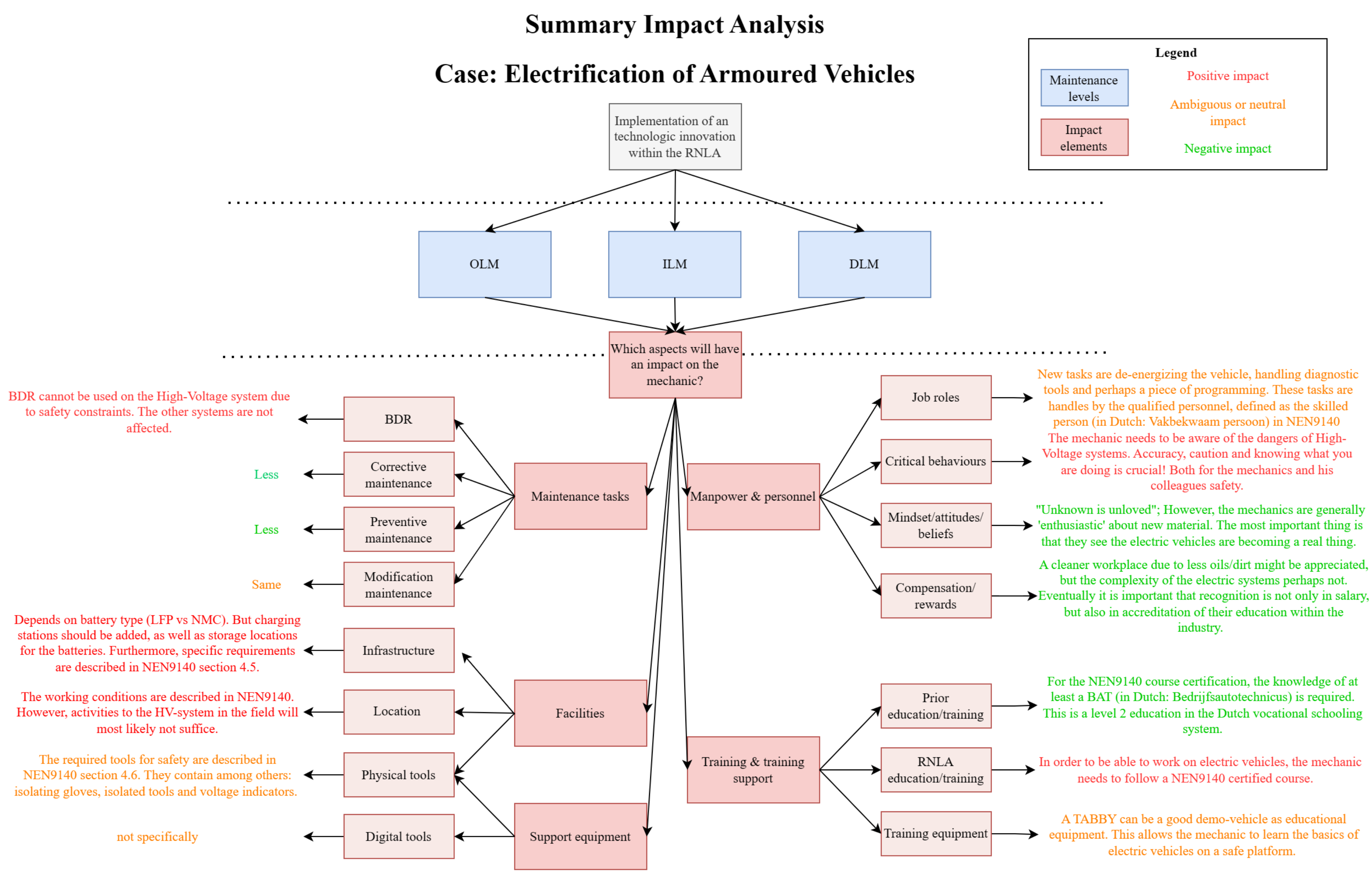

Figure B.6: A complete overview of the summarized impact analysis of case 1

Appendix C

Case 2: Impact Analysis Report Increased Use of Data in Maintenance Operations

This chapter contains the impact analysis report for the second case of this research, namely: the increased usage of data within maintenance operations. Each impact element is discussed and the results of the focus-group sessions, questionnaires and interviews are summarized here. In several of the subsections in this report, the analysis is subdivided into the different maintenance levels in order to take into account the different tasks associated with each maintenance level. To clarify here, the following assumption is made: the OLM is done by the mechanics of the MDR-group, the ILM is done by the mechanics of the MSU, and the DLM is executed by the mechanics of the department of Tech.

The interviewees could already notice an increase in data usage within maintenance in the current systems. *"You can already see it in the Boxer a little bit, there are a lot of sensors on it. We see that we need software to read certain components. Data-driven maintenance then actually becomes more of a feature in this"* (I-1). Examples of these digital sensors aboard vehicles are the added rear-cameras or the tire-pressure system which is regulated using electronics. Because of these changes in the system, it becomes more complex and that is also noted by the MDR-commander; *"So you actually notice very quickly that the mechanic wants to think systemically. But that the systems have now become thus complex that they occasionally become overwhelmed. This causes the mechanic to draw a conclusion too quickly, and therefore end up with a diagnosis for an error which misses the cause of the errors"* (CMDR-1).

C.1 Maintenance tasks

C.1.1 Impact on the maintenance activities

At OLM

The physical actions remain mostly the same when dealing with sensors. However, diagnosing errors becomes more complex because the number of components connected to the system is increasing (more sensors/components are added to the same system). This causes trouble for the mechanic when finding the cause of an error.

As an example: for the rear-camera in the Boxer it is not only possible that an error is caused by a physical problem, but the error can also be caused by a software issue. This adds a layer of complexity to diagnosing the true cause of an error for the mechanic.

"If you take another system, such as the tire-pressure system, then you need a laptop to make a diagnosis. What often happens is that a blow-off valve gets stuck. Then then the first action you take is to dismount the valve, clean it, grease it, and mount it back into the system.

If it turns out that there is an electrical error, then you can check with a computer if every valve is still *functioning properly. So you can determine whether the computer or the valve is the defect component. However, I do not have that laptop available for myself. So then I have to go to a MSU to borrow the laptop. Officially this is the job of the MSU, but knowing that the MSU cannot keep all system operational, and because I want to keep the knowledge and experience within my group of MDR mechanics, I sometimes borrow the laptop from the MSU. Then we learn with the laptop by going step-by-step through the process. This also means, that if an error like this happens during operations, then I have to re-direct the vehicle to an MSU. Which means that as an MDR-group, I cannot."* (CMDR-1)

At ILM

At ILM, it will still be important that the mechanics are able to replace the components on the same level of 'depth'. *"However, it is getting harder and harder to meet the prerequisites. This can be seen by taking a look at the equipment we currently need to replace an engine, which used to be possible with a small toolbox."* (CMSU-1)
A new form of equipment that is required for example is the laptop. But also the educational level required by the mechanic becomes higher.

At DLM

When replacing a component that is part of the CAN-BUS system, it is necessary that this part is 'introduced' to the network. That requires specific knowledge. This because the 'computer/switch' has to be able to communicate with the new components.
"For the speed advantage, it is important that you keep replacing components instead of repairing." (DoT-1)

C.1.2 Impact on the maintenance types

Regarding corrective and preventive

The MDR-group usually only performs corrective maintenance. However, due to the increase of electronic components in the system, the MDR group sees that more attention and time is spend on the following 2 problems:

1. Educating the driver. If the system displays an error, it is often caused by faulty handeling of the driver. This means that the MDR-mechanic has to spend more time on educating the driver.
2. "Faulty error-diagnosis". This means that the system shows an error, while the system still works properly. This is often due to a faulty sensor.

The reading out of data does provide benefits for allowing the transition of time-based maintenance towards condition based maintenance, which in turn can lead to a shift of corrective maintenance towards preventive maintenance. However, for the mechanics job it will not have a significant impact. *"The maintenance service remains the same."* (CMSU-1)
At the DoT, the CAN-BUS system does not make a significant difference between preventive and corrective maintenance. However, a shift in maintenance tasks from reparations towards diagnostics is likely. This means that there will be less mechanical wear, however the maintenance workload becomes higher because it requires more time to for the diagnosis (DoT-1).

Regarding BDR

"For BDR, the diagnosis becomes more intensive, but also more complex" (CMDR-1). It becomes harder and harder to do BDR on the new advanced vehicles. If it is a piece of 'conventional' technology then the problem can usually be fixed. But if it is a problem in the CAN-BUS system, then it is a no-go for BDR.
"As an example, the Scania Gryphus: imagine there is a leak in the air duct, then I can fix it quite easily myself. However, if there is a broken sensor which puts the car in a 'driving ban'. And if we do not have the sensor available, then I cannot ignore the error to get the car drive-able." (CMDR-1)
The MSU also sees more and more problems due to the electrification of components. For example, if a problem occurs in a mission such as a broken ECU, then the vehicle has to be towed off or be destroyed.

C.1.3 Impact on the specializations

It is recommended by the participants that there will be mechanics present in the field, who have sufficient knowledge about the Information & Communication Technology (ICT) / CAN-BUS systems.

- "*I think a new specialization should be added. If I put a piece of tape on a fuel tank, then it will fix the leak. This does not work in the same manner for a computer. When looking at combat operations, it is not a wrong idea to have someone in the vicinity who has more knowledge of the ICT-side. And you can already see that the newer generations picks it up more easily than the older generations"* (I-1).
- "*I think that it is not a unnecessary luxury to actually have someone trained who specialised in the ICT. And if it is at the workshop floor, at company level, or at DLM, does not matter. But there should be someone who is in charge of the sensors within the diagnostic systems."* (CMSU-1)

Currently the RNLA is still behind when it comes to working with the CAN-BUS systems. *"If I look at the situation: the Boxer and the Scania Gryphus both have a quite complex CAN-BUS system. And we will have to deal more and more with the complex CAN-BUS systems. But when I look at the education the mechanic receivers: there is still very few information about the CAN-BUS in the curriculum.*" (CMDR-1) "*Therefore, you should think about having a specialized CAN-BUS mechanic. If you posses the right tools, then you can perform targeted diagnostics. By looking at it: okay, this computer is broken. And now the wrong computer cannot be replaced because we do not posses the knowledge and experience to do a proper diagnosis. So actually, you need a data-diagnostician.*" (CMDR-1) *"If you give the mechanics a more goal-oriented training, it delivers more knowledge, experience, and insight about CAN-BUS systems. Then you do a more in-depth diagnosis, and get a diagnosis easier and faster in 9 out of 10 times."* (CMDR-1)

C.1.4 Workload

The interviewed commander of the MDR-group believes that the workload will become higher; *"This is because the amounts of malfunctions increases, which results in an increase in time spend diagnosing*" (CMDR-1). The interviewed commander of the MSU agrees: *"The civilian version is set up to lower the maintenance level and increase the ease of use. However, every electronic component that the DMOD has, should be replaceable or repairable. And then you find that it will take more time. Because the education level of the mechanic within the RNLA is way down. We have systems at a certain point, which might be relatively easy to replace the sensors, but the personnel have absolutely no clue about them. So the more sensors that are added, the more system knowledge is required. Therefore, for the RNLA the maintenance workload will become higher."* (CMSU-1)
This effect is also seen by the instructor of the STM, who also expects that the pressure on the mechanic becomes higher, the more advanced the technology becomes. But he also mentions that this effect can be mitigated, if the mechanic does not have to analyse/process the information output of the system.
Furthermore, the instructor also saw that the because the systems become more complex, the maintenance workload also becomes higher. For example: the Boxer, with more complex systems aboard, takes more hours for periodic maintenance than the Bushmaster, even though both vehicles are roughly the same size. *"You can see it. When we had the DAF 4-ton vehicles, when I gave the mechanic a workorder it said 2 weeks for periodic maintenance. If we take the Boxer, when the mechanic does periodic maintenance, then it takes around 4 weeks. This is because the systems in the Boxer are more complex."* (I-1)

C.1.5 Overview maintenance tasks

So to summarize, the increase of sensors in the systems (especially within the CAN-BUS), causes the maintenance tasks of the mechanic to become more complex (regarding diagnosis). The OLM mechanic has to spend more time educating the driver, as faulty handling also causes the system to generate errors. But also because broken sensors can create faulty diagnosis which the mechanic has to solve.
The increase of sensors in the vehicles also provides problems with BDR. As problems to ECUs can often not be repaired in the field because it requires the availability of spare parts and the computer to install it within the systems.
The main impacts on the maintenance tasks, concluded from the interviews, are briefly summarized in Figure C.1.

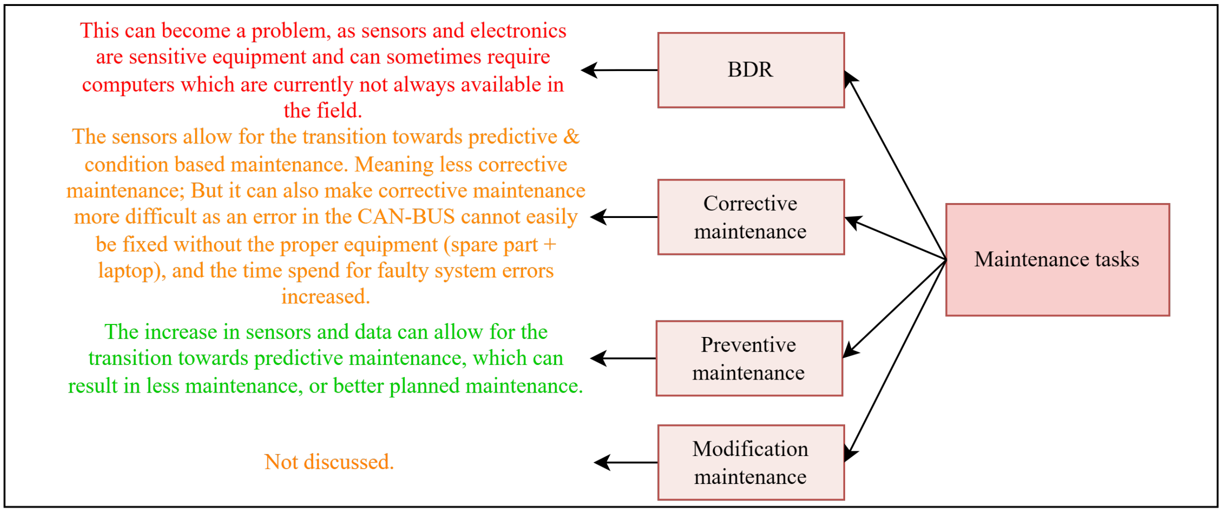

Figure C.1: Summarized overview of the impact on the maintenance tasks

C.2 Facilities

C.2.1 Infrastructure

Depending on the systems, an internet connection might be necessary. Especially when the manfacturer needs to be able to monitor the systems. However, systems as the Boxer can function offline.
Also for DLM, some special rooms might be required. For example, for testing temperature sensors a sealed and controlled environment is required.

C.2.2 Location

The location in which the systems can be maintained remains largely unaffected.

C.2.3 Overview facilities

The facilities required remain largely unaffected. However, a (stable) internet connection might be required for updating the systems or when the manufacturer needs to be able to monitor the systems. The main impacts on the facilities concluded from the interviews, are briefly summarized in Figure C.2.

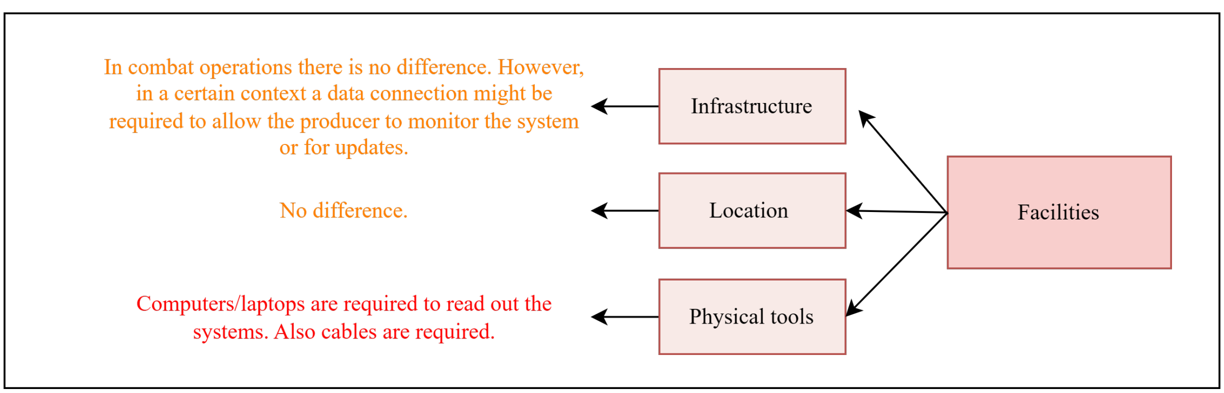

Figure C.2: Summarized overview of the impact on the facilities

C.3 Support equipment

C.3.1 Physical & digital tools

For the tools, the big problem is currently that they are not universal. This means that because of the (relatively large) number of different contractors there are too many laptops and other kinds of read-out systems are present in the workshop. *"All these systems work differently: One has to be updated, the other has to be send out, the other has to be 'fed', and the other one has to be connected to a server continuously. This makes it more complex. Therefore we should go to one system. Because eventually, the systems do exactly the same thing"*. (CMSU-1)
This is in agreement with the input from interview with the instructor of the STM: " *The size of the tool set is an issue. If I have to read the sensors from a Boxer, then I need a laptop, certain programs, and a certain cable. It would be best if this could be one system for all assets, but that is actually quite difficult to achieve*". (I-1)
"*If we currently already have problems with the different cables, and programs, then I expect it to become more of an issue in the future. This is because the amount of sensors is increasing and more maintenance activities will with using data.*"(I-1)

C.3.2 Overview support equipment

The main impacts on the support equipment concluded from the interviews, are briefly summarized in Figure C.3.

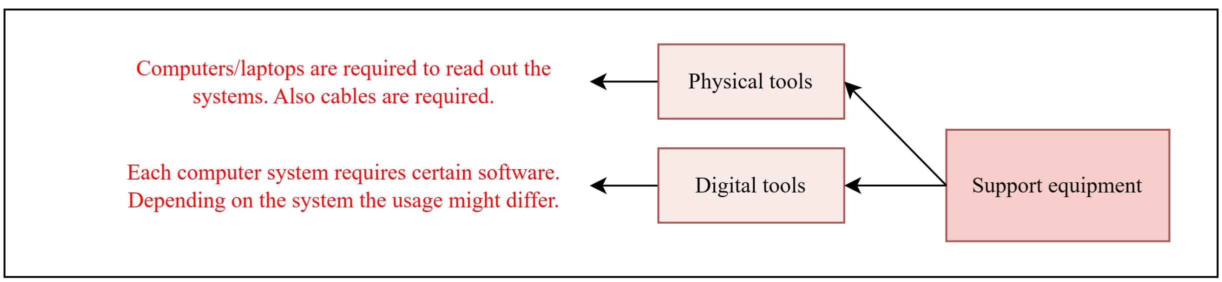

Figure C.3: Summarized overview of the impact on the support equipment

C.4 Manpower & Personnel

C.4.1 Job roles

At the DoT they notice a transition described as: "from mechanic towards detective" (DoT-1). This means that the focus shifts towards diagnosises. The mechanic has to find out why a problem occurred and "analyse" it. He or she has to watch what happened, if faulty actions where taken, and then determine what is wrong with the system.
Also according to the instructor of the Boxer, the work with computers become more important. This digital work requires a different kind of handling, and he can already see that this sometimes forms a problem for the 'older generations.
The technical knowledge and skills remain applicable for the mechanic, but they do change. For example: the transition of oil dipstick to float-sensor. With the oil dipstick the mechanic had to pull the stick out, wipe it clean, put it back, and then inspect. With the float-sensor, the mechanic has to digitally log into the system, read out the software, and then see if the amount of oil in the system is still sufficient.

C.4.2 Critical behaviours

The instructor of the Boxer does not think that there will be a significant change in critical behaviour. *"But a bit of discipline is required. This is because computers can be more sensitive systems"* (I-1).
The commander of the MDR-group thinks that a critical behaviour required by the mechanic is the willingness to learn. *"He has to be able to keep his own knowledge & skills up to date. He has to read new techniques and also understand a part of it. As I say: it has to come from the person"* (CMDR-1).
At the DoT they also think that interest & curiosity is one of the important critical behaviours required to keep up with the technology. But also have to be able to think logically. Furthermore: "*You need precise people*" (DoT-1). This is because with connecting the wrong wires a lot can brake. This risk can also partially be mitigated with making sure the instructions are clear.

C.4.3 Mindset, attitudes and beliefs

"This differs a lot per generation. At the DoT, you have the older generation and the younger generation, with very little inbetween. The younger generation is more interested in computer-driven systems, partially because they are grown up with this. This attitude was also seen with the implementation of the DO-MAINT app" (DoT-1).
At MDR-group commander sees 2 global flows:

1. The mechanics who want to learn, who are interested and who will do anything to understand a new system.
2. The mechanics who are reluctant when it comes to new systems. This is due to the fact that the new systems are fairly complicated. Consequently, you see this flow coming back more and more.

The instructor of the Boxer also noticed that because the Boxer is a more technological advanced vehicle, this also piques the interest of the mechanic. *"For the mechanic who seeks more of a challenge, the more technologically advanced systems can be fun"* (I-1).

C.4.4 Compensation rewards

At the DoT, they also warn for when you make the shift towards fully preventive maintenance, or make the decisions all based on data with the mechanic only requiring to fulfil simple tasks, then it will affect the appreciation of the job in a negative way. *"I think that for the mechanic the most important thing he does, is that he is able perform his tasks and that he has the feeling that he can find a problem himself and also fix it. There is a lot of talk about making the transition to the future here (at the DoT), and as a knowledge company only perform preventive maintenance, and then to provide the unit with a list: this is broken and you have to fix it. In that manner you will not have any mechanics left in the future, they want to also do the corrective maintenance. They want the feeling that they can fix a problem themselves and send the vehicle away driving"* (DoT-1).

C.4.5 Overview manpower & personnel

The main impacts on the manpower & personnel concluded from the interviews, are briefly summarized in Figure C.4.

C.5 Training & training support

C.5.1 Education/training

The MDR-commander recommends a training for the CAN-BUS systems (as mentioned before). However, it is important to note that this is only useful if the MDR-group also has a laptop available.
At the DoT they also recommend that the mechanic receives a proper CAN-BUS training. Currently there is already a CAN-BUS training, *"but it is not very in-depth"* (DoT-1). Also mentioned by the DoT, the prior education required to follow an in-depth CAN-BUS training requires at least an level 3 vocational education

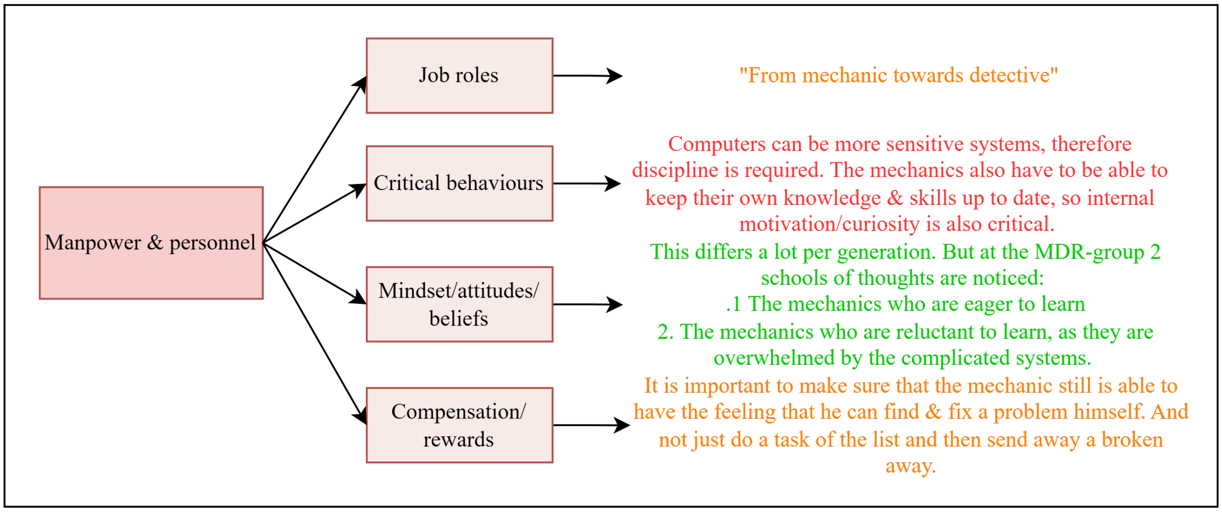

Figure C.4: Summarized overview of the impact on the maintenance tasks

in vehicle-mobility (in Dutch: ”eerste bedrijfsautotechnicus”).
Furthermore, in the training for the Boxer vehicles is already noticed that there is a significant impact by the digitization and electrification of systems. When mechanics with a background in relatively simple systems, such as aggregates and/or the older DAF trucks of the DMOD, arrive at the Boxer training they can immediately notice that the increase of systems aboard the vehicle, the increase of data output by these systems, and the opportunities to read those systems out is quite overwhelming.
The instructor also prefers to educate mechanics within the organization, as the RNLA instructors have experience themselves in the operational context that these mechanics will be required to work in. For ’peace-operations’, it does not matter if the education and/or trainings are provided internally or externally.

C.5.2 Training equipment

Regarding the training equipment, there is no specific materiel required.

C.5.3 Overview training & training support

The main impacts on the training & training support concluded from the interviews, are briefly summarized in Figure C.5.

C.6 Summary of the Impact Analysis of case 2

In Figure C.6 a complete overview of the summarized elements is shown. The green letters represent a positive impact, the red a negative impact, and the orange letters represent an impact which is not definitively positive or negative.

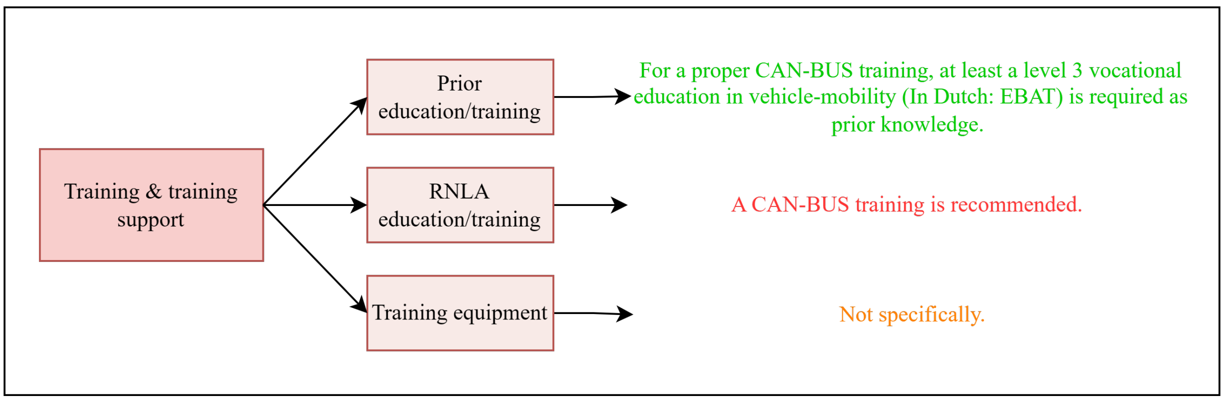

Figure C.5: Summarized overview of the impact on the training & training support

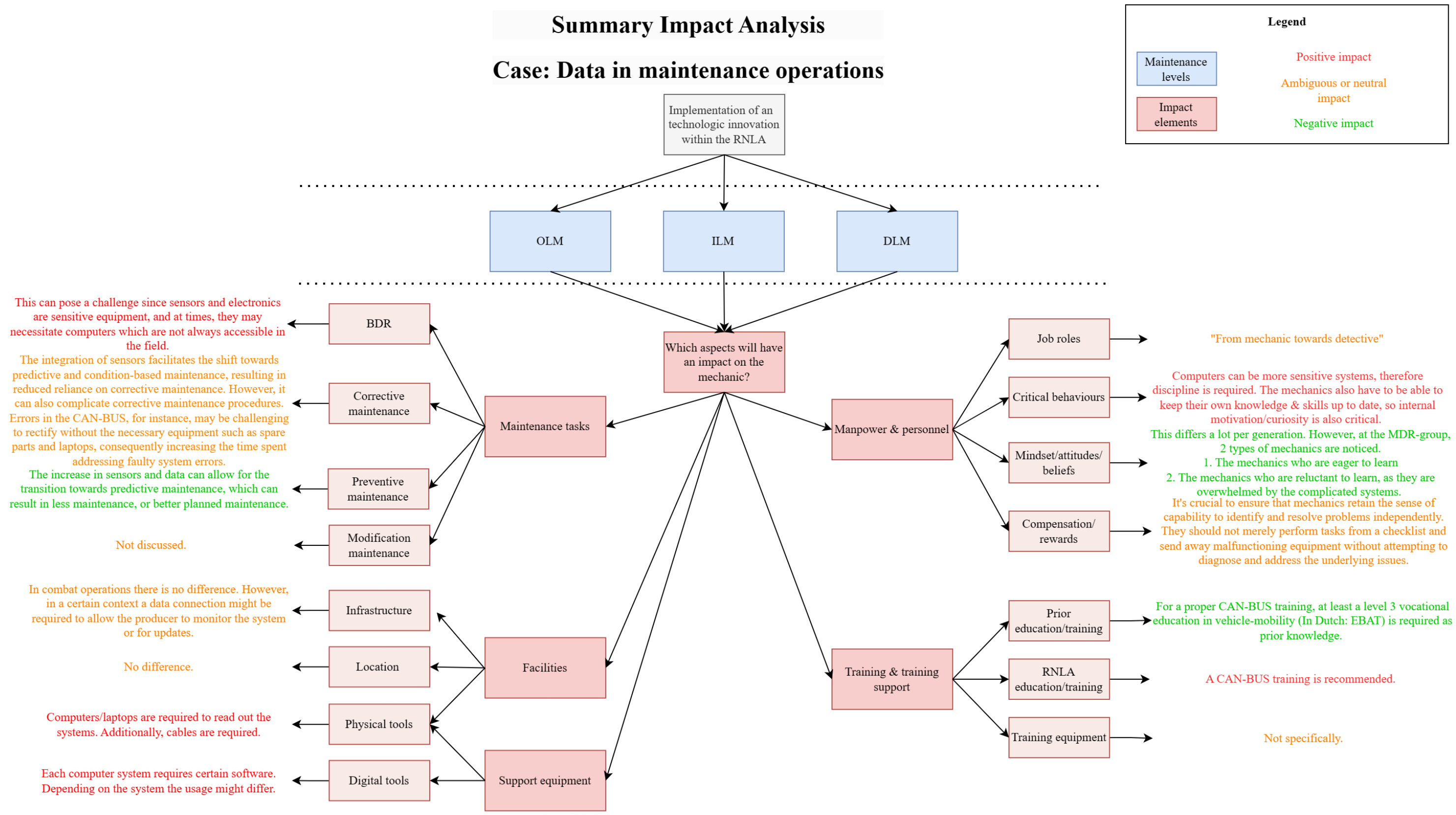

Figure C.6: A complete overview of the summarized impact analysis of case 2

C.6.1 Risks & opportunities

Based on the impact analysis report, several risks are identified.

Risks	**Opportunities**
Dependence on the availability of a compatible computer & spare part to perform repair.	The data can allow for keeping up a better log, and therefore to make the transition towards condition-based maintenance and/or PdM. This then in turn can lower the maintenance workload or increase the material readiness.
Problems with a CAN-BUS component cannot be fixed with BDR.	If the mechanic has sufficient knowledge of the CAN-BUS system and is properly trained, then you can come easier and faster to a diagnosis.
More time required from the mechanic to educate the driver, as error codes show up when the system is handled wrong.	Currently there are too many different 'read-out' systems, which all work in a different manner and also causes the toolbox to bigger. This problem can be mitigated by creating a 'universal computer' which works for all systems, preferably in the same manner.
More time required on faulty diagnosis (systems shows an error code while there is no fault).	Opportunity for the driver to acknowledge a problem earlier. This can prevent more significant problems and/or execute the maintenance tasks in more favorable moments.
Diagnosis becomes more complex. The more sensors are added, the more system knowledge is required.	
If the mechanic will only receive preventive maintenance tasks, he or she will lose interest in the job. They need to be able to find & fix problems themselves to get a feeling of accomplishments. (especially relevant for DLM)	

Table C.1: Risks & opportunities followed from the impact analysis report for the second case.

Appendix D

Case 3: Impact Analysis Report Digitization of the Inspection Work Card

This chapter contains the impact analysis report for the third case of this research, namely: the use of the DO-MAINT platform for maintenance tasks in the RNLA. Each impact element is discussed and the results of the the interview is summarized here. In several of the subsections in this report, the analysis is subdivided into the different maintenance levels in order to take into account the different tasks associated with each maintenance level. To clarify here, the following assumption is made: the OLM is done by the mechanics of the MDR-group, the ILM is done by the mechanics of the MSU, and the DLM is executed by the mechanics of the department of Tech.

D.1 Tasks & skills

D.1.1 Impact on the maintenance tasks

The usage of DO-MAINT is made universal for the entire DMOD. Therefore, the platform works in principle the same at all maintenance levels (OLM, ILM, and DLM). Furthermore, the maintenance tasks themselves remain unchanged: "*So entering mileage, running hours, and inspection points remains the same. Only previously was this with paper, and with the DO-MAINT platform it becomes digital*" (PM-1).
This also means that no new specialization type is required for mechanics, as there are no major changes in tasks.

D.1.2 Impact on the mechanic's skills

Basic knowledge of how to use a mobile device is important, as you must be able to open the application and log in with the user account. The user is then guided through the steps within the application. However, the usage of the app does not require special specific skills. *"The process becomes easier, there is more guidance in the activities that need to be performed. However, there are also added functionalities that were previously not there."*(PM-1)

D.1.3 Overview tasks & skills

The main changes in tasks & skills, which are concluded from the interview, are briefly summarized in Figure D.1.

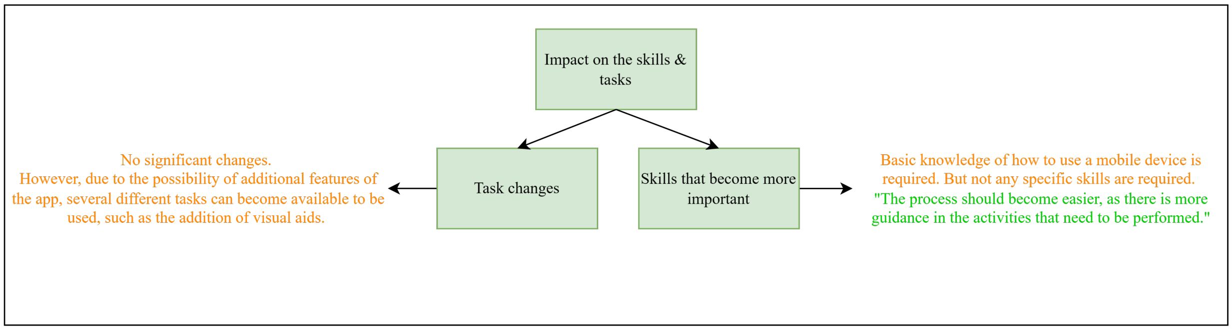

Figure D.1: Summarized overview of the changes in tasks & skills

D.2 Facilities & support equipment

D.2.1 Infrastructure & Location

An internet-connection is required, along with a device coupled to the DMOD network. The location remains unaffected further, as long as the devices are able to withstand the environment.

D.2.2 Physical & Digital tools

As the maintenance tasks remain the same, only the addition of the platform changes the toolset. Therefore, the TI only requires a mobile device/computer that is connected to the network of the DMOD. On this network, the app is available online.

D.2.3 Overview facilities & support equipment

The main impacts on the facilities & support equipment, which are concluded from the interview, are briefly summarized in Figure D.2.
As can be seen, the necessity of a network connection to the DMOD can form a risk, as this is not always available in the field. This can then mean that the mechanic will have to fall back to the physical inspection work card, which still means that he or she has to be able to properly use this card.

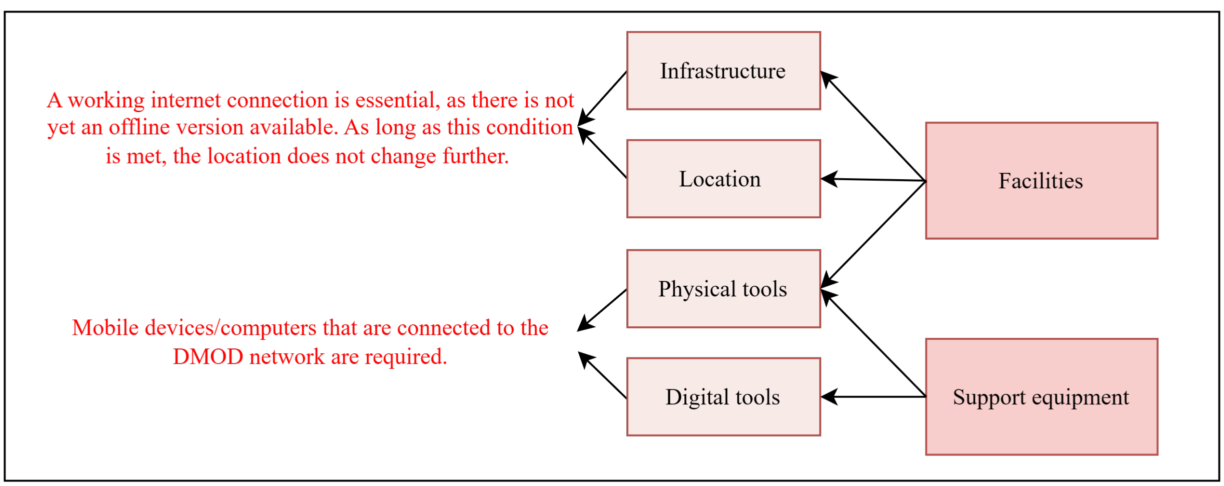

Figure D.2: Summarized overview of the impact on the facilities and support equipment

D.3 Training & training support

D.3.1 Education/training

There is not a lot of training or education required to be able to use the DO-MAINT platform. However, it is beneficial to provide a short training (at most a half-day) to show how the documentation works.

D.3.2 Training equipment

There is no specific training equipment needed.

D.3.3 Overview training & training support

The main impacts on the training & training support, which are concluded from the interview, are briefly summarized in Figure D.3.

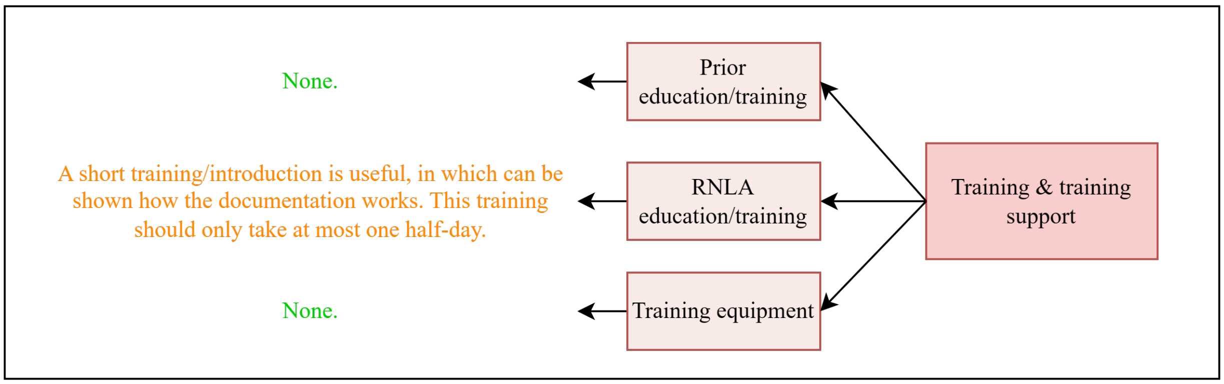

Figure D.3: Summarized overview of the impact on the training & education

D.4 Manpower & personnel

D.4.1 Job roles

In essence, the job roles do not change.

D.4.2 Critical behaviors

It is important that the personnel is open to change, when it comes to working with the DO-MAINT app. It is also important that if they have questions or run into problems, that they are pro-active in stating these problems.

D.4.3 Mindset, attitudes and beliefs

"Most of the people are content with the app, however there a couple of 'older' colleagues who have been working the past 25-30 years in the same manner who are less eager to change. But once they start using the app, then in most cases it goes well. They become more open-minded, and also more pro-active in helping with improving the app." (PM-1)

D.4.4 Compensation rewards

"The job satisfaction increases" (PM-1)

D.4.5 Overview manpower & personnel

The main impacts on the concluded from the interviews, are briefly summarized in Figure D.4.

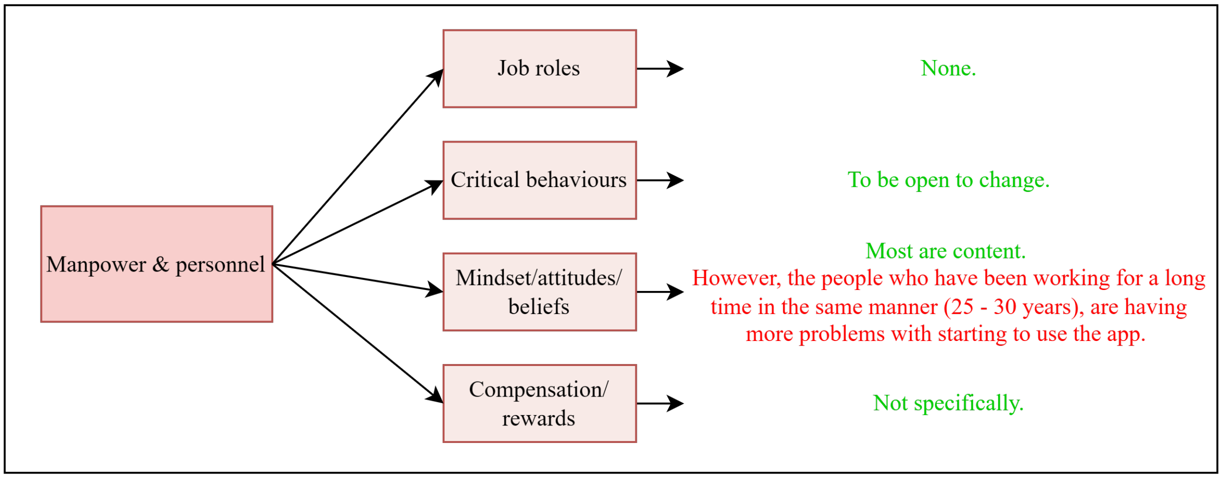

Figure D.4: Summarized overview of the impact on the maintenance tasks

D.5 Job quality

D.5.1 Mental strain

Not really affected.

D.5.2 Autonomy

There process becomes less autonomous, as the DO-MAINT app guides the mechanic through the process.

D.5.3 Difficulty & development opportunities

"In principal, the whole process becomes easier. If you perform an inspection, you just have to fill in the data that are asked. So, the mechanic is guided more in the process" (PM-1)

D.5.4 Social & functional support

No change.

D.5.5 Variation in tasks

"The inspection lists remain the inspection list." (PM-1)
So, there is no change in the variation in tasks.

D.5.6 Physical strain

No change, as the physical actions remain the same.

D.5.7 Overview job quality

The main impacts on the job quality, which are concluded in the interview, are briefly summarized in Figure D.5.

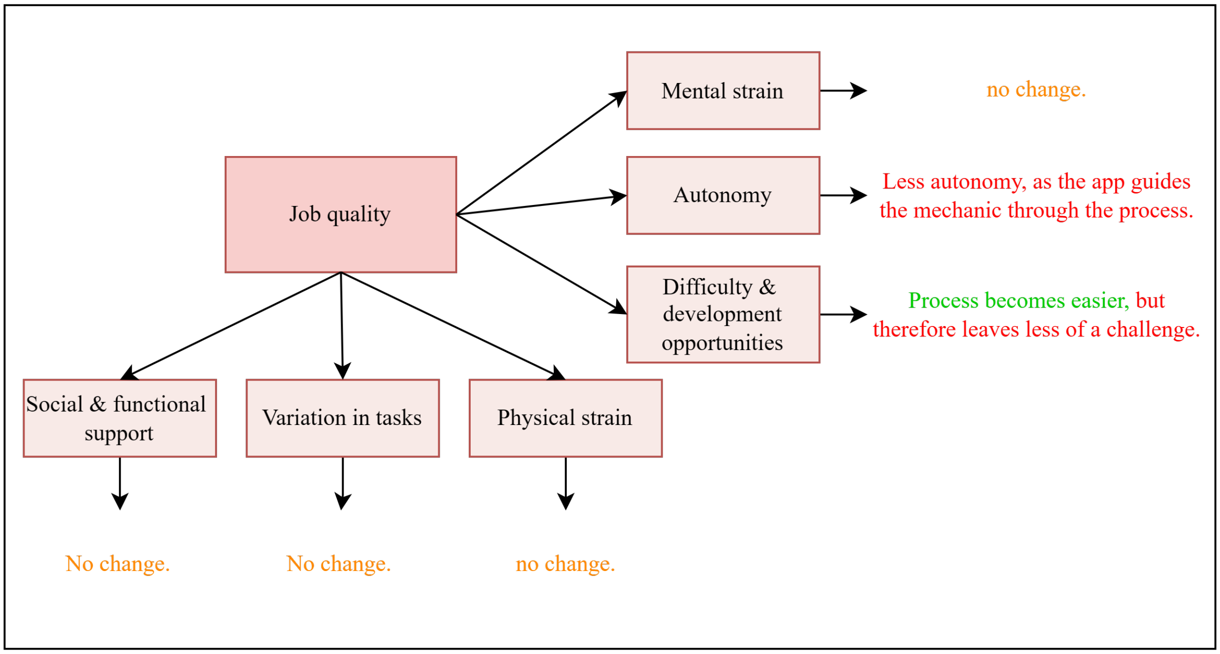

Figure D.5: Summarized overview of the impact on the job quality

D.6 Summary of the impact analysis of case 3

In Figure D.6 a complete overview of the summarized elements is shown. The green letters represent a positive impact, the red a negative impact, and the orange letters represent an impact which is not definitively positive or negative.

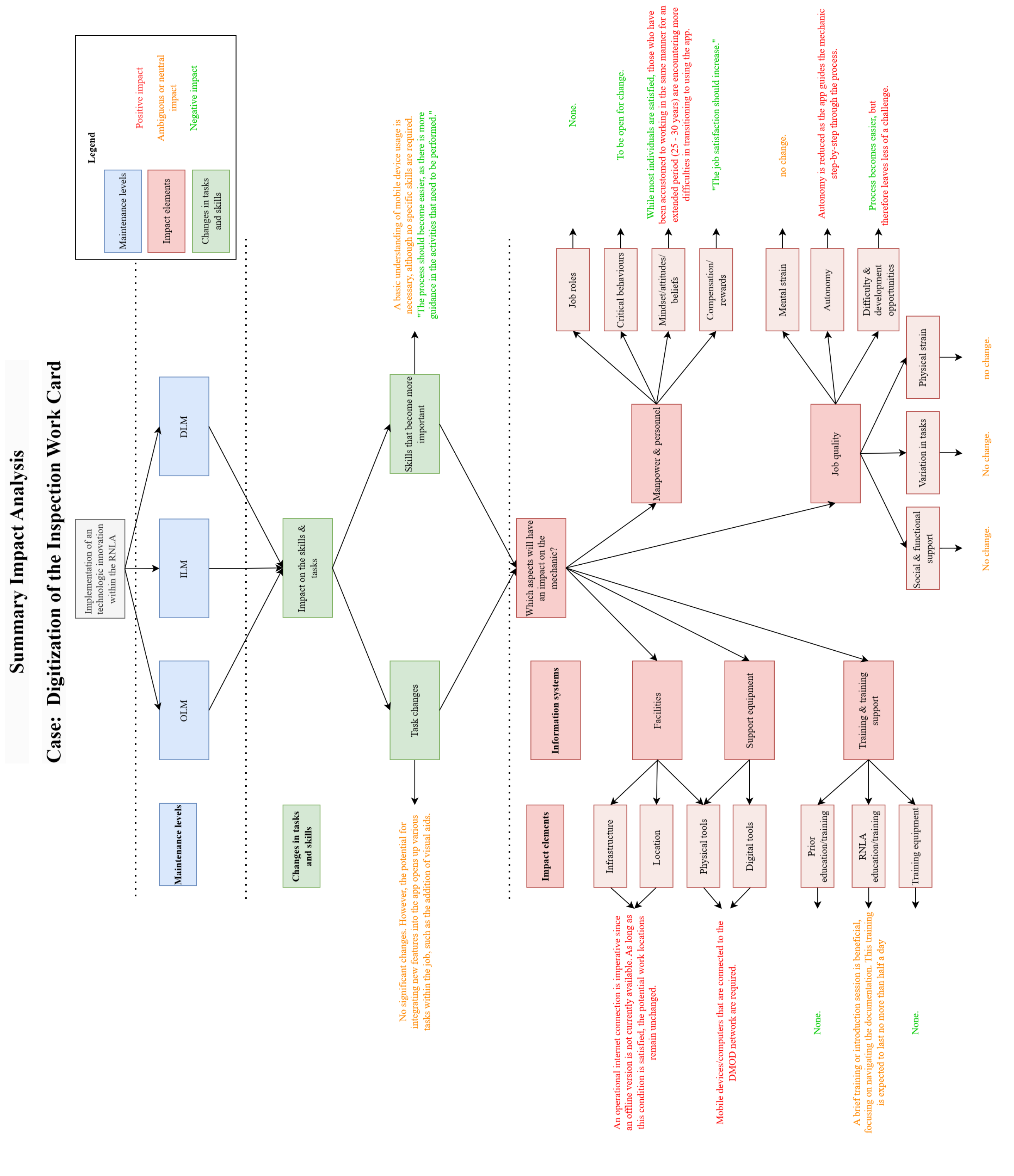

Figure D.6: A complete overview of the summarized impact analysis of case 3