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Improving coordination of after-sales service logistics with a service control tower

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Preface

Dear reader,

Writing this Thesis has been an interesting process. Circumstances, some personal, some globally felt, have contributed to making this period of graduation more than just another box to be checked in my academic career. From the very start of this project I have felt extremely welcomed by the people I met at the RNLN and it cemented my believe that there were some interesting and exciting months ahead of me. It is with great pleasure that I now, after almost seven months of working on this project, can affirm this believe. For this I want to take the opportunity to thank some of the people that have helped make this project so memorable.

First of all I would like to thank my supervisors Rogier Harmelink and Bart Pollmann. Throughout the months that I have gotten to know them I have always felt supported and encouraged to finish this project to the best of my ability. They took the time for weekly meetings, many feedback sessions, hours of discussing ideas and ways of structuring things. Rogier was a great supervisor, and I respect his ability to level with a student. He always knew how to guide me towards finding the answers I needed myself, without simply spoiling them. This made the entire process so much more educational. Besides that I was impressed by his vast knowledge on some of the topics that we discussed. Bart too, was a very good supervisor, which I am thankful to have had. He impressed me as a very considerate and wise man, who also had a vast knowledge about his field of work and I enjoyed our lengthy conversations, whether they were on-topic or not. For the final stage I also wish to thank Engin Topan for his work as a secondary supervisor from the UT. Many thanks to him for his time, feedback and questions.

Besides my supervisors I wish to thank some other people that have contributed to this research. Berend Jongebloed from Thales, although not being my supervisor took his time to discuss the many ideas I had about the interaction between the RNLN and Thales. It was very selfless of him to attend so many meetings and to help provide information that I needed for my research. Wieger Tiddens from Data Voor Onderhoud helped me by providing feedback and was always available to discuss ideas that I had. Dennis and Jan also made me feel right at home at the Data Voor Onderhoud division.

I want to give a special thanks to the entire crew of the Van Speijk for taking me aboard of their beautiful ship and allowing me to see them work from such proximity. Their hospitality, willingness to explain things and interest in my project truly amazed me, and my time on board of their M-Frigate was the so-called "cherry" on top of this project. I also wish to thank Marcel Koning, Jelger Bischop, Bert Kloosterziel, Peter Sluijter and all the other employees at the RNLN that took their time to answer questions in interviews with me. Minou Olde Keizer from CQM also selflessly and enthusiastically reserved time to assist me on the topic of Service Control Towers, which was much appreciated.

Lastly, I want to thank Carlijn de Vries, who is very dear to me, for helping me to keep focus, even through the more challenging times. Without her, this project would not have been the same and I am very thankful for all of her support.

Executive Summary

The Royal Netherlands Navy (RNLN) operates RADAR systems produced by electronics manufacturer Thales Netherland B.V. (Thales) on their fleet. Directie Materiële Instandhouding (DMI) is responsible for the maintenance of these systems throughout their End Life Of Type (ELOT). Thales provides the RNLN, now the asset owner, with a after-sales service that consists of, among other things, spare parts service, assistance with repairs, and obsolescence management. The logistics that support this after-sales service are called after-sales service logistics.

Both organizations wish to improve the communication and coordination within the after-sales service supply chain, as it is believed that this could reduce obsolescence related costs and improve the maintenance planning adherence. In the literature a fairly new concept has been introduced that supports the inter-organizational communication concerning after-sales service logistics, namely a Service Control Tower (SCT). This generated an interest from both parties to investigate what possibilities this SCT could provide concerning the improvement of the coordination of the after-sales service logistics. As more parties within the naval sector were interested in these developments the Maritime Remote Control tower for Service Logistics Innovation (MARCONI)-project was initiated, which aimed to develop innovative service logistics for this sector. We contribute to this MARCONI-project by investigating the possibilities for a SCT within the context of the after-sales service logistics between the RNLN and Thales. This gave rise to the following research question of this Thesis:

How can a service control tower support the coordination of the after-sales service logistical processes?

We conducted our research by using two methodologies we deemed suited for our research goal. Firstly we used the Managerial Problem Solving Method (MPSM) to design a general structure in which to conduct our research. This methodology provides the user with a research cycle, which can be used to solve a knowledge problem.

Our knowledge problem concerned possibilities for functions of an SCT within the current enterprise architecture of the asset owner and the OEM. In order to describe this enterprise architecture and to develop a new one where the SCT is integrated, we used the Architecture Development Method (ADM). The ADM is a research method developed by The Open Group Architecture Framework (TOGAF) to assist the transition between two enterprise architectures.

We set our scope to four processes within the after-sales service, namely (i) the procurement of spare parts, (ii) obsolescence management, (iii) order tracking and (iv) asset monitoring. We choose these elements as they were the processes that were mentioned multiple times as processes were improvements in coordination with the OEM could be made during our oriental interviews with employees of the RNLN. We then choose to map the enterprise architecture of these four processes, describing the problems that were encountered by the parties of the after-sales service supply chain.

Based on these architectures and problems we devised four new architectures where said processes were supported by a SCT environment, in which data could be shared throughout the supply chain.

In the process of procuring spare parts we recommend that within the SCT environment the status of the procurement process is monitored and delays are communicated throughout the supply chain. From appendix D we learned that there were often hundreds of parts that had delays within the ordering process, without this delay being communicated downward in the supply chain. This resulted in mechanics at DMI not being informed about the absence of spare parts that they required for their maintenance tasks. This wasted time across all parties involved and frustrated many employees. By monitoring the status of orders, employees can know beforehand whether or not the maintenance planning can be adhered, and if delays do occur, the planning can be adjusted so to not waste days were maintenance cannot be conducted because of the absence of parts.

Regarding obsolescence management our main recommendation is that data concerning obsolescence is registered more precisely and more detailed within the information system SAP of the RNLN. Currently information about obsolescence is received via paper reports or emails, but it is not always known who is responsible for these obsolescence notifications, thus they are also not always processed within the Enterprise Resource Planning (ERP) system of the RNLN. When obsolescence is registered, it is registered within the long text of a part in SAP that is normally used for miscellaneous comments. We suggest that obsolescence becomes a standardized data type, that is linked to discontinuance date in order to be able to analyse this data and to communicate it more effectively throughout the supply chain.

Concerning order tracking, we found a very cumbersome process for the registration of delays on outstanding orders from Thales. When a part was ordered, and a delay occurred, there was not automatic notification send by Thales. Employees of DMI could find out about the delay in two ways. They either had to log in to a customer portal and manually search for the order, comparing the new estimated delivery date with the delivery date stated in SAP. The second method was by manually processing a Excel file that Thales sent once every month, in which all outstanding orders were presented in an unfiltered manner. Meaning that still every order number in the Excel file had to be compared with the order number and status that the employees of DMI had registered previously in their ERP-system SAP. We recommend that within the SCT environment delays on orders is automatically shared an notified to DMI, so that a faster response can occur.

Lastly, concerning the process of asset monitoring we recognized that during the operational lifetime of a RADAR system a lot of data was generated and registered by the RNLN which could support other after-sales service processes if shared with the OEM. Currently most of this data about, failure rates, failure modes, repair rates and the eventual spare part demand is kept private within the environment of the RNLN. We recommend however that both Thales and the RNLN discuss what data each party might be willing to share for the benefit of the entire after-sales service supply chain. Sharing failure rates for example could help improve the accuracy of Last Time Buys (LTBs) resulting in better obsolescence management. On the other side, communicating more details about the system configuration down to a Shop Replaceable Unit (SRU) level can provide DMI many benefits regarding their maintenance capabilities.

All in all we recognized multiple opportunities for improvement and suggested ways in which an SCT environment could support the coordination of after-sales service logistics between the RNLN and Thales. We suggest that this report is taken as a starting point for a conversation between the RNLN and Thales about the future of the after-sales service supply chain.

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Abbreviations

ADM Architecture Development Method.

AM Assisted Maintenance.

APAR Active Phased Array Radar.

API Application Programming Interface.

ATB Aanvraag Tot Bestelling.

BO Benoemd Onderhoud.

COTS Commercial Off-The-Shelf.

DLM Depot Level Maintenance.

DMI Directie Materiële Instandhouding.

DMO Defensie Materieel Organisatie.

ELOT End Life Of Type.

ERP Enterprise Resource Planning.

ETO Engineer-To-Order.

FMECA Failure Mode, Effects, and Criticality Analysis.

IC Integrated Chip.

IDM Information Driven Maintenance.

ILM Intermediate Level Maintenance.

ISS In Service Support.

KPI Key Performance Indicator.

LCF Luchtverdedigings- en CommandoFregat.

LRU Line Replaceable Unit.

LTB Last Time Buy.

M-Frigate multi-purpose frigate.

MARCONI Maritime Remote Control tower for Service Logistics Innovation.

MILSPEC Military Specified.

MPSM Managerial Problem Solving Method.

MRP Material Requirement Planning.

MTBF Mean Time Between Failure.

MTO Made-To-Order.

MTTR Mean Time To Repair.

NWO Nederlandse Organsiatie voor Wetenschappelijk Onderzoek.

OEM Original Equipment Manufacturer.

OLM Organic Level Maintenance.

OPS Directie Operaties.

PrimaVera Predictive Maintenance for Very Effective Asset Management.

RADAR RAdio Detection And Ranging.

RFQ Request For Quotation.

RNLN Royal Netherlands Navy.

SAP Systems Applications and Products in data processing.

SCT Service Control Tower.

SKU Stock Keeping Unit.

SLR Systematic Literature Review.

SRU Shop Replaceable Unit.

SWS Sensors and Weapon Systems.

TCO Total Cost of Ownership.

Thales Thales Netherland B.V..

TOGAF The Open Group Architecture Framework.

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1 Introduction

With an aging fleet and a trend of military budget cuts, it has become more important than ever for the Royal Netherlands Navy (RNLN) to look at smart innovations, in order to maintain their operational capabilities (Veenstra, 2016). 80% of the RNLN's fleet is expected to reach their End Life Of Type (ELOT) within the next 20 years. This in turn gives rise to important discussions surrounding the upkeep and maintenance trajectories of certain systems (Molenaar, 2020).

One such type of system on board a naval vessel is a RAdio Detection And Ranging system, commonly known as a RADAR. The fleet of the RNLN operates mainly with RADAR systems produced by Thales (Thalesgroup.com, 2019). These RADARs play crucial roles within the vessels offensive and defensive capabilities. Malfunctioning of these systems can make a ship incapable to fulfill its operative role. Because of this, it is crucial for the RNLN and Thales to cooperate in keeping these complex electronical systems operational for the years to come.

To do this, Thales, the Original Equipment Manufacturer (OEM) of these systems, provides the RNLN with a so-called after-sales service. After-sales service entails all the processes required to support and maintain an asset after its initial purchase and installation (Cohen & Lee, 1990). The logistics composing and supporting these processes are referred to as the the after-sales service logistics.

For certain assets, such as a ship's hull, the after-sales service is quite straightforward, being limited to periodic inspections and relatively simple maintenance procedures. For more complex assets, such as RADARs, the after-sales service is a lot more complicated. This is partly due to the complexity of the system, with single RADAR systems sometimes being composed of tens of thousands of parts.

On top of this, the after-sales service for these systems is further complicated because of the nature of the parts they are constructed with. The electronic systems used by the military specifically have become more sensitive to aging, requiring proficient obsolescence management. Where historically speaking permanence of electronic parts was the norm, nowadays electronics tend to go obsolete faster and faster, as armed forces have shifted from using Military Specified (MILSPEC) electronics, towards Commercial Off-The-Shelf (COTS) electronics (Condra et al., 1997). The production window and availability of COTS electronics follows the rapid advances of the commercial market. This makes it that the electronic parts that compose a system, often have a life cycle that is much shorter than the planned life cycle of the system they go in to (Singh et al., 2011). For the after-sales service this entails complex problems, surrounding the upkeep of the system throughout its lifetime.

A relatively novel concept has been introduced in the literature, that aims to help coordinate part of the after-sales service logistical processes between two parties, namely a Service Control Tower (SCT). The existing literature currently limits the functionality of the Service Control Tower to only supporting the operational spare parts service logistics (Topan et al., 2020). However we aim to take this a step further and investigate the possibilities of having a Service Control Tower supporting multiple aspects of the after-sales service including asset monitoring, obsolescence management and the procurement process of spare parts.

2 Background Information

2.1 MARCONI project and information driven maintenance

This thesis supports part of a PDEng study that Rogier Harmelink is conducting for the RNLN. He plays a large role in the Maritime Remote Control tower for Service Logistics Innovation (MARCONI) project. The MARCONI project is a project initiated by the Nederlandse Organsiatie voor Wetenschappelijk Onderzoek (NWO), which aims to support the development of Service Control Towers in the maritime sector with three goals in mind. Abstracted from Nederlandse Organsiatie voor Wetenschappelijk Onderzoek (2019), these goals are formulated as:

1. To develop and demonstrate innovative service logistics aimed at (i) reducing maintenance costs, (ii) increasing safety by lowering the chance of unplanned system failures, and (iii) reducing unnecessary emissions through smarter planning and combining of maintenance activities.

2. To demonstrate the functioning of a Service Control Tower, with the long-term goal of developing and exploiting a scalable supply chain function in the maritime world.

3. To create value propositions aimed at valorization and dissemination of knowledge, experiences and results, but also to contribute to an increased intake of students in the logistics world.

These goals are in line with the vision and plans that the RNLN have. Currently the RNLN is on its path of introducing information driven maintenance by the year 2030 (Pollmann, 2020). This type of maintenance would be, as the name suggests, increasingly driven by input data from many different sources. A Service Control Tower could play a crucial role in this, by monitoring and supporting the after-sales service logistical aspects of an information driven maintenance strategy.

However to achieve this goal, many hurdles, especially within the data collection methods, have still to be overcome (Tinga et al., 2017). Some of these challenges and hurdles are illustrated in the roadmap presented in appendix B. In this roadmap the steps toward integrating information driven maintenance are delineated. Supply chain cooperation and coordination is seen as one of these steps and the RNLN plans to make progress in this field by cooperating in projects such as the MARCONI project and the Predictive Maintenance for Very Effective Asset Management (PrimaVera) project.

2.2 The RNLN

The Royal Netherlands Navy is a large organisation, consisting of more than 10.000 employees with either a civilian or a military background (Ministerie van Defensie, 2019). The foundations for the Royal Netherlands Navy were laid back in 1488, but the development into a proper naval power happened mostly in the 17th century, during the Eighty Years' war. The RNLN has always played a large roll in keeping peace at sea and has allowed the Netherlands to prosper as as trading haven in Europe (Nederlands Instituut voor Militaire Historie, 2010).

The size of the RNLN and its fleet has always fluctuated over time, being influenced by geopolitical events. The trend of the fleet size of the RNLN has been downwards for a long period (1955-2015). This was due to a multitude of factors, such as budget cuts, relatively low geopolitical tension and the increasing functionality of a ship by the improvement of technology (Marineschepen.nl, 2018). In the past years this trend has stabilized and recently an order has been placed for two new multi-purpose frigates (M-Frigates), which are expected

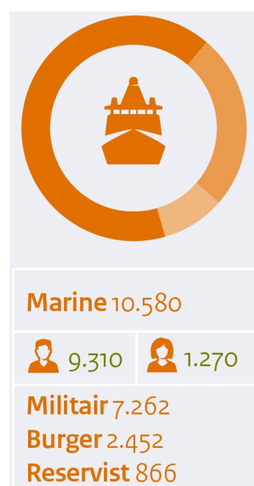


Figure 1: Personnel composition RNLN. Adopted from: Ministerie van Defensie (2019)

to be put in service in 2027 (Marineschepen.nl, 2020). Although still in design, these new M-Frigates will be fitted with RADAR systems produced by Thales.

The RNLN is mainly based at de Rijkszee- en Marinehaven in Den Helder, but it also has bases located in Amsterdam, Vlissingen, Texel, Willemstad, Rotterdam, Doorn, Suffisant and Savaneta.

A total of five sub-organizations together, form the whole of the RNLN. For this study only the Directie Operaties (OPS) and Directie Materiële Instandhouding (DMI) are of relevance. The other sub-organizations carry Managerial- and HR-related tasks, and operational and coast-guarding tasks in the Caribbean. Since the research is focused around the maintenance of the Thales radar systems, DMI is of our main interest. The effectiveness of this department influences the operational capacity of Directie Operaties.

DMI, which is also located in Den Helder, is responsible for the upkeep and maintenance of the Dutch fleet. There are three different levels of maintenance that are conducted within the RNLN, namely Organic Level Maintenance (OLM), Intermediate Level Maintenance (ILM) and Depot Level Maintenance (DLM). OLM is the lowest level of maintenance, which is performed by the crew of a ship (OPS) in order to keep a ship operational when it is not docked. ILM is done by both DMI and OPS and can take place on a day to day basis, but is mostly planned in an Assisted Maintenance (AM) period. AM happens once or twice a year, during the in-service phase of a vessel. After four years of service, a ship is made ready for DLM for its Benoemd Onderhoud (BO) period, which takes up about a year. The keys are handed over from OPS to DMI. During this intensive maintenance period, malfunctioning systems are repaired and the entire ship is serviced. After this period, the ship is ready to operate again for a period of approximately four years (Koning, 2020).

2.3 Thales

Thales is an electronics specialist that produces electrical systems for the aerospace, defence, transportation and security market. It is a multinational company, with its headquarters based in Paris, France. Thales Netherland B.V. (Thales) is a subsidiary, based in Hengelo. Thales was founded in 1922 as NV Hazemeyer's Fabriek van Signaalapparaten where they started the production of naval fire-control systems (Hurib Visser, 2000). After the second World War, the company was nationalized and renamed to Hollandse Signaalapparaten. The company continued their production of naval fire-control systems but also began working on other naval defence systems, such as sensors, RADARs and infrared systems. Since 1990, after its acquisition by Thomson-CSF, it is a subsidiary of what is now known as Thales, resulting in its current name: Thales Netherland B.V..

Nowadays Thales produces multiple advanced RADAR systems for, among other customers, the RNLN. Different ships require different radar systems, specialized for the function and necessities of the ship they are installed on. Most ships are fitted with a so-called Integrated Mast. This mast accommodates all major radar systems, sensors and antennas of the vessel. Thales produces a series of these masts, each type specialized for a specific function (Thales Group, 2008). Within the mast the systems have a mostly undisturbed line of sight and can be easily accessed from within for service or repairs. The systems within the mast are non-rotating. Some larger, rotating radar systems, like the SMART-L, are placed on the back of the vessel.

Some of the radar systems produced by Thales that are currently being used by the RNLN are:

SMART-L Long range aerial detection radar.

STIR Medium to long range fire-control radar.

APAR Multi-functional 3D radar.

The functionality of these systems is outside of the scope of this research. However it is important to keep in mind that different systems require different maintenance procedures and parts. Some systems, like the STIR are older than e.g. the SMART-L. This has an impact on the availability of spare parts.

2.4 Supply Chain Network design

To gain a basic understanding of the actors that we encounter and their role within the after-sales service supply chain, we refer to Figure 2.

When the RNLN needs a new RADAR system, either because a new type of vessel is being designed, or because an old RADAR system is being replaced, it tasks Defensie Materieel Organisatie (DMO) with procuring a new RADAR system from Thales, the OEM. The procured asset is then installed in cooperation with DMI and Thales, to be operated by OPS. During the asset's life-time, DMI conducts maintenance on the asset. This maintenance is conducted by 'Maritieme instandshouding'. When a part within the asset is broken, the part is either repaired by 'Techniekgroep sensor en Wapensystemen', or a new spare part is ordered by 'Maritieme Logistiek' to replace the broken part.

Thales role is to provide the RNLN with a after-sales service by either helping repair broken parts if 'Techniekgroep Sensor en Wapensystem' requests this, or by providing spare parts when 'Maritieme Logistiek' orders them.

Thales produces little of the parts that compose the final RADAR system that they offer to the market. It used to be the case that Thales produced many of the components in house. However, over the years there has been a shift in the business strategy of the company (Jongebloed, 2020). Nowadays Thales mainly designs and composes its RADAR systems by the use of parts produced by sub-suppliers. It orchestrates the design, assembles all of the parts and develops software that makes the system run. Because of this there is another link added into the after-sales service supply chain, named *Supplier of spare parts and components for radar systems.*

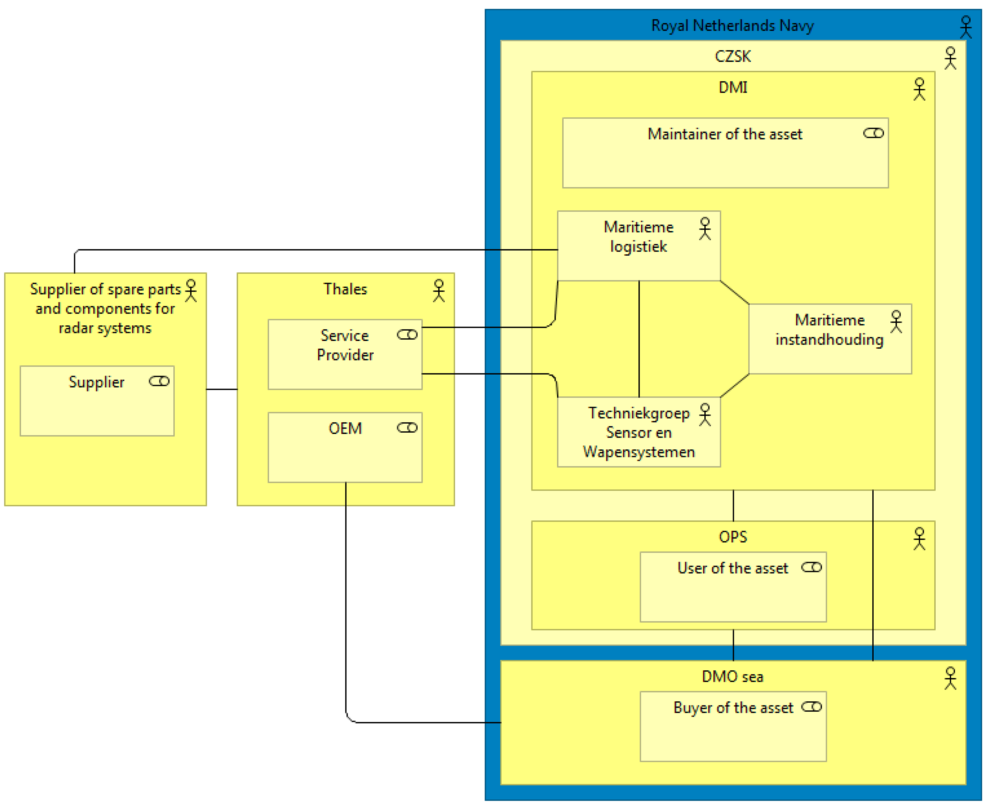


Figure 2: Supply chain network between Thales and the RNLN Retrieved from de Vries (2020)

3 Research Methodology

In this chapter we explain why conducting this research is relevant, and how we will approach the research from a research methodological perspective. The research methodologies we will be using during this research are the Managerial Problem Solving Method (MPSM) provided by Hans Heerkens' book: Solving managerial problems systematically (Heerkens & van Winden, 2017) and The Open Group Architecture Framework (TOGAF) Standard version 9.2 (The Open Group, 2018). The use of these methodologies are discussed in greater detail in Section 3.1.3. By the use of these methodologies, we start the research by identifying relevant problems encountered within the after-sales service supply chain. From these problems we construct a problem cluster. We then select a core problem from this problem cluster, that we aim to solve by the integration of the SCT environment. Furthermore, the research design is discussed.

3.1 Research approach

3.1.1 Background and relevance of the study

Through the years, advances in technology have allowed for better supply chain management by, for example, data driven supply chain analytics (Biswas & Sen, 2016), the development of Enterprise Resource Planning (ERP) systems (Moon, 2007) and the ease of sharing information digitally (Lotfi et al., 2013). This results in opportunities for improvement for the after-sales service provided by Thales towards the RNLN. For DMI specifically, one of the future possibilities would be a shift in the maintenance strategy, from a more reactive and time-based strategy, towards a predictive and condition-based maintenance strategy. Currently, in the maritime industry, predictive maintenance strategies are often seen as resource-demanding and difficult to implement (Mokashi et al., 2002). However, this view is slowly changing, meaning that more and more research is being done on the possible benefits of different maintenance strategies for the maritime industry (Jimenez et al., 2020).

These advances however are not only limited to the maintenance strategy but also encompass possibilities for other aspects of the after-sales. The implementation of information driven maintenance can influence the after-sales service logistics positively by e.g. sharing data between organizations and their departments in the respective supply chain. The MARCONI project proposes implementing a Service Control Tower to support these processes. However they wish to gain more knowledge on what the actual functionality of an SCT should encompass Pollmann (2020). This research aims to find practical applications and functions that an SCT could have and what their benefits would be with respect towards the after-sales service logistics between Thales and the RNLN.

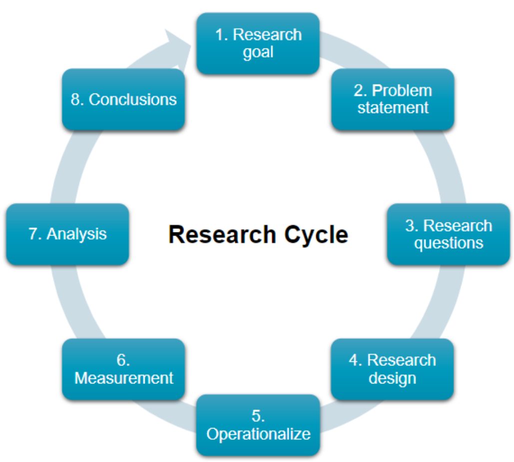
3.1.2 Research scope

The scope of this research is limited to the after-sales service between Thales and the RNLN. This includes the procurement of spare parts, obsolescence management, order tracking, and asset monitoring. Other aspects surrounding the maintenance of the radar systems, such as the difference in maintenance strategies, will be touched upon but not discussed in further depth. The focus lies at the processes performed in the after-sales service supply chain that precede the actual maintenance i.e., starting from the OEM (Thales) to eventually the mechanics at DMI, the asset owners. Within this scope, we look at what role a service control tower could play to improve the coordination of the after-sales service logistics.

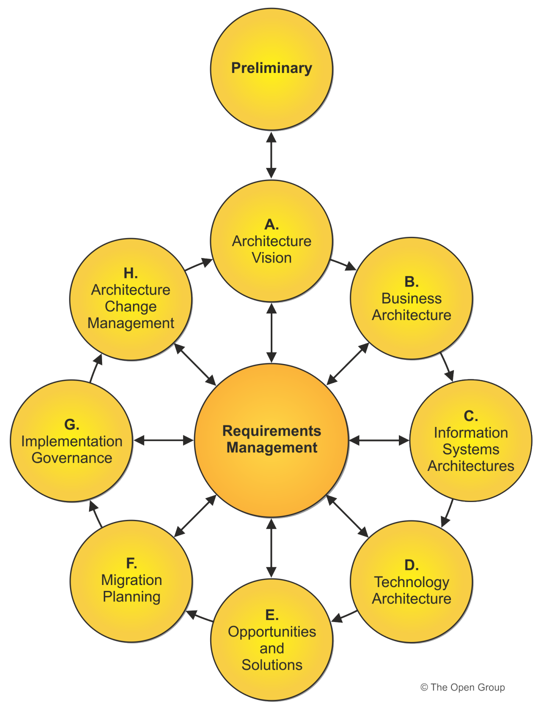
Simatupang et al. (2002) defines coordination, within the context of the supply chain, as an act of properly combining a number of objects (actions, objectives, decisions) for the achievement of the chain goal. An example of this would be the relating of historical spare part usage information (an object) with information about the factory specified Mean Time Between Failure (MTBF) values (another object), to arrive at a better future usage prediction (which is a goal of the after-sales service supply chain).

3.1.3 Research methodologies used

This research made use of two separate methodologies. The first methodology used is the MPSM, described by Heerkens & van Winden (2017). This methodology provides a framework for identifying and solving managerial problems. Within this methodology there is a distinction made between knowledge and action problems. Action problems are defined as problems where there is a measurable discrepancy between the norm and the reality. Within this research no such norm and reality exist, as we are faced with the problem of identifying possible functionalities of an SCT. We therefore deal with this problem as the methodology advises us to deal with a so-called knowledge problem. Within a knowledge problem, there is no measurable norm or reality, but there is a lack of knowledge or insight into a process (Heerkens & van Winden, 2017). As we learn more about the current functioning of the after-sales service, we might be able to propose ways that an SCT could support the current after-sales service logistics.



(a) Research cycle - MPSM



(b) Architecture development method - TOGAF standard

Figure 3: Methodologies used

For knowledge problems the theory provides us with a research cycle that we can follow. This cycle can be found in Figure 3a. In this research the MPSM was used as a structured way of doing the research required to get to the eventual conclusions and insights. Each step in the cycle can be linked to certain sections within this paper. Step 1 was discussed in Section 3.1.1 and step 2 is discussed in Section 3.2.1. The research questions (step 3) are formulated in Section 3.2.2 and this section is concluded with the research design (step 4) in Section 3.2.3. Step 5 and 6 are discussed in Section 4.4.4 and Section 5. Finally the analysis is done in Section 6 and the conclusions are drawn in Section 7.1

Where MPSM provides the researcher with a research cycle, the TOGAF standard offers the Architecture Development Method (ADM). This cycle can be found in Figure 3b. As the name suggests, this method supports the user in developing an enterprise architecture. (The Open Group, 2007). Since the integration of an SCT is of influence on the organizations' enterprise architecture, the ADM is of value for this research. We will use the ADM to match the vision of an SCT framework with the organizations' current business, IT and technological architecture.

The architecture vision has been discussed during Section 2.4 and Section 3.1.2. The business architecture, information systems architecture and technology architecture are described in depth in Section 5. We then formulate the opportunities and solutions within Section 6. In that section, we also formulate a way to migrate towards these proposed solutions. Finally we discuss the implementation governance in Section 7.2 and we propose an architecture change management plan in Section 7.3.

3.2 Problem identification

3.2.1 Problem cluster

Following the MPSM, we now construct a problem cluster based on our research scope. This cluster can be found in Figure 4. For the after-sales service, the RNLN is divided in two stakeholders, namely DMI and OPS. DMI's main goal is to do effective maintenance on the fleet on the RNLN. This in order to support OPS's main goal, which is to operate the vessels. A requirement for doing effective maintenance and having operational vessels is the functioning of the after-sales service, which is supported by the after-sales service logistics. We identify parts of this after-sales service to be the maintenance of the asset, obsolescence management, the procurement of spares, and the tracking of orders. After-sales service consists of more elements, such as inventory management, but for the sake of the time period this research was conducted in, we focus on these four elements. These parts of the after-sales service are based largely on data management and inner supply chain communication. They are therefore good candidates to be supported by an SCT.

All of the aforementioned elements have one thing in common. They all, in some way or another, produce and require data to function, and from the interviews we conducted we found that their primary reason of malfunction were mistakes with the usage, gathering, registration, communication, etc. of the data (Molenaar (2020), Koning (2020) Bisschop (2020), Kloosterziel (2020)). We aggregated this to one term, namely data management and we define the insufficient management of data as our core problem to tackle in this research.

We will now shortly describe the function of these four elements and their relationship with data management. In our research, we investigate how these elements function and what problems connected to data management are occurring presently. This is described in more detail in Section 5. We then use these elements as a direction in which to search for possible solutions that implementing an SCT could provide.

Procurement of spares

The procurement of spares is another core part of the after-sales service logistics. In this research, we view the procurement of spares as the process of ordering spare parts at the OEM. Within this function a lot of communication and interaction is taking place, both internally at the asset owner and with the OEM, to eventually come to placing an order. During these interactions a lot of data is generated and used, so we will research whether we can support this function by better data management.

Obsolescence management

With agings systems developing obsolescence problems, as introduced in Section 2.4, obsolescence management is required to ensure the spare part availability for a system throughout its lifetime. In this research we view obsolescence management processes as all the processes that support the eventual decisions made regarding the upkeep of RADAR systems that have obsolete spare parts. Data is used to support this by e.g. helping calculate the size of Last Time Buys (LTBs), by using the historical spare part usage, factory specifications, failure rates, etc (Molenaar, 2020). In this research, we will think of functionalities that an SCT could have that would support this function of the after-sales service.

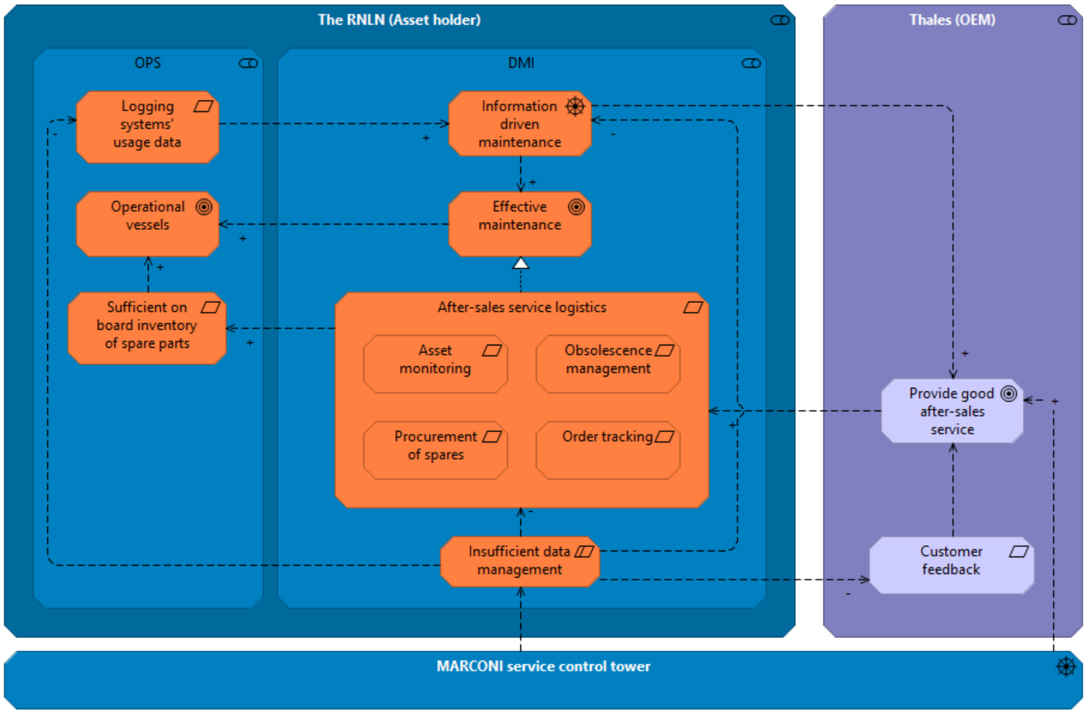


Figure 4: Problem cluster

Order tracking

After an order is placed, it is important to track its status in order to inform the supply chain of any useful updates, such as e.g. delays. We view order tracking as all the processes that follow and track the order, after the actual placement of the order. The communication between DMI and Thales during this is mainly based on the exchange of data, such as order status, order size, expected delivery dates, etc. This data has to be managed and we will look at what roll an SCT might play within this function of the after-sales service.

Asset Monitoring

Asset monitoring is key to keeping informed about the performance of the asset after its initial purchase and installment. In this research we view asset monitoring as observing how an asset, in this case a RADAR system, is functioning throughout its operational life, and keeping track of this data. Asset monitoring is useful to do, as this allows the asset owner to (i) give customer feedback towards the OEM and (ii) to do better Information Driven Maintenance (IDM). This is because proper asset monitoring results in useful information (e.g. failure rates, failure modes, spare part usage) for links further down the supply chain. From the interviews we conducted however, we learned that improvements can be made regarding the registering, processing, and communicating of this data.

Lastly within Figure 4 we define information driven maintenance as a driver for more effective maintenance is.This concept was discussed in Section 2.1 and in Section 3.1.1. Information driven maintenance can be broadly applied across the maintenance processes of DMI. To implement successfully information driven maintenance, OPS has to collect usage data about the systems on board. This data can than for example be used to provide feedback on the predicted spare part needs in the future. Information driven maintenance however does not only support predictive functions of e.g. spare part needs, but the concept also applies to the problems noted in Figure 4. Having correct and updated usage data, being aware about the obsolescence of parts in your systems, having more insight in the state of the orders and processing feedback from the supplier of your spare parts are all linked to information driven maintenance in the sense that they increase coordination by proficient data management.

3.2.2 Research questions

With our research goal and problems in mind, we now formulate the research questions that we wish to answer in this thesis. The goal of the research is to explore what functions an SCT could incorporate to support the coordination and performance of the after-sales service logistics. From this we derive the following research question: *How can a service control tower support the coordination of the after-sales service logistical processes?* In order to come to an answer to this research question, we constructed three sub-research questions to base this thesis on. These were formulated as:

1. What is a Service Control Tower (SCT)?
2. What can the literature tell us about the role of an SCT within after-sales service logistics?
3. What does the current supply chain network look like?
4. What does the business, information systems and technology architecture at DMI look like?
5. How can an SCT support the four described elements of the after-sales service logistics on a data managerial level?
6. How can we communicate data between the asset owner and the OEM within the after-sales supply chain?
7. Can there be ownership of an SCT, and if so which party within the supply chain should take this ownership?
8. What further research should be done on this subject?

3.2.3 Research design

To answer these questions, the research is conducted in two main ways. First of all, a literature study will be performed to understand the underlying concepts and some of the main principles of after-sales services. During the literary study, peer-reviewed articles will be preferred. On the concept of control towers however, not a lot of research has been done. Therefore other sources, such as white-papers and seminars will also be included in the research. Secondly, interviews will be conducted with the stakeholders, to help gain insights on the current situation concerning the after-sales service and on the organization's needs. From these conversations we will distill opportunities for improvement. Summaries of these interviews are presented in appendix C. This type of qualitative research has its limitations. Mainly that interviews are often based on an individual's perception. We discuss the implications of these possible biases in more depth in Section 7.2.

4 Literature Review

Now that we formulated our problem cluster and research questions, we conduct a literature review. This literature review serves this research with two purposes, namely (i) to supplement our knowledge on the fundamental concepts that our researched is based on, and (ii) to see if in the literature studied cases already exists that are alike our research, which might provide methods, advises, or even solutions that can assist us in coming to our own conclusions.

Firstly we studied the literature concerning the topic of control towers and their specialized Service Control Tower variant. We included white-papers within this search. On top of papers we contacted an expert, and author, on the field of SCTs. The literature shaped our view on the concept of an SCT and provided us with a method of measuring the maturity of an SCT, which we used throughout the research.

Secondly, we researched the concept of after-sales service logistics in order to gain a better understanding of the elements that compose these logistics, and their importance. Moreover, we used the literature to help set a definition of after-sales service logistics which we used throughout the research.

Thirdly, we studied the concept of obsolescence, as this is more heavily focused on in this research. This gave us insights in the costs and impact of obsolescence on the operationability of the RADAR systems. It also explains some common concepts and terms within obsolescence management such as Last Time Buy.

4.1 Service control tower

The term Service Control Tower has already been used extensively during the previous chapters, however no clear explanation of what this SCT is, has been given. To help visualize what an SCT is we first look at what the control tower element means. If we dissect the term, we can gain some basic understanding of its role in the supply chain. The comparison between a control tower and an air traffic control tower is made by de Vries (2020). Where an air traffic control tower monitors and guides planes, the control tower we discuss guides and monitors logistical processes. We propose the following visualization:

Tower implies that the control tower has a good overview of the logistical processes going on at an organization. This is often referred to as a organizations supply chain visibility. One could say that the ”higher” an organization builds its control tower, the more visibility it will have on its supply chain, and the further down the chain it can ”see”.

Control implies that the system gives the user some form of control over the processes that are being monitored. This can for example be realized by giving the user warnings when the planning is no longer adhered, or, in further integrated variants, giving the users proposed actions to support the supply chain processes. The amount of control that should be allocated to the control tower might differ between organization. Where some organizations might prefer limiting the control of the control tower to simple warnings and notifications, others might prefer fully integrated, or even automated decision support.

When talking about after-sales service logistics, the term *Service* Control Tower is used. Accenture (2015), cited by Topan et al. (2020), defines a service control tower as a centralized hub that uses real-time data from a company’s existing, integrated data management and transactional systems to integrate processes and tools across the end-to-end supply service chain and drives business outcomes.

In this paper, Topan et al. (2020) discuss the challenges in the field of operational spare parts planning. Some examples of the framework of an SCT are proposed that we integrate in this research, as it is our believe that a similar framework can also be used for the other elements within the after-sales service that we discussed in Section 3.2.1. The proposed framework is divided by two types of elements, namely the practice-driven elements and the model-driven elements.

Under practice-driven elements, four elements are identified. These are Key Performance Indicators (KPIs), interventions, triggers for interventions, and information content.

We reviewed the KPIs given by Topan et al. (2020) (fill rate, time-based fill rate, downtime waiting for parts, call resolution time and transportation performance) and wish to adjust and expand on these KPIs so that they cover the after-sales service more broadly, and fit the business environment of the RNLN. We think that KPIs such as the fill rate and the time-based fill rate are good starting points for monitoring the after-sales service performance. Furthermore we believe that a KPI such as downtime waiting for parts can be even more beneficial as it helps to stress the importance of a well functioning after-sales service supply chain towards all parties involved. We keep this in mind when investigating new KPIs that fit the elements of the after-sales service that we aim to support with the SCT.

An integral part of the framework discussed by Topan et al. (2020) is the ability of the SCT to intervene and alert the supply chain. These interventions are supported by the monitoring of the after-sales service processes and can be triggered by special events occurring or by KPIs exceeding a threshold value.

Lastly, information content is discussed. Topan et al. (2020) describe this as the different types of real-time information that is collected in the business layer and is processed and stored in the data perception layer of the SCT. Examples given for the operational spare parts planning are on-hand and pipeline inventory levels in each warehouse, and status information about return, resupply and repair processes, completion times. We see ways to integrate this theory into the after-sales service, but we think it is important to firstly investigate the level on which this information content is currently collected.

The model-driven elements described by Topan et al. (2020) are interesting in that they provide five model characteristics on which decisions should be made regarding the design approach of the SCT. To illustrate with an example, the planning horizon of the SCT has to be decided on. Topan et al. (2020) identifies three categories, namely (i) a finite horizon with a single decision opportunity, (ii) a finite horizon with multiple decision opportunities, and (iii) an infinite horizon in which the horizon length is not specified and a steady state analysis is assumed. These elements are interesting to think about when designing the SCT but we decided to not discuss them in any further depth, as the practice-driven elements suffice our research scope of finding practical ways that data management could be improved by an SCT. We do however advise that further research conducted on the eventual implementation of the SCT take these elements in to account within their research.

To extend our view on the functionality of the SCT we reviewed the white paper by Driessen & Keizer (2019). Driessen & Keizer (2019) describes the SCT with three main functionalities, stating that: A Service Control Tower is a central after-sales service support system for physical assets that uses (semi) real-time information from multiple sources in order to (i) monitor relevant aspects of after-sales service, (ii) anticipate on after-sales service issues, and (iii) support operational service decisions.

The question arises whether an SCT has to be a separate entity within the business architecture of the organization it is implemented, as both Topan et al. (2020) and Driessen & Keizer (2019) respectively describe the SCT to be a centralized hub / central after-sales service support system.

As the literature unfortunately could not provide us with an answer to this question, we contacted an expert and co-author in this field. From this interview we concluded that the important definers of an SCT are the three functions described above, and not necessarily the self-containment of this system (Keizer, 2020). This is a very important finding within our research as this means that an SCT does not have to be a separate, stand-alone entity on which discussions of ownership can exist. On the contrary, it can be an extension on a already existing system, such as an Enterprise Resource Planning (ERP) system, which merely exercises the three key elements described in the definition given by Driessen & Keizer (2019). Based on this definition, we can determine that our SCT can exist within the existing business architecture, as long as this architecture has processes in place to monitor, anticipate and support their service logistical processes.

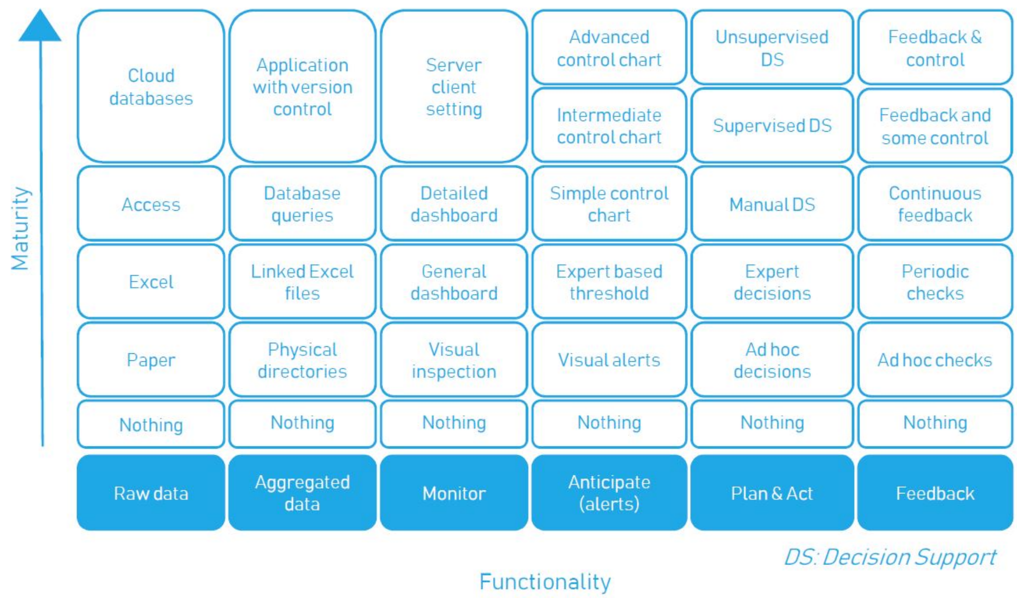


Figure 5: Maturity grid for a service control tower. Retrieved from Driessen & Keizer (2019)

By combining these insights with the literature provided by Driessen & Keizer (2019) we can conclude that an SCT does not neccesarily have to be a separate entity within the business architecture of an organization. Instead it can be seen as a concept that is gradient based on how well service logistic are supported and developed within said organization. Driessen & Keizer (2019) provide a method to measure the maturity of the individual service logistical supporting processes that together describe the maturity of an SCT. These can be seen in Figure 5.

The first two columns of this maturity grid describe the level of the data storage and data integration methods. Sufficient maturity in these two functions, can be seen as prerequisites to attain higher levels of any of the SCT functions. Supervised decision support for example, can only be attained if raw data and aggregated data are digitally accessible and properly kept.

The following columns describe the level of maturity of the fundamental SCT functions, namely process monitoring, data analysis and decision support. The base levels of these functions are solely supported by human enactment. They rely on an employees visual inspection and alerts (e.g. physically checking the stocks in the warehouse and noticing that certain shelves are empty), and ad hoc decisions and feedback on the situation. The further the SCT matures, the more actions it will start to automate and process behind the screens, eventually leading to unsupervised decision support and real time feedback and control over the service logistical processes based on advanced control charts and monitored by a server client setting.

4.2 After-sales service logistics

To help better understand what we mean when we talk about after-sales service logistics, we divide the term into two parts, namely *after-sales service* and *logistics*. When speaking about after-sales service we are talking about the activities that support products after they are delivered to the customer. Logistics, imply all the logistical processes that take place behind the scenes to make the after-sales service possible. In this thesis we discuss the service Thales provides the RNLN after the initial sale of their RADAR systems and the logistics required to provide this service. In certain industries after-sales service is more critical than in others (Cohen & Lee, 1990). The maritime industry is one of those industries, since the assets are (i) of high value, (ii) have a long ELOT, (iii) are few in produced numbers and (iv) are technically complex (Mokashi et al., 2002). These factors stress the importance of well managed after-sales service.

The after-sales service comprises of many supporting processes, but as discussed in Section 3.2.1 we focus in this research on asset monitoring, obsolescence management, order tracking, and the procurement of spares. Therefore the logistical processes that support these elements, are aggregated within this research as the after-sales service logistics.

After-sales services have always existed, but have mostly been viewed as a necessity that a business has to provide its customer with in order to retain a healthy relationship and continue its business. A recent shift in paradigm however has painted after-sales services as less of a costs entailing necessity, but more and more as a potentially major source of profit (Jalil, 2011).

Especially for complex systems, such as naval vessels and RADAR systems, profitability has become a driver for servatization. This is because a relatively large part of the Total Cost of Ownership (TCO) consist of the maintenance and downtime costs. A study done by Öner et al. (2007) gives us a good estimate of these ratios, stating that in a case study of a complex Engineer-To-Order (ETO) system the maintenance costs and downtime costs can often overwhelmingly exceed the initial acquisition costs (see Figure 6 and Table 1).

This case study is, on many levels, comparable with the situation we investigate in this thesis. Although not all RADAR systems are Engineer-To-Order, the integrated masts produced by Thales often are Engineer-To-Order in accordance with the ship they are placed on, and all other large RADAR systems that Thales supplies to the RNLN are at least Made-To-Order (MTO).

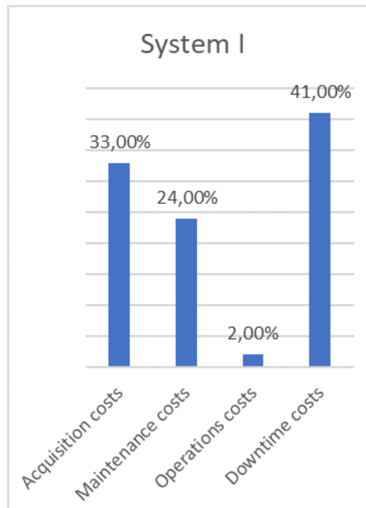


Figure 6: TCO distribution. Adopted from: (Öner et al., 2007)

The distribution of costs shown in Table 1 stress, once more, the importance and extent of after-sales service logistics, as proper after-sales service logistics can minimize downtime and maintenance costs (Jalil, 2011).

Table 1: Percentages of the cost buckets. Abstracted from Öner et al. (2007)

	Including the operations costs and the downtime costs		Excluding the operations costs and the downtime costs	
	System I	System II	System I	System II
Acquistion costs	33%	-	58%	55%
Maintenance costs	24%	-	42%	45%
Operations costs	2%	-		
Downtime Costs	41%	-		

4.3 Obsolescence

4.3.1 Types of obsolescence

Obsolescence plays a large role in the after-sales service logistics, especially within the electronics industry. Broadly speaking obsolescence describes the state of an item which is no longer wanted / valuable. This state can be induced by company strategy (e.g. planned obsolescence) or by advances within a items environment that make the original part outdated and unwanted. Within the literature many different definitions can be found and different types of obsolescence have been identified. Schallmo (2018) summarized these types of obsolescence, which can be found in Figure 7. For this research we only look at two types of functional obsolescence, as the other types of obsolescence discussed in the respective paper are of no interests for our research (e.g. social obsolescence). Schallmo (2018) describes the two types of obsolescence we focus on as:

Technical obsolescence
: Products become technical obsolete from the engineering point of view (the product is not state-of-the-art anymore) and from the usability point of view (the product is not comfortable to use).

Compatibility cause obsolescence
: Compatibility caused obsolescence: products that are compatible to a basis product become obsolete when the basis product has been technically developed. Products also become obsolete when spare parts are no longer available.

An example of technical obsolescence would be the introduction of a new RADAR system developed by Thales. The LW-08 for example is the predecessor of the newer L-band RADAR: the SMART-L. On newer vessels, the SMART-L is installed, but the LW-08 is still operational to this day on the M-Frigate van Speijk. However, as the LW-08 is no longer in production, the after-sales service for this installation is heavily influenced by technical obsolescence.

Even on newer systems compatibility caused obsolescence often plays a role. A RADAR system produced by Thales is composed of thousands of smaller sub-components. These components often have their own suppliers and therefore their own obsolescence issues. An example would be the obsolescence of a single Integrated Chip (IC) located on a circuit board. Technological advances can render this original IC obsolete for the its manufacturer. In this scenario Thales can no longer produce the circuit board with the original IC on it, rendering the entire circuit board obsolete.

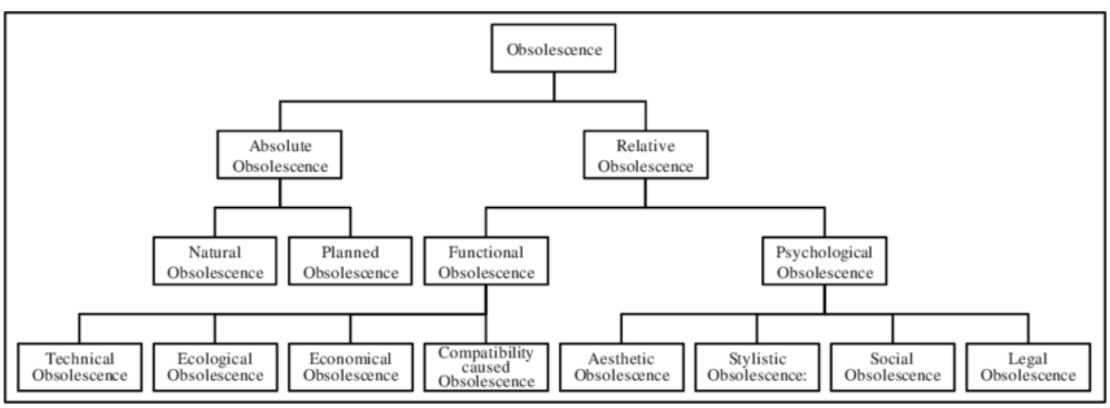


Figure 7: Obsolescence types identified by the literature. Retrieved from Schallmo (2018)

4.3.2 Life-cycle of an item

In Figure 8 the typical life cycle of a product is described. Obsolescence management focuses on the last two phases described by the figure. During the phase-out the OEM notifies the asset owner that the product will be discontinued. This is often done by giving the asset owner a Last Time Buy (LTB) date and a discontinuance date (e.g. item x will be discontinued 1 the first of November 2020, and the last possible order date (LTB) is set on the first of june 2020).

A last time buy gives the asset owner a last chance of stocking up spares for the remaining life cycle of the asset. The size of an LTB is commonly based on the historical use of a part (Rojo et al., 2009). This can be based on data provided by the OEM (order history & factory specified failure rates) or usage data gathered by the asset owner (observed failure rates).

The costs of miscalculating an LTB can be detrimental for an asset owner. If the item in question is expensive, having an oversized LTB brings with it high unnecessary costs and wastage. After the ELOT of the system has passed the asset owner remains with too many, now useless, spares. However if an LTB is undersized, or the ELOT of a system is postponed the asset owner will not have sufficient spares left to maintain the system and keep it operational. Not only is this downtime expensive for capital intensive goods, such as the fleet of the RNLN, it can also be outright dangerous for the personnel to operate a vessel with non-operational RADAR systems. Improving the accuracy of LTB calculations is therefore of great importance.

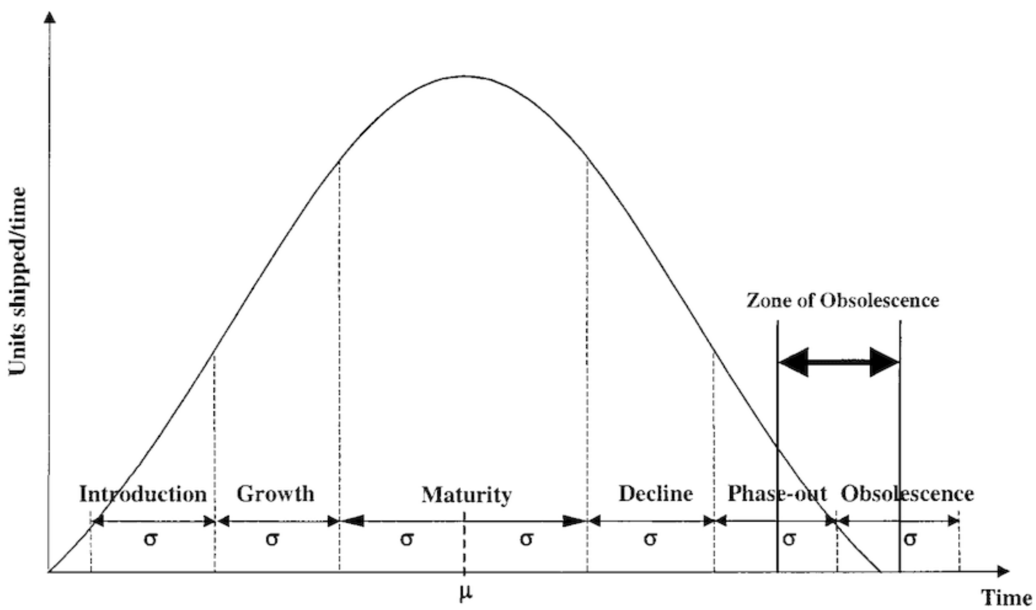


Figure 8: Obsolescence curve of a items life cycle. Retrieved from Pecht & Das (2000)

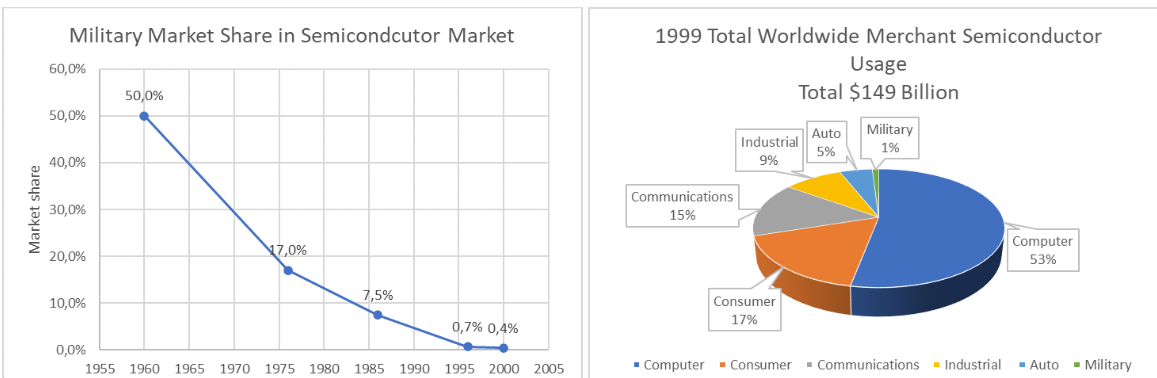
After the phase-out period, the obsolescence period is entered. During this period the product is no longer produced by the manufacturer. Logistical maneuverability is very limited in this phase and asset owners are basically stuck with the inventory that was stocked up during the previous phases. The product remains in this phase during the rest of its life cycle. Spares might still be found and bought on the after market, but pricing for this is often very high, if applicable at all (Pecht & Das, 2000).

4.3.3 Obsolescence in military and maritime industry

For military systems in particular, obsolescence is becoming an increasingly large issue. This is because historically speaking military institutes have often been able to use systems specifically designed for military consumers (Ozkan & Bulkan, 2016). However, with the increased development speed of technologies and with continuous defense budget cuts, military institutes have increased the use of and dependence on Commercial Off-The-Shelf (COTS) products. Thales is an example of this, producing not solely for military customers, but also producing many of their systems commercially. This shift in procurement policy brings with it new challenges in obsolescence management, as life cycles of COTS products are generally much lower then military specialized products.

In Figure 9 the change in market share that the military sector has experienced within the semiconductor market is illustrated. As we can see the market share of military institutions has plummeted throughout the year. This is both because of declining military budgets, but also because of the exponential growth of electronic applications within other sectors. This shift in balance of the semi conductor market has made military specialized electronics a niche market, which has created the necessity for military institutions to look at COTS electronics as an alternative.

Petersen (2000) concludes that in the long run the use of commercial components within military systems will become a necessity, resulting in additional challenges for obsolescence management. Furthermore he states that there is no other way than to accept this challenge, since the military semiconductor supply base is expected to continue to erode in the future.



(a) Market share through time

(b) Market share compared to other sectors

Figure 9: Military market share in the semiconductor market. Abstracted from (Petersen, 2000)

4.4 Data management

In Section 3.2.1 we discussed in some extent the role of data management within the supply chain. We constructed our view on data management based on the interviews we conducted throughout the research and defined it as the usage, gathering, registration, and communication of the data produced and required by the links in the after-sales service supply chain. Here we dive a bit further in depth in the different types of data we encounter throughout the research, what the literature can tell us about data collection and data communication within a supply chain, and what current methods are offered to standardize and transact data between organizations.

Before we dive into these details however, we would like to stress that proper data management within an organization does not only allow for, but can be seen as fundamental to information sharing between links in the supply chain. R. S. Kumar & Pugazhendhi (2012) performed a literary study on how information sharing might influence the performance of a supply chain. They found that, depending on the type of information shared, how the information is shared, and with whom the information is shared, information sharing within the supply chain can bring about a significant amount of advantages to the entire supply chain.

Lotfi et al. (2013) findings are in line with this, also stating that information sharing may bring a significant amount of advantages to the the supply chain. Examples given are advantages such as inventory reduction and efficient inventory management, cost reduction, increasing supply chain visibility, significant reduction or complete elimination of bullwhip effect, improved resource utilization, increased productivity, organizational efficiency, improved services, building and strengthening social bonds within the organizations, early problem detection, faster response, reduced cycle times from order to delivery, better tracing and tracking, earlier time to market, expanded network, and optimized utilization of assets.

With this in our mind, we now describe some of the elements of data management in more detail.

4.4.1 Enterprise Resource Planning system

Organizations can choose from a variety of tools to support its data management. One of these tools we are interested in during this study is the Enterprise Resource Planning (ERP) system. Ranjan et al. (2016) defines an ERP system as an enterprise information system designed to integrate and optimise the business processes and transactions in a corporation. Processes throughout the entire organization can be supported, coordinated and managed by the use of an ERP system. An ERP system runs on and interacts with a database, in which data can be stored and analyzed. ERP systems are dynamic and can be tailored to fit the requirements and needs of the organization that it is implemented in. The literature is clear about the benefits of an ERP system for an organization. It realises these benefits in terms of improved productivity of its processes and an increased competitive advantage against competitors that function without ERP systems (Moon, 2007).

There are many ERP software providers. Some notable ones are Systems Applications and Products in data processing (SAP), Oracle, and Microsoft Dynamics. In this research our focus is on SAP, as the RNLN makes use of this ERP software. Thales, the OEM makes use of Oracle.

Within ERP systems, there are different types of data. For the scope of the research we aggregate these data types under two main groups, namely master data, and transactional data. These are discussed in the following sections.

4.4.2 Master data

P. Kumar (2014) defines master data as information that is at the foundation of the functioning of business intelligence applications, by the way in which it interacts and connects with the transactional data from its business environment. Guru (2020) gives a more concrete definition, based on the SAP environment, by stating that master data is the core data that is used as a base for any transaction. If one is producing, transferring stock, selling, purchasing, doing physical inventory, etc., certain master data is always required for these transactions to be done. Within SAP examples of this master data are:

Material master data (E.g. a spare part's size, weight, configuration, material composition, etc.)

Customer master data (E.g. Address of customer, warehouse locations, contact details, etc.)

Vendor master data (E.g. parts catalogue, estimated lead times per part, adress of vendor, etc.)

Pricing/conditions master data (E.g. part prices, contract framework agreements, process cost estimations, etc.)

Table 2: Types of data generated at different stages of a supply chain. Retrieved from Biswas & Sen (2016)

Node	Data Generation
Supplier	Design data, Order status, Stock level, Schedule, Shipment & Routing, Return/Dispose, Finance data (e.g., a/c receivable, tax, pricing etc.)
Manufacturer	Basic/Activity data, Design data, forecasting data, Prod. Plan/schedule, Capacity planning data, Process data (Lot size, cycle time, takt time, throughput time, process capability etc.), Yield data, Quality/Reliability data (FTR, % rejection, % failure etc.), Stock (RM/WIP/FG), Maintenance records, Customer feedback data, Vendor data, People data, Finance data (wage, conversion cost etc.), Return/dispose
Warehouse / Distributor	Demand, Stock level, Schedule, Shipment & Routing, Order, Return/Dispose, Customer feedback, Finance data (pricing, payment etc.)
Customer	Point of sales (POS), Order status/ Demand, Product feedback, Customer opinions, Payment, Delivery, New product, Promotion/Recommendation, Return/ Dispose

In this research we refer to all of these data types simply as master data, as only the basic understanding of the difference between master data and transactional data is needed in order to help design the SCT architecture. We summarize therefore, that we see master data as data that acts as a basis for any transaction occurring in the ERP system.

4.4.3 Transactional data

The second data type we encounter is transactional data. Transactional data contains data about how, when, by whom, etc., processes are performed. It registers for example when a process was performed by someone within the organization. This data can be used to track how processes are being performed (Sluijter, 2020).

To exemplify this and to contrast this to master data, we refer to appendix D. The dashboard displayed here shows, among other measured performances, the amount of proposed orders by SAP that have not been processed within five days. This is all based on transactional data, which contains the moment the order was proposed by SAP and the moment when the order proposal was processed. The contents of the order itself (e.g. what part is ordered) is an example of master data.

4.4.4 Data generation and communication throughout the supply chain

Biswas & Sen (2016) states that the sharing of data within a supply chain can help improve the supply chain visibility. For parties to be able to transmit and interpret information, data standardization is required. In the literature we found guidelines for standardizing processes and data streams within service logistics. The sx000i initiative is a multifaceted approach to standardize logistic support processes in order to ensure compatibility and commonality throughout the supply chain (AeroSpace & Defence Industries Association of Europe (ASD) and Aerospace Industries Association (AIA), 2018). The specification has been developed by multiple defence oriented organizations such as Rockwell Collins, Lockheed Martin, Airbus and even the German Bundeswehr.

By specifying logistical processes and standardizing the respective data, agreements can be made about the sharing of the data. Application Programming Interfaces (APIs) can be constructed that function as communicators between information systems, such as ERP systems (Sturm et al., 2017).

5 Current Situation

In this section the current situation concerning the four previously discussed elements of the after-sales service is described. Following the Architecture Development Method (ADM) we will describe the current business, information systems and technology architecture of these after-sales service processes. We discuss each element individually with the following structure. Firstly we introduce the after-sales service element and describe the reason for its existence and the problems that it tries to solve (e.g. arising obsolescence issues, and the influence of these issues on both stakeholders). We then describe the business and information systems architecture of these elements, resulting in a clear overview on how each element is currently constructed and functioning (e.g. how obsolescence management is currently implemented between the RNLN and Thales). We discuss the technology architecture separately, as this architecture is the same for all four elements. Lastly we identify opportunities for improvement by describing the issues found within each after-sales service element. The solutions for these opportunities of growth are described in Section 6.

After we have discussed all four elements with the previously described structure, we will be able to grade the current maturity of the Service Control Tower (SCT) using the maturity grid shown in Figure 5, provided to us by Driessen & Keizer (2019). This is part of phase five and six of the research cycle described by Heerkens & van Winden (2017), and discussed in Section 3.1.3, as we operationalize the research using the maturity grid and conduct measurements of this maturity by using phases B, C and D of the ADM.

5.0.1 A quick note on the SCT

Before we investigate and model our after-sales processes, we would like, once more, to explain our perspective on what an SCT is, and how we will grade it, based on the current architecture. We touched upon this subject in Section 4.1 but we wish to raise this point once more, to help put the coming sections into more perspective.

During our research we came to the conclusion that an SCT does not have to be a separate piece of software which an organization either has or not. Rather, we see the concept of an SCT more as a way to measure how well an organization has visibility of, and control of its in this case after-sales service logistical processes. This is also the reason why we can use the methodology provided by Driessen & Keizer (2019) to grade the SCT. It can therefore be perfectly possible that both Thales and the RNLN already posses some form of an SCT within their current enterprise architecture. The (empty) maturity grid shown in Figure 5 visualizes this, showing the SCT more as a gradient ranging from undeveloped to completely mature.

Therefore, when talking about measuring the SCT in this section, we mean the investigation of how well currently some typical SCT processes are integrated and supported within the enterprise architecture of the RNLN and, in a lesser extent, Thales. By modelling the current enterprise architecture, we can grade the maturity of the existing SCT elements. Based on this we determine where there is room for improvement and what processes could be further supported by SCT functions.

5.1 Procurement of Spares

The procurement of spare parts is at the base of almost all maintenance processes. This is because, except for parts that can be repaired, all spare parts that are needed to conduct maintenance have to be procured. de Vries (2020), in his thesis, explained in depth the processes behind the procurement of spare parts from the perspective of Thales, the OEM. In this section, we wish to explain and model the processes from the perspective of the RNLN.

In this section we focus on the procurement of spare parts. We also briefly describe the initial procurement of an entire RADAR system, as this is needed to fully understand how a brand new system is installed, mapped and integrated within the business and information systems architecture. This is important as a lot of the procurement process of spare parts is based on the data communicated during this initial installment.

5.1.1 Business Architecture and Information Systems Architecture

From the aforementioned processes we now map our business and information systems architecture in ArchiMate. Figure 10 shows the current procurement process. We divided this in to two main process flows, namely the procurement of individual spare parts, and the procurement of an entirely new system.

To start with the procurement of a new system, we illustrate the following. Defensie Materieel Organisatie (DMO) sea is responsible for procuring a new RADAR system, as this is a big purchase. This is done after negotiations with the RNLN, Original Equipment Manufacturer (OEM), and the Dutch government in order to allocate the proper funds.

When a new system is purchased, Thales helps to install the system at the RNLN and it provides the master data required to map the new system within Systems Applications and Products in data processing (SAP), the ERP system of the RNLN. They provide, for example, data about the system's configuration (what parts make up the system), the factory specified Mean Time Between Failure (MTBF)s of the parts and the expected lead times for ordering these spare parts. Information about the system configuration is initially communicated and mapped within SAP on a Line Replaceable Unit (LRU) level (Koning, 2020). During the lifetime of the system the smaller sub-components that make up the LRU, also known as Shop Replaceable Units (SRUs), are sometimes mapped manually by system engineers when deemed necessary. This can be the case for SRUs which might frequently be repaired, and can be ordered separately. In this case a system engineer is able to map the SRU in SAP.

The second part of the procurement process that we modelled is the procurement of individual spare parts after a system has been installed. Directie Operaties (OPS) operates the system and monitors any break downs of parts. By doing this they are supposed to keep failure rates and failure modes. From interviews we learned however, that this is not always done properly (Bisschop, 2020).

When Benoemd Onderhoud (BO) and Assisted Maintenance (AM) are planned by DMI, work orders have to be formulated by a work planner. To bring overview in what needs to be done to service a vessel, project teams at DMI classify the maintenance into six sub-divisions. These are:

SWS Sensors and Weapon Systems (e.g. SMART-L & Goalkeeper)

Mechanical Large mechanical systems (e.g. engines, pumps, the rudder)

C4I Communication Systems (e.g. Satellite communication)

Specials Guided weapon systems (e.g. torpedo's)

Casco Structural build of the ship (e.g. hull maintenance)

Electrics General electrical projects (e.g. lighting on the ship)

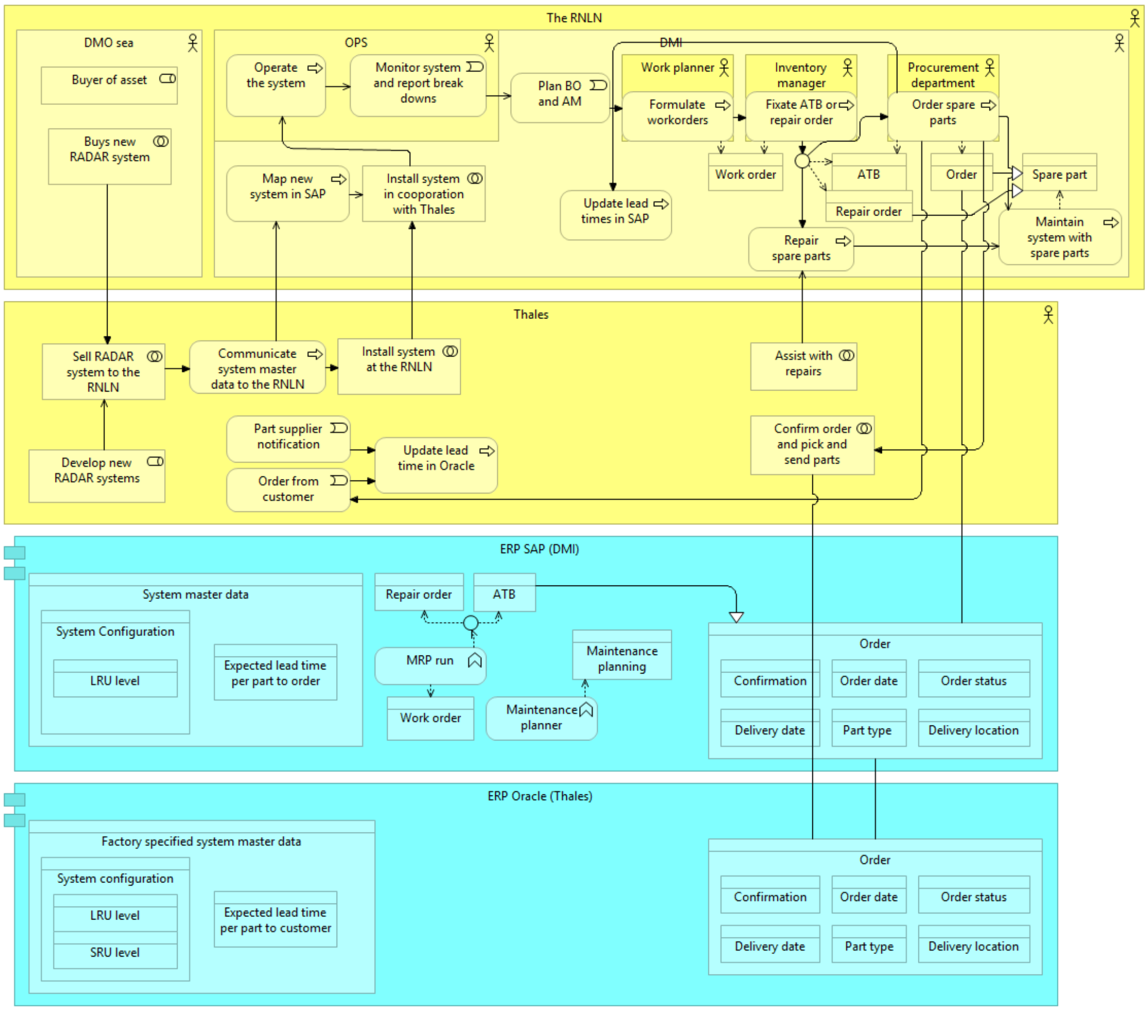


Figure 10: The current procurement process (of spare parts)

The RADAR systems from Thales fall under the Sensors and Weapon Systems (SWS) division. This division is tasked to maintain and service these systems in order to be able to deliver functional and operational systems when the ship is done with its maintenance period. A further breakdown of how maintenance is planned within DMI is illustrated in Figure 11. From left to right, we start with the aggregated maintenance of an entire ship. This is then subdivided in the maintenance projects noted above. We look at SWS in particular, since they are the ones responsible for maintaining the RADAR systems. Their projects are further divided in work orders. Work orders describe maintenance procedures such as servicing a system, repairing parts if they are recorded as broken, checking oil etc. These work orders are composed of the work order requirements. These requirements are linked with SAP, and allow for communication with a multitude of databases that can be found in appendix E.

All of the work orders together, aggregate to the entire maintenance period for one vessel. By correctly filling out every work order DMI knows in advance what materials and spare parts they will need when they start e.g. maintenance project: multi-purpose frigate van Speijk.

As seen in appendix E, the work orders together are processed by a planning system within SAP. This planner takes the work orders as an input and in turn constructs a coherent planning for the

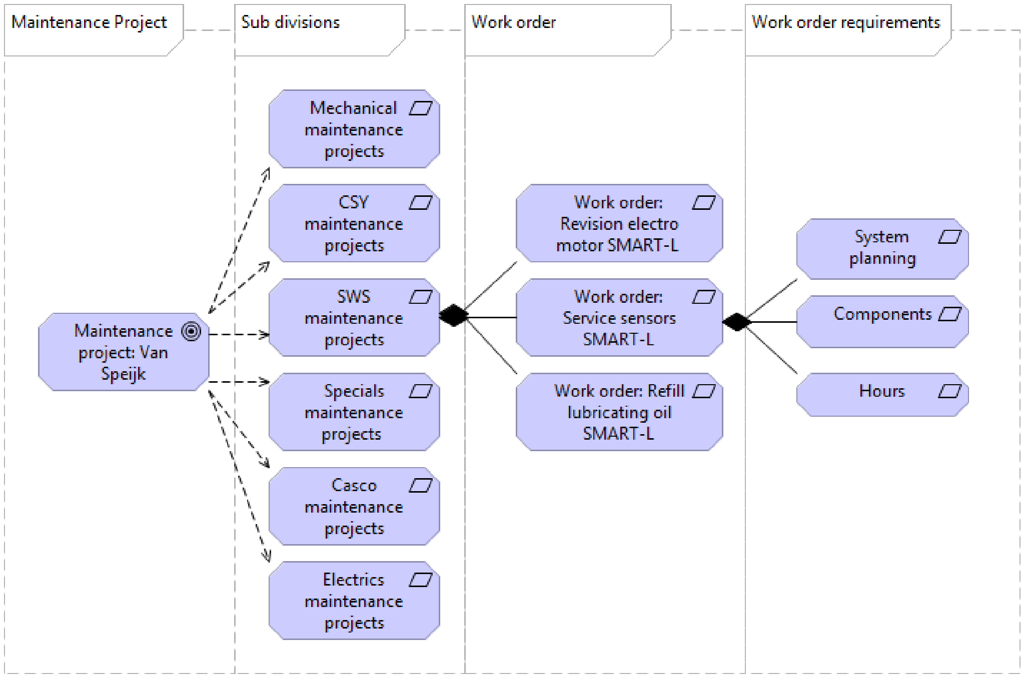


Figure 11: Breakdown of work order

Table 3: Two example work orders described with their required actions

Work order	**Actions required**
Replace circuit board x	Dismantle front panel, open circuit board tray, dismantle circuit board x, install new circuit board, close tray, install front panel.
Replace front panel	Dismantle front panel, install new front panel

entire maintenance project. To plan this, the input variables shown in Figure 11 are taken into account. The variable "system planning" means where the work order is located planning-wise within a system. An example of this would be the swapping of certain circuit boards in relation to the replacement of a front panel on a computer. See Table 3 for these two simplified work orders. When both orders are entered into the system, the planner "knows" that it is better to swap the circuit boards when the front panel of the computer is still disassembled. It will then plan the work order *Replace circuit board x* within the work order *Replace front panel*. This is an important functionality of SAP, and it gives the work planners a bit more flexibility. We keep this functionality in mind when we discuss potential benefits of an SCT.

The logging of new work orders is a constant process. Logging work orders of a ship that will be entering its maintenance period is spread out over a period, and during the actual maintenance new work orders are constantly produced when a maintenance crew finds something that needs to be repaired. An example of this would be the initial work order of inspecting a system, that results in multiple work orders for the replacement of some of the inspected parts, that were found in need of repairs during the inspection.

To process these constantly incoming work orders, SAP does a daily Material Requirement Planning (MRP) run. This MRP run processes every night, to ensure an updated overview of the materials required to order when employees at DMI start at the beginning of the work day.

The MRP run, as the name suggests, processes the materials required for the planned maintenance. It compares the materials that a work order needs with the materials on stock to see if new parts need to be ordered. It has a predictive function, that allows it to suggest an amount of spares to be ordered, given the historical usage of the spares. There is human confirmation needed to accept the proposed requirements of the MRP run. This allows for inventory managers to fine tune the output of the MRP run. An example of this use would be when a proposed order of 60 spares is done. The inventory manager knows from experience that the specific spare is delivered in packs of 25, so the employee makes the decision to change the proposed order to 75. Important to know is that the MRP run, and even the inventory managers do not order any materials. They formulate an Aanvraag Tot Bestelling (ATB), which is then send to the procurement department. This department is then responsible for making the actual order.

Every article within SAP has a time variable as part of the master data, that estimates the required time between the logging of the work order, and the actual arrival of the spare at the ODC (Opslag en Distributie Centrum). This estimation of time is in its turn based on two main factors. Namely the time required for the processes at DMI preceding the order and the time lead time of the product, given by the OEM. SAP reserves five days for the processing of the proposed ATB's by the MRP run. This means that an inventory manager has five days to accept a proposed ATB and send it through towards the procurement department for further processing. The procurement department in its turn is allowed ten days by SAP to process the ATB and place an order for a part. After these fifteen days, an order should have been placed if DMI wishes to stick to the proposed planning done by SAP.

Additional to the time required by DMI, the lead time of the part, given by the OEM, is also used to calculate the arrival date. This lead time is part of the master data within SAP. However, the lead times that are registered in SAP are not always correct, they are an estimation based on historical lead times. This can result in an incorrect planning as lead times may be longer than was thought before a part was ordered. Items that are seldomly ordered are especially vulnerable for this error.

Sometimes a maintenance schedule is updated and a work order is set to an earlier date. If this occurs, the proposed order by the MRP run is marked with a red dot. This is added to show that the ATB has surpassed the SAP planning (i.e. the five days that are reserved for it). The material planner sees this in the system and can act on it in multiple ways.

- If it concerns an item that is in repair, he can expedite this action and bring the repair date of the item forward.
- If it concerns an item that has to be ordered, he can expedite the ATB and inform the procurement department. The procurement department can then expedite the internal ordering process (i.e. take less then the 10 days SAP reserves for the ordering process), and they can try to reduce the lead time of the order by expediting the OEM.
- If neither of the above actions suffice in delivering the item on time, then the material planner can inform the work planner that the item will not be delivered on time. The work planner can then postpone the work order.

To summarize, when a new system is procured its components are mapped in SAP. During the systems lifetime, work orders are placed to plan maintenance. The required spare parts are processed by a daily MRP run, which generates ATBs that inventory managers have to fixate. Based on these ATBs, the procurement department of DMI places the eventual order for the spare part. Inventory managers have five days to fixate the ATBs after they have been generated by the MRP. The procurement department then has ten days to place an order. If these time limits are exceeded, the order is expected to arrive too late for its planned maintenance.

5.1.2 Encountered Issues

With the business and information system architecture mapped, we would like to touch upon some of the issues that we encountered with the current procurement process. These findings are all based on interviews with actors within the supply chain. We identify these issues in hopes of finding possibilities on which an SCT could mitigate these hinderances.

- Currently within the business architecture, the planning made by SAP takes in to account that it takes five days for an ATB to be formulated. However it often occurs that these five days are exceeded (Koning, 2020). From one interview we learned that it is not uncommon for hundreds of ATBs to have not been fixated within this given period (Sluijter, 2020). In the dashboard shown in appendix D this is presented in more detail. The data presented here is unfortunately not specified to solely spare parts from Thales, but it still gives a good overview of how the procurement process within DMI is functioning on a whole. From this dashboard we learn that inventory managers often exceed their five day planning. Quite a large part of these unfixated ATBs exceed this five day mark by far: E.g. 907 unfixated ATBs of which 661 have been unfixated for more than 35 days, on a random date of measurement. This is in stark contrast of the norm set by the supply chain managers of a maximum of ten ATBs exceeding this 35 day mark at any given time.

- Not only inventory managers exceed their five day planning. From this same dashboard we learn that the procurement department also surpasses the norm of ATBs not being converted to orders within the ten day period that SAP allows for. On a random day of measurement 1114 fixated ATBs were still not processed into orders after 35 days. This surpasses the norm of 700, set by the supply chain managers by almost 60%.

- A last insight from this dashboard is the performance of the supply chain that is responsible for the spare part inventory of the RNLN (see ML-IK-E4a in appendix D. Compared to the performance of similar supply chains at other defense organizations within the Netherlands, the RNLN consistently underperforms. The dashboard we received was unspecific on how this performance was exactly measured. However, only once does the RNLN surpass the supply chain performance norm of 70%, by a meager 3% (week 19). On all other dates the norm of 70% is not met. This is not the case for any other defense organization, with the army and airforce often surpassing supply chain performances of 80%.

- The start of the procurement process for spare parts is determined by a planning made within SAP. This planning tool uses the estimated lead times of a spare part to determine when a part should be ordered. However, the lead times used for the SAP planning are not always up to date. When e.g. SAP has registered the expected lead time of a spare part of Thales to be four months, it will initiate the procurement process about five months in advance of the planned maintenance that the part is required for. It can occur that when this part is then ordered, the actual lead time turns out to be six months, because Thales has switched, for example, from sub-supplier. In this scenario the constructed maintenance planning starts with a delay two months.

5.2 Obsolescence Management

Obsolescence is one of the main hurdles that the RNLN as the asset owner, and Thales as the OEM, jointly face. This is due to both the aging fleet of the RNLN and the developments in the electronics's sector as discussed in Section 4.3.3. The goals of both stakeholders, as described in Section 3.2.1, are negatively impacted by obsolescence issues.

In some cases, the obsolescence of a spare part results in an expensive redesign of an asset. Unstructured registration of obsolescence can delay the response, often increasing the resolvement costs Kloosterziel (2020). Furthermore, a redesign is a very time intensive process, so it can often take months before the new part is available to order Bisschop (2020). This makes the availability of spare parts very limited during this period. If maintenance procedures are planned while spare parts are not available, this can lead to the cannibalisation of operational parts from other ships. Cannibalisation of spare parts is to be avoided when possible and it is seen as a last resort to repair a ship for which the repair is seen as essential (because e.g. the ship is going on a mission soon) (Koning, 2020).

For the RNLN obsolescence issues can be very costly. Sometimes resulting in higher obsolescence related costs, than the initial value of the respective asset Kloosterziel (2020). This is unfortunate as the defence budgets has seen a trend of declination as shown in Figure 24 (see appendix A). Besides being costly it can also be the source of delays within the maintenance process. Both have a negative impact on the goal of effective maintenance and the operationability of the fleet.

From one interview, for example, we learned that the current obsolescence induced costs of redesigning the obsolete spare parts for the Active Phased Array Radar (APAR) go into the millions (Kloosterziel, 2020). On the issue of delays we learned that it often occurs that planned maintenance activities have to be cancelled or postponed for sometimes months because the spares required to conduct the maintenance turned out to be obsolete when they were ordered. This can seriously delay the entire maintenance planning of a vessel, resulting in either extended maintenance periods, in which the vessel is not operational, or in operational vessels on which certain maintenance projects have not been conducted (Molenaar (2020), Bisschop (2020), Koning (2020)).

For Thales the arising obsolescence issues make it more difficult to provide good after-sales service. It can become difficult for Thales as OEM to supply its customers with spare parts throughout the lifetime of the respective assets (Jongebloed, 2020). This in turn can have a negative impact on the customer valuation of its services.

In order to mitigate these problems that obsolescence issues cause, obsolescence management is implemented as part of the after-sales service, functioning both at Thales as at DMI. Before we discuss the business, information systems and technology architecture of obsolescence management as an element of the after-sales service, we have to make a distinction between two main obsolescence management strategies that the RNLN uses.

The first strategy is based around the agreements that the RNLN and Thales have made in so called In Service Support (ISS) contracts (Molenaar, 2020). Under these contracts the agreements, made between the RNLN and Thales, surrounding the obsolescence management of the APAR and SMART-L are delineated. All other systems however that are currently in use by the RNLN do not fall under these ISS contracts. This is an important distinction to make, as all others systems simply do not have an obsolescence management strategy. On those systems, the obsolescence of spare parts is managed on a case to case basis (Koning, 2020).

5.2.1 Business Architecture and Information Systems Architecture

The business and information systems architecture we model in this subsection is based on the obsolescence management strategy formulated in the ISS contracts. However, we also modelled the business event of when a part turns out to be obsolete after it has been ordered by DMI. We modelled this event to showcase how obsolescence is managed on the systems that do not fall under the ISS contracts. This does not mean, unfortunately, that this event is exclusive to the spare parts of systems that are not under the ISS agreements. Within the current agreements, it to can occur that cases of obsolescence are not properly communicated, resulting in unpredicted delays and costs for both DMI and Thales.

The agreements made in the current ISS contracts try to mitigate this issue by reducing the interval between obsolescence updates. Within earlier versions of these contracts, the interval between the agreed upon obsolescence updates from the OEM were found to be too lengthy, which resulted in the use of outdated information for obsolescence management (Molenaar, 2020). The current third edition of ISS contracts have mitigated this issue by reducing said interval to half yearly updates from the OEM towards the asset owner. This means that it is now agreed upon that Thales delivers a half yearly update about the obsolescence state of the components within the APAR and SMART-L.

The current business and information architecture surrounding obsolescence management is modelled in appendix F. A shorter version is shown in Figure 13. In this shorter version we leave out the quotation, order releasing and shipping process. Here we only focus on the notification of the discontinuance of a spare part, resulting in the formulation of a Last Time Buy (LTB), and on the event in which a part turns out to be obsolete after an order for this part has been placed.

Currently, within the ISS contracts, Thales delivers information about obsolescence on a Line Replaceable Unit (LRU) level. Within the after-sales service logistics there is a distinction made between LRUs and Shop Replaceable Units (SRUs). SRUs are smaller components (e.g. an Integrated Chip (IC)) that make up the larger LRU (e.g. a circuit board). LRUs can often simply be swapped out during a maintenance procedure, replacing a malfunctioning one by a functioning one. The cause of a malfunctioning LRU is often a broken SRU on this LRU. Swapping out an entire LRUs takes up less time than repairing the broken SRU, but it is also more expensive. In Figure 12 a practical example is given of the break down structure of a system on board of a Luchtverdedigings- en CommandoFregat (LCF). The radar system depicted in this figure is the SMART-L, which falls under the ISS contracts.

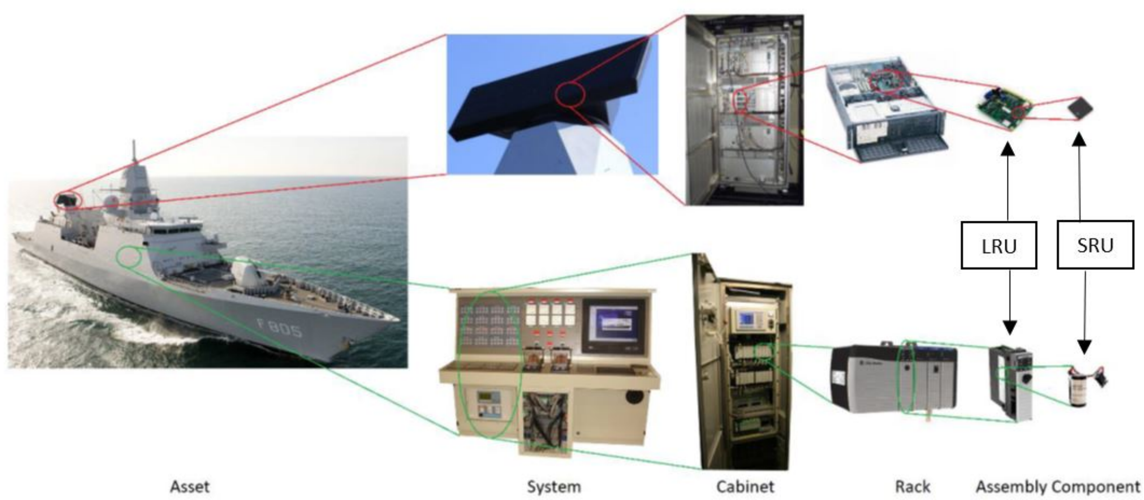


Figure 12: Structure break down of a system, with SRUs and LRUs. Abstracted from Seuren (2018).

As of right now these are two main ways that we found in our research by which obsolescence is encountered and acted upon. We marked these both starting points as darker yellow within the figure. Under the ISS contracts, the supplier of the part informs Thales when it plans to discontinue the production of a certain part. This gives Thales a date before a LTB can still be placed. Thales receives this notification and registers this discontinuance date. It also notifies DMI of the upcoming obsolescence and starts the process to formulate an LTB. Thales investigates the consequences that the discontinuance of the part will have for the systems that Thales supports. Based on this investigation, and the order history of the spare part, it calculates the required size of the LTB to be able to support all of its customers throughout the End Life Of Type (ELOT) of the systems that contain said part. This is done in cooperation with DMI. Under the ISS contracts, DMI is involved in this LTB calculation process. From interviews we learned however, that the Mean Time Between Failure (MTBF) rates that Thales uses to calculated the size of the LTB are not adjusted based on operational experiences and actual usage data. Thales uses the factory specified MTBF rates and the order history of its customers to do these calculations.

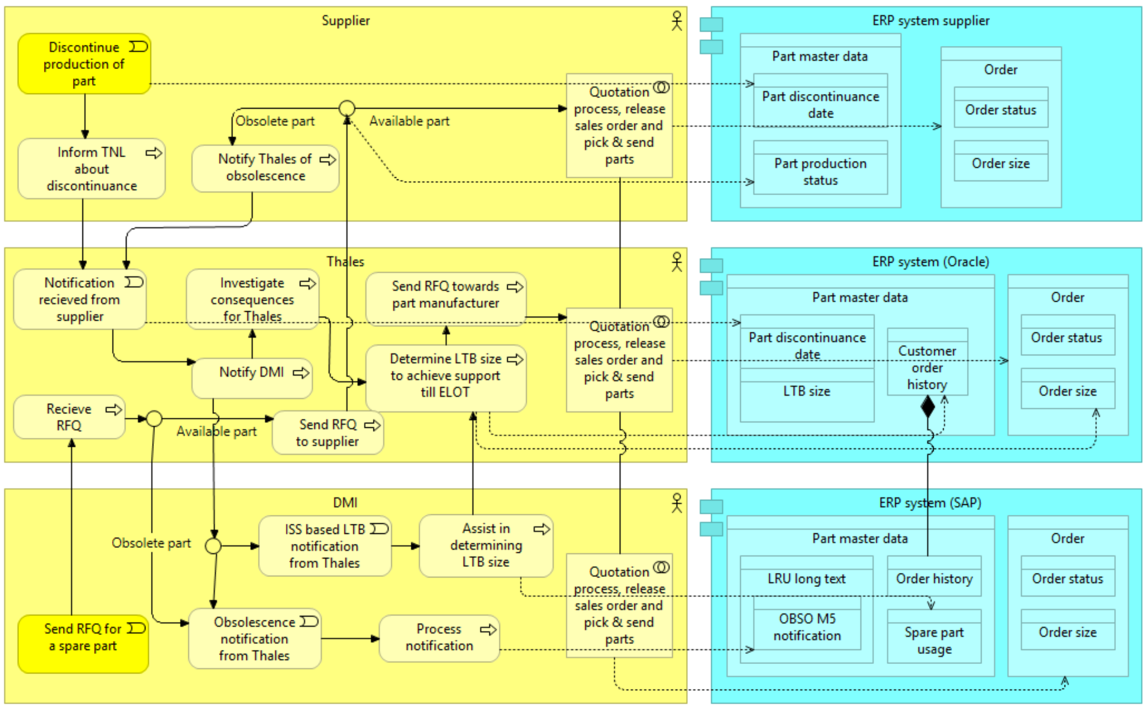


Figure 13: The Last Time Buy process under ISS contracts and the registration of obsolescence notifications. (shortened version of the one shown in appendix F)

The rest of the actual ordering process is shown in more detail in appendix F. Here we show that Thales then sends out an Request For Quotation (RFQ) towards its supplier to gain an indication for the price of the LTB. Based on this price it formulates an offer that it proposes towards DMI. DMI evaluates this offer and, if it accepts the offer, places an LTB at Thales, which in turn places the order at its supplier. The parts are then delivered from the supplier to Thales, which in turn sends the parts to DMI.

Next to this more ideal scenario, a scenario also exists where discontinuance of the production is not notified in advance, but obsolescence is noticed after a part has already been discontinued. This is mostly the case with spare parts of systems that do not fall under the ISS agreements, as on these systems no agreements are made about proactive obsolescence management. The event we modelled, also shown in Figure 13, starts when DMI places an order for a spare part at Thales. When this order is placed, Thales either has already registered this part as obsolete, resulting in an obsolescence notification that DMI processes in SAP, or Thales still thinks this part is in production. In that case, Thales processes the RFQ and sends an RFQ to its supplier to get a price indication. If the supplier has already discontinued the production of this part, it notifies Thales of the part's obsolescence.

Thales then passes on this notification to DMI, which in turn processes it in SAP.

The processing of this obsolescence notification in SAP consists of two main actions. Firstly, DMI processes this notification by marking the part with the term "*OBSO*" within the long-text of the part's master data. By this mark, the employees of DMI know that the item is obsolete. Secondly, if the order still has to be full-filled, a so called M5-Melding (M5-notification) is done within SAP. By this notification system engineers are alerted that a part has become obsolete and that a search for a technical alternative should be instigated. Marking parts as obsolete is important for DMI, as e.g. repairing obsolete parts can be given a priority since they can no longer be ordered.
For a more detailed process description surrounding the ordering, processing and picking and sending of parts we refer to de Vries (2020). Here these processes are described in great detail. The description we provide however suffices for this research.

5.2.2 Encountered Issues

As with the procurement process, within this business and information systems architecture we also encountered multiple issues. These came forth from interviews with actors concerned with obsolescence management. We would like to delineate these issues here.

- Our first main finding is that there is big difference between the obsolescence management of systems that fall under the ISS contracts, and of systems that do not fall under these contracts. For the APAR and SMART-L obsolescence management is designed to be somewhat proactive. For the other systems obsolescence management is reactive and uncoordinated (Koning, 2020).

- Another problem we encountered was the enormous delay that obsolescence can cause to the maintenance planning of certain vessels. In cases where obsolescence was not registered, weeks could be lost to order an item that was not available. This caused maintenance crews to either delay the maintenance of a vessel by many months, reducing its operationabillity, to cannibalize spare parts out of another system when a ship's maintenance simply cannot be delayed, or to release a ship with unfinished maintenance from BO.

- Obsolescence notifications are currently delivered on a LRU level. This is unfortunate in cases where the obsolescence of a LRU is caused when in reality it is a relatively simple Shop Replaceable Unit (SRU) that has become obsolete (Molenaar (2020), Koning (2020)). If, say, an Integrated Chip (IC) on a circuit board is deemed obsolete by a supplier, it might be much easier and cheaper for DMI to find an technical alternative or to start a redesign on this SRU, instead of having to redesign the entire LRU.

- The LTB calculations that are currently done by the OEM, are based on the customer's order history and the factory specified MTBFs. Although there is nothing inherently wrong with using these rates to estimate the future usage of spare parts, they do not tell the full story. Order history, for example, can be influenced by DMI repairing a broken spare part. Say DMI repairs a certain part instead of ordering a new one, it can seem to the OEM as if the part rarely breaks, thus lowering the LTB size. This can lead to problems, such as too small LTBs being placed by the OEM, resulting in insufficient spare parts to support an asset throughout its remaining ELOT.

- The way obsolescence is currently registered within SAP is quite cumbersome. The long text within a part's master data is intended to be used for miscellaneous notes about a part. It now functions as the basis of DMI's entire obsolescence management strategy. By putting information in the long text, room for error, e.g. spelling mistakes, is created.

5.3 Order Tracking

So far we have discussed how orders are formulated, and how obsolescence influences this process. Another important after-sales service element that we investigate in this research is the tracking of the placed orders. We investigate this element, as within order tracking data has to be communicated between links in the supply chain. We suspect, for example that updates about an order's status has to be communicated from the OEM towards DMI. We describe the current order tracking processes within the supply chain and map this process within ArchiMate in the following chapter.

5.3.1 Business Architecture and Information Systems Architecture

When DMI requires a spare part for a maintenance procedure it can either order the part, or repair it if possible. In this section we focus on the situation in which DMI orders a spare part from Thales, the OEM. How the order is formulated, was already discussed in detail in Section 5.1.1. The process we describe in Figure 14 however, shows how a placed order is tracked and how updates about this order are registered and communicated throughout the supply chain.

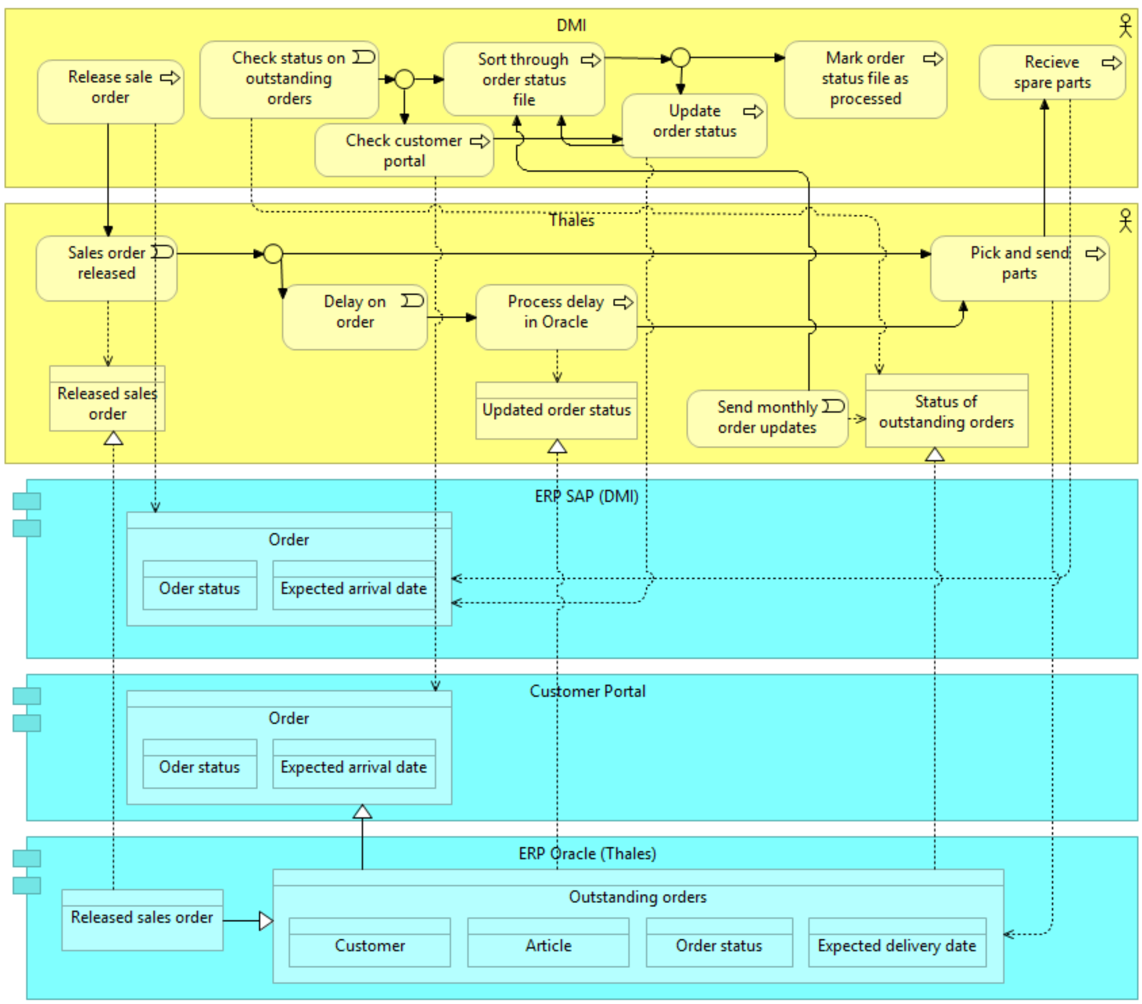


Figure 14: The current order tracking process, describing how delays on placed orders are updated

This process is initiated when DMI releases an sales order. Thales process this order and starts all the processes required to deliver the spare part. Here we distinguish two scenarios. In the first scenario a order is placed and processed exactly as planned. There are no delays and Thales picks and sends the part on time, resulting in the spare part being present on the planned date.

In the second scenario there occurs some type of delay within the order. Reasons for an order to be delayed are plenty, but some examples are delays with transportation or production of the part, delays caused by obsolescence, or a part that was initially reserved to be shipped to DMI being sold to a higher bidder that e.g. expedited its order (Koning, 2020). Whatever the cause, when a delay occurs, Thales registers this delay within its ERP system. Besides Thales' ERP system, they have recently developed a so-called customer portal. Within this portal, customers of Thales can view, among other things, the status of orders that they have placed. Thales updates the order status within this customer portal, with the information stored in its ERP system. Besides updating its customer portal, Thales sends a monthly report in the form of an Excel file towards DMI, in which all the outstanding orders and their respective status are shown (Kloosterziel, 2020).

This leaves DMI to do two things. It can either log into the customer portal to view the status of their outstanding orders, checking each order for a possible delay, or it can process the monthly excel file by comparing the order status described in the file with the expected order status denoted in SAP. By following one of these procedures, updates about the order status of spare parts ordered at Thales can be updated within SAP.

5.3.2 Encountered Issues

The problems delays in orders cause have already been discussed in Section 5.1 and Section 5.2. Here we would like to focus on the issues we encountered with the current way these delays are processed and acted upon.

- The first main issue that we encountered with the current process of order tracking, was how cumbersome it is for employees of DMI to get updated information about outstanding orders. This causes frustration within the procurement department, as employees receive large unfiltered data files concerning the status of their orders, instead of distilled information (Kloosterziel, 2020). Manually searching the customer portal for every outstanding order is a very tedious task, and leaves room for employees to oversee interesting information. As is manually sorting through large excel files which make no distinction between orders with useful updated information and orders without and peculiarities. Both activities are labor-intensive and prone to human error.
- Secondly we learned from interviews that, even though there is a procedure to track orders and to process delays within SAP, this new information apparently does not always flow down correctly through the rest of the supply chain. Although we could not find any data to put the size of the problem in a numerical perspective, we learned from interviews that it is a regular occurrence within DMI that mechanics show up to enact a prepared maintenance procedure, only to find that the required spare parts are missing (Molenaar, 2020). After investigating why the parts were missing, it is then found out that there has occurred a delay within the delivery of the parts, which was either overlooked by work planners, not processed by the procurement department or not communicated by Thales. We do suggest further research to be done on this topic in order to gain more details about where and why this information strands.

5.4 Asset Monitoring

The last element of the after-sales service that we discuss during this research is the monitoring of the asset during its lifetime. Modelling this process is a bit different than the previously discussed process, as the monitoring of the asset is broadly enacted throughout many layers of the supply chain, and is not always actively pursued. Some of the monitoring can be done passively by, e.g. the automatic logging of transaction data. In order to model this process, we therefore sought any useful information that is generated by both OPS, DMI and Thales, during the asset's lifetime.

5.4.1 Business Architecture and Information Systems Architecture

In Figure 15 we described the current business and information systems architecture surrounding the monitoring of the asset during its lifetime. We will go through the data types described in Figure 15, discussing the processes that generate and keep this information.

We start in the center of the model in Figure 15, with the configuration of the RADAR system. As the RADAR system is composed of a lot of different parts that all have to communicate, a system configuration is kept within the system. From this, the system can monitor exactly what parts are installed and running.

The RADAR systems installed on a vessel are operated by OPS. By operating this asset, data is constantly logged on board of the ship. We call this operating data. In this operating data it is e.g. registered in what, for example, weather conditions the system has operated. Another thing that is monitored by OPS, is the amount of on board inventory of spare parts. Some (mission critical) spare parts are always kept on board of a vessel. OPS keeps track of the inventory levels on board. This information is currently only communicated to DMI. Lastly OPS gains a lot of user experience while operating the asset throughout its lifetime. This data is not kept in SAP, yet engineers at both OPS and DMI have a very broad knowledge about the stronger and weaker links within a system. One example explained during one of our interviews was the impact of a design choice Thales made regarding a coolant tube passing the rotating axis of a RADAR (Kloosterziel, 2020). OPS and DMI experienced a lot of issues with this design choice.

OPS also conducts Organic Level Maintenance (OLM) on the RADAR. While doing this, data is generated. Failure rates can be deducted and registered by OPS and DMI when maintenance is conducted and spare parts are replaced. Further more, failure modes can also be logged, explaining why a component failed. This is important to do because this might effect whether or not a failure should be taken into account when calculating the failure rates. If a failure occurs because someone, for example, spilled coffee on it, then this should not influence the failure rates. Lastly, the operating hours per spare part are also kept. This can be deducted from the time a system has been active within the time frame that a spare has been installed. Spare part operating hours are important for DMI as most of their maintenance plans are based around a system requiring service after a certain amount of operating hours. For example, service system x after 5.000 operating hours.

We now investigate the data that is generated and kept by DMI. DMI maintains the asset by conducting Intermediate Level Maintenance (ILM) and Depot Level Maintenance (DLM). This maintenance is based around a certain maintenance plan. This plan describes e.g. how often a part should be inspected, serviced or replaced. DMI gets a maintenance plan from Thales when the system is put in to use, but over the years adjustments might be made, based on experience with the system. By logging break downs and removing broken spare parts, DMI has historical data about Mean Time Between Failures (MTBFs) and Mean Time To Repair (MTTR)s (MTTRs). Currently MTTRs are not being kept well, as broken spare parts are often not immediately repaired, but are put back on the shelf awaiting repairs for when the spare part is needed again. From DMIs maintenance experience, a better Failure Mode, Effects, and Criticality Analysis (FMECA) can be done about the breakdown of individual spare parts. DMI also keeps maintenance and repair logs. This ranges from simple transaction data showing that maintenance has been conducted and that a repair has been successful

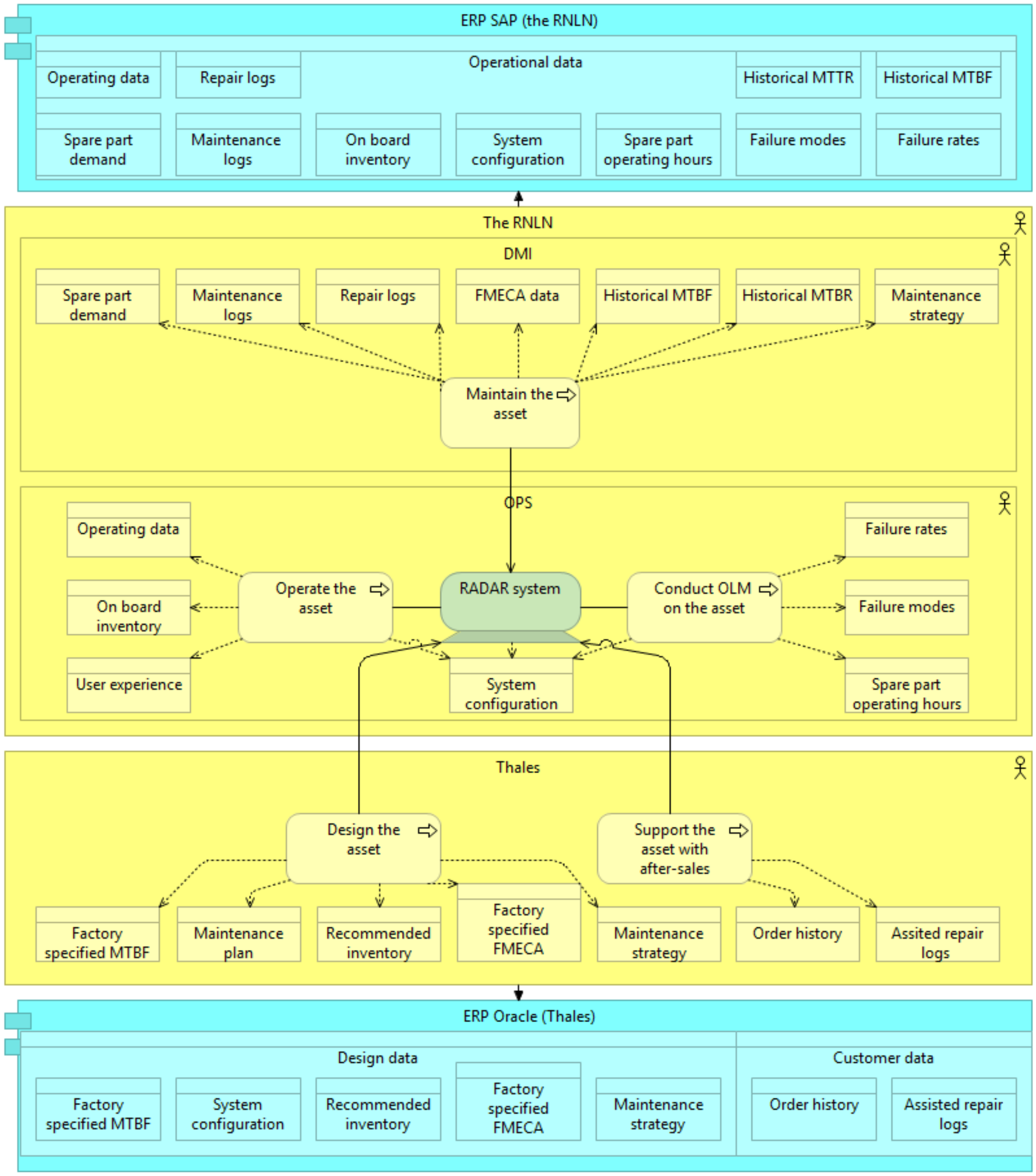


Figure 15: The current asset monitoring process. Describing what data is monitored and collected during the lifetime of an asset

or not, to actual logs describing difficulties experienced during maintenance or repair procedures. This transaction data is kept in SAP, these more detailed logs are often send by mail or stored somewhere else. Small notes however, can be kept in the long text of SAP. By comparing the failure rates of a spare part, to the amount that can be repaired, a spare part demand can be calculated. As not every broken part has to be replaced by a ordered new one. This spare part demand rate differs from MTBFs and the order history.

Although Thales does not have any direct way of monitoring the system once it has been put to use at DMI, there is still certain data kept during the lifetime of the asset. Also, a lot of data is construed when a asset is designed and produced. Examples of this are the factory specified FMECAs, MTBF, the maintenance plan, maintenance strategy and the recommended inventory. Thales has some basic insights on the FMECA when a system is designed. It might know and inform DMI in advance which broken parts influence the rest of the system and how critical the breakdown of certain parts are. The same goes for the MTBFs. Thales has an idea of how long spare parts will function in a system before they will break down, but this is based on estimates and second hand information provided by their sub-suppliers. Based on these MTBFs, Thales recommends a certain inventory level to be kept by DMI. Thales also draws up maintenance plans, describing how DMI should conduct maintenance on the asset. This describes for example what steps should be taken in what order to replace a certain spare part. Next to these maintenance plans, there is also a maintenance strategy prescribed by Thales. This describes for example after how many hours a system should be inspected or serviced. Then there is also data generated while the system is in use. Thales keeps an order history of all its customers. By this Thales can gain some view on whether or not the MTBFs are accurate. Lastly when Thales is contacted to assist with repairs, they gain some data in the form of repair logs.

5.4.2 Encountered Issues

- The current configuration of the RADAR system is logged on a LRU level. This for example does not show it when a spare part that has been repaired or modified is put back in to a system. Also it is not always registered properly when spare parts are interchanged between systems. Currently DMI is sometimes forced to cannibalize spare parts of an other vessel, when the vessel they are conducting maintenance on has be completed. If it is not registered when a item is swapped, this can corrupt data about the operating hours of the spare part, in turn influencing the MTBFs.
- Operating data is seen as confidential and is therefore not registered precisely, or made available to external parties. The data that is kept, is often only made accessible after a long time, or is deleted after a short interval.
- Failure modes are often not registered, or are registered very vaguely. This is a problem, because the failure mode can be very important to see for both DMI and Thales.
- Operating hours per spare part can be corrupted when parts are switched without registering this within SAP. This leads to false MTBFs.
- Updated maintenance plans are often only kept on paper. When visiting an operational vessel, we learned that the crew preferred working with maintenance plans on paper. This also meant that if adjustments to maintenance plans were made, these were made on the paper sheets, but not properly registered within SAP.
- When a item is removed from a system and is sent for repairs, it often ends up on a shelf, waiting for further action to be taken. When this item is needed later on, it is then sent for repairs. Sometimes it occurs that a spare part degrades so much during this waiting time, that it can no longer be repaired. This is a shame, because if repairs would have started earlier it might have been able to be repaired.
- Maintenance and repair logs are not always registered properly by DMI's employees. This might give false indications on MTTR rates.
- Thales gets little feedback from DMI on their initial factory specified data that it communicates towards DMI. Getting feedback on these rates could be very interesting for both parties, as this could improve e.g. LTB calculations.

5.5 Technology Architecture

Modelling the technology architecture is phase D of the ADM. We constructed this architecture in ArchiMate, like we did with the business and information systems architecture. The technology architecture gives a good view on how the business and information systems architecture is supported by (physical) technologies, such as databases, communication nodes, firewalls, etc. Our model of the technology architecture can be found in Figure 16. The technology architecture of Thales was based on the technology architecture modelled by de Vries (2020). Important to note is the use of firewalls between zones. These firewall make sure that only specific data can flow from zone to zone. These firewalls should also be used within our SCT, as by these firewalls parties have control over what data they allow to flow throughout the after-sales service supply chain.

The view proposed in Figure 16 is very limited, as we focused on the business and information systems architecture within this research. Future research should be conducted to gain more details about the technological architecture implemented within the after-sales service supply chain.

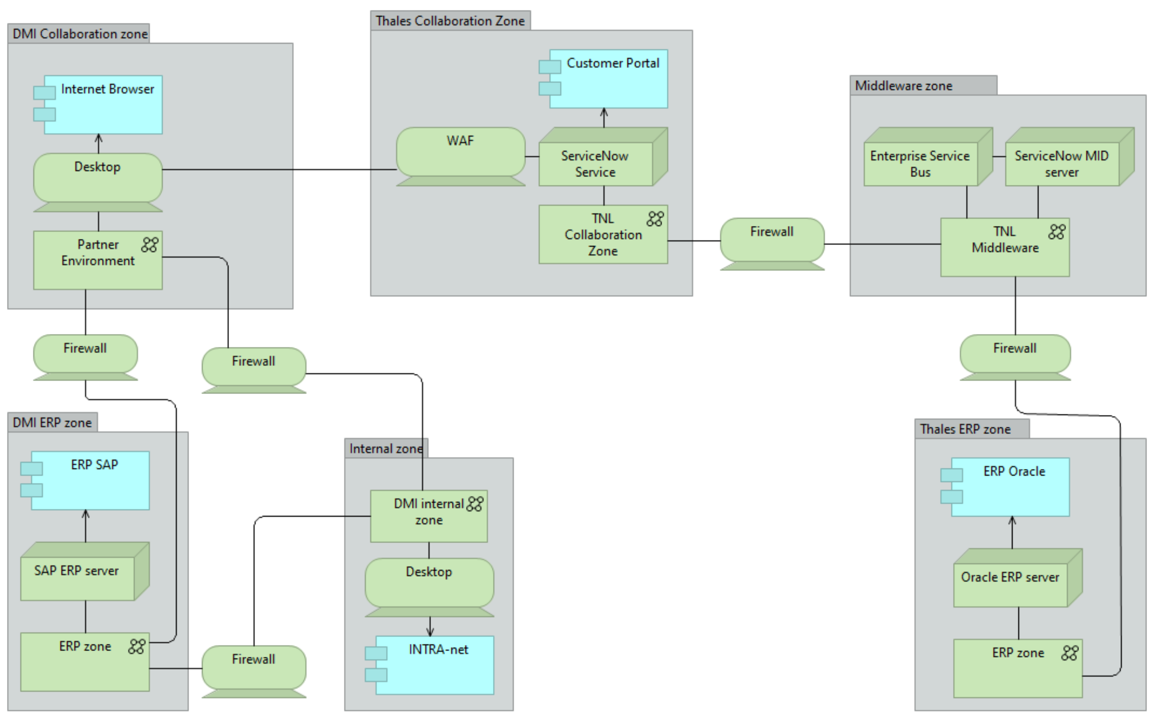


Figure 16: The current technology architecture. Based on interviews and insights from de Vries (2020).

5.6 Maturity of the SCT

We can now combine the insights that the literature has given us about an SCT, with the current situation regarding the four elements of the after-sales service. If we go from left to right, we can fill in the maturity grid, based on the current business, information systems and technology architecture that the RNLN already has implemented.

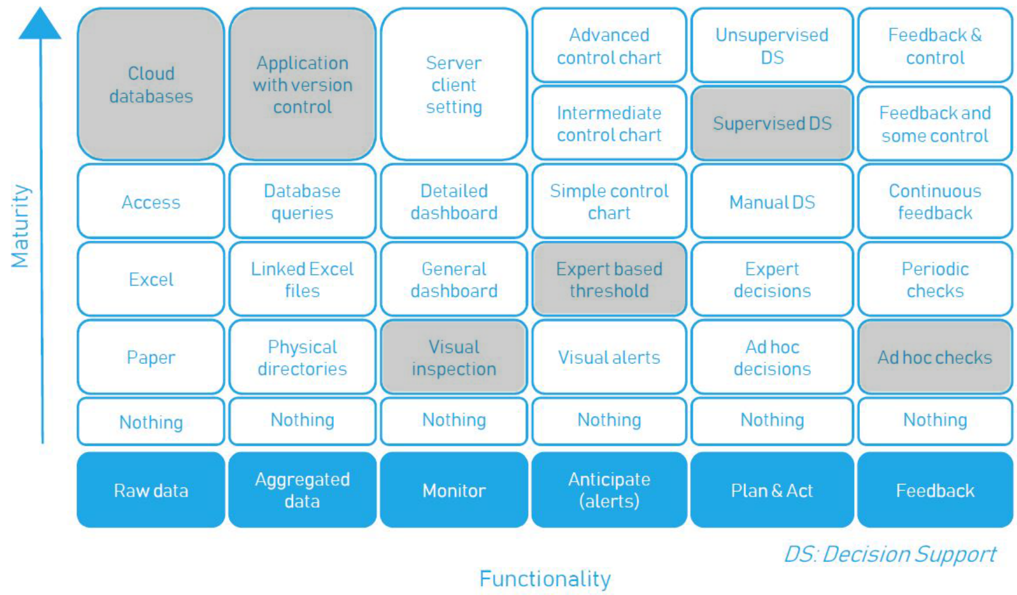


Figure 17: Current maturity grid for a service control tower. Abstracted from Driessen & Keizer (2019)

Raw data

DMI has multiple databases in place that are able to communicate with each other. The data that is kept, is stored in the cloud, and can be accessed easily accessed. This makes the SCT very mature in this regard. **However**, unfortunately not all employees adhere to the company policies surrounding data collection. Although all the systems are in place to work with and process data concerning the after-sales service, many employees are still used to the more conservative way of doing things. This is internally sometimes referred to as the *fietsendrager-methode*. Using this method means that no further transactional data is kept regarding a Stock Keeping Unit (SKU) when it is picked up from the shelf for a maintenance procedure. The SKU master data is limited to the data surrounding the part such as its configuration data. The data of the individual SKU's of the same type, such as their location, life cycle data, failure rates, etc. is lost.

For this maturity grid, we will mark the cloud databases, as in theory this is what DMI is working with. In practice however, it is very crucial to keep stressing the importance of data collection under DMI's employees.

Aggregated data

For this criteria roughly the same can be said as was stated under the raw data criterion. Version control is the ability of a system to record changes to a file or to a data entry. SAP is capable of version control, because it keeps transactional data. Transactional data is the registration of when and by whom something is done within a process. Some examples of this are the registration of when an ATB is forwarded to the procurement department, when a part arrives at the ODC or when a spare is replaced by a mechanic. SAP allows for the registration of this data, and some of this data is registered automatically. However, the same problem discussed under raw data, also applies here. Transactional data that has to be entered into the system is often overlooked, so the collection of this data has to be improved in order to keep good supply chain visibility. Because all the systems are in place however, we can mark this criterion as fully mature. As SAP automatically registers this data we can mark this criterion as fully mature

Monitor

SAP allows for some monitoring of the service logistical processes. However, the process of making the performance of the supply chain visible is quite exhaustive. A separate software package, called *Every Angle* is used to do these performance analyses. Not all employees however are as ample with this software as others, and there is no central dashboard all parties can view in order to monitor the performance of the supply chain. We therefore mark monitor on the visual inspection level, since dashboards are only available by user request and have to be formulated before they can be spectated.

Anticipate (alerts)

Currently some alerts are generated within SAP, as discussed in e.g. Figure 14. This means that there are underlying thresholds that, when exceeded, generate an alert. There is room for improvement by e.g. increasing the types of alerts and the amount of input data used to generate alerts. Also, thresholds could be converted to control charts, but this would also require the SCT to be further developed on the monitoring scale. Charts could then be based on a dashboard. As such a dashboard does not yet exist, we currently have to rank this criterion on the expert based threshold level.

Anticipate (alerts)

Currently some alerts are generated within SAP, as discussed in e.g. Figure 14. This means that there is a underlying control chart generating these alerts. However, the complexity of this control chart is limited, and only planning based alerts are generated. Some processes have set parameters and exceeding these thresholds will result in an alert, but there is room for improvement by e.g. increasing the types of alerts and the amount of input data used to generate alerts. We therefore rank this criterion on the simple control chart level.

Plan & Act

SAP has some form decision support integrated. Examples of these are proposed order dates, order quantities and maintenance planning. The MRP run can be seen as an enactor of the plan & act criterion. All decision support that is implemented is still supervised, since employees have to give the final go on proposed actions. We can therefore mark this criterion on the supervised DS level. Besides these supported decisions, there are however still a lot of processes that have no form of integrated DS, and are still done ad hoc.

Feedback

Currently there is little feedback integrated within SAP. The dashboard shown in appendix D is one of the first strivings of DMI to provide some feedback on how the after-sales service processes are functioning. Although alerts are generated, the feedback often still has to be formulated ad hoc. We therefore note this maturity level on ad hoc checks.

6 Future Situation

In the past chapter we described the current situation, concerning the after-sales service logistical processes. Per element we identified the business, information systems and technology architecture. While researching and modelling these after-sales service processes, we also identified some issues that are linked to the core problem stated in Section 3.2.1, namely insufficient data management. Our aim in this chapter is to go over each aforementioned after-sales service process and to provide solutions to the problems encountered in the form of Service Control Tower (SCT) functionalities. We support this by providing a new business, information systems and technology architecture, modelled in ArchiMate, for each of the four after-sales service processes.

To conclude, we then illustrate what influence this has on the maturity of the SCT, by once again grading our SCT, with our new propositions taken into account, and comparing it to the maturity grid we constructed based on the current situation (Figure 17). We close this section of by giving some extra recommendations that are not specific to one after-sales service process.

This chapter contains phase seven of the research cycle described by Heerkens & van Winden (2017). Within the Architecture Development Method (ADM) this section covers phases E and F, as we identify opportunities and solutions for the issues encountered in the previous chapter, and provide a migration planning by modelling a future architecture to migrate to.

6.0.1 Interpreting the SCT in the proposed enterprise architecture

In Section 5.0.1 we discussed how we see an SCT and how the grading of one should be interpreted. Now, before we provide our new business, information systems and technology architecture models, we would like to clarify how the integration of the SCT within these business processes should be interpreted.

In the following sections, we present new models, created in ArchiMate. In these models we will have modelled a Service Control Tower environment. This environment is drawn over the information systems models of both modelled the RNLN and Thales, to indicate that the SCT environment is achieved by cooperation of both information systems. In the propositions we make, the actual SCT functions are not programmed in a separate software system, but rather come to being by programming some functionality in, for example both SAP and Oracle. To illustrate this we provide one example, which is also part of our recommendations and thus is further discussed in more detail, later on in this chapter.

On the monitoring scale, the current maturity of the SCT is relatively undeveloped. Information about the performance of the after-sales service supply chain is not easily visible for various departments at DMI. To improve this, we propose a dashboard displaying relevant information as part of the SCT environment. When we model this in Archimate, we model it as a functionality in the SCT environment that stretches over the information systems of both DMI and Thales. What we mean with this is that to create a dashboard information has to be exchanged throughout between both ERP systems. The programming and display of this dashboard could be programmed within SAP. To support this, functions in Oracle have to programmed to communicate relevant information towards SAP, such as order status. In SAP functions have to be programmed that are able to read this information and that can combine it with other information already stored in SAP, such as the maintenance planning. By combining this information a dashboard can be constructed that shows for example the amount of delayed orders that are going to have an impact on the maintenance planning.

We refer to and model all of these functions together within the SCT environment, however if we dissect this SCT functionality we can see that it is composed of multiple functions that have to be implemented at the already existing information systems (Oracle and SAP).

We hope that this provides sufficient insight in how SCT functionalities should be interpreted within the coming proposed business, information systems and technology architecture.

6.1 Procurement of Spares

We start by presenting opportunities and solutions for the problems described in Section 5.1, which we then present in a new business and information systems architecture for the procurement of spares. The solutions we propose are all linked to the core problem of insufficient data management, and give specific examples of how this data management could be improved. The procurement process is a process in which a lot of valuable information is involved for the entire after-sales service supply chain. Most of our solutions therefore focus on how to improve the communication of this data throughout the supply chain and how to make effective use of this data.

When formulating these recommendations, we kept the current maturity of the SCT in mind. If we put our recommendations in perspective of the SCT maturity grid, we mostly tried to improve the level of monitoring and feedback. We propose some ideas for the generation of a dashboard that is accessible and personalized for the entire after-sales service supply chain, and we propose ideas for generating better feedback on the monitored processes.

6.1.1 Opportunities and solutions

Monitor the status of the procurement process in relation to the maintenance planning

To keep better track of the status of the procurement process for spare parts, we propose that within the SCT environment the transactional data, that is generated when these processes are performed, is tracked. By doing this it becomes easier for the SCT to monitor how effective these processes are being conducted and how they impact the maintenance planning. The SCT can then generate alerts to e.g. the procurement department and the inventory management department of DMI when the time frame is exceeded. It can also notify work planners when the date of a maintenance task has to be moved, because delays occurred with the procurement process.

Present status of procurement process in a dashboard

We suggest constructing a centralized dashboard which contains information about the status and performance of the procurement process. This dashboard could be personalized to each department, showing general Key Performance Indicators (KPIs) about the performance of the after-sales service supply chain, and showing department specific KPIs. Inventory managers can see for example the status of the ATBs that were generated by the MRP run. The procurement department could see how many unprocessed orders have exceeded their ten day planning limit. Work planners could see which, why and how many maintenance procedures are delayed, allowing for adjustments to be made in the planning, so that it can be adhered. Mechanics could see in advance whether or not their required components for their planned maintenance have arrived, and how often and on what systems spare parts are sometimes missing. Besides this personalized data, some general data about the after-sales supply chain performance could also be displayed to all the actors within the supply chain. Topan et al. (2020) proposes some KPIs that are interesting to share within the SCT environment, namely: fill rate (fraction of demand satisfied immediately from stock), time-based fill rate (fraction of demand satisfied within a fixed period), downtime waiting for parts (cumulative time that the system is down due to the unavailability of parts within a certain period), call resolution time and transportation performance. We would like to add to this percentage of delays on orders, planning adherence (expressed in percentage of work orders executed within their given time window) and the average length of an delay on a work order.

Communicate SRU level configuration when procuring a new system

When a new system is procured, it's parts and configuration have to be mapped within SAP. Currently this is done on a LRU level. We propose that when a new system is procured, it is mapped, where possible, to a SRU level within SAP. This gives the engineers at DMI more options when it comes to maintaining the system. It will be easier to log SRU failures, giving more detailed failure modes and a better FMECA. It could reduce the costs of ordering spare parts, and it could result in less waste. It could stimulate ordering a SRU in order to repair a broken LRU, instead of simply buying a new LRU. Of course it would still be possible to order LRUs, but modelling SRUs in SAP, would give the after-sales service supply chain more options to maintain a system.

This could also be a benefit when the lead time of a LRU are long, while the lead time of the broken SRU on the spare part is shorter. In that case, ordering the SRU and repairing the broken LRU could be preferred over waiting for the delivery of the LRU. In any case, we see the mapping of SRUs as an essential extension to conducting more information driven maintenance.

Automatic updates about lead times

To minimize the risk that the start date of the procurement process of a spare parts is based on outdated information about the expected lead times of said spare part, we suggest the following: Within the SCT environment, information about the lead time of a spare part should be synchronized between both ERP systems of Thales and DMI. The simplest way to do this would be by updating the lead times whenever another customer of Thales orders the part in question. If we aggregate the orders of other customers that use Thales' systems, the time in between these aggregated orders becomes lower. E.g. if three customers require each order one part once every three years, Thales on average has one order a year. In this example the lead times registered at DMI can be updated or verified to be the same on average every year, instead of once every three years when it orders the spare part. Whenever Thales is notified in advance about lead time updates from its suppliers, this information could also be shared automatically within the SCT environment.

6.1.2 New business and information systems architecture

In our new business and information systems architecture, we mapped these aforementioned functionalities within the Service Control Tower environment. The process of manually updating the lead times of a part, whenever an order has been placed, is removed and replaced by an SCT functionality. This automatically synchronizes the lead times registered in Oracle, with the lead times registered in SAP. The transactional data that is generated during the formulation of work orders, fixation of ATBs and placements of orders will also be stored and monitored within the SCT environment. Based on this data, alerts can be generated when these processes are not fulfilled within the given time frame. On the topic of monitoring, a dashboard is constructed within the SCT that would be accessible to the entire after-sales service supply chain. This dashboard is modelled within the SCT environment, making it possible for the OEM to see how their actions are influencing the performance of the supply chain. Lastly, when a system is procured, information about its configuration can be shared via the SCT environment.

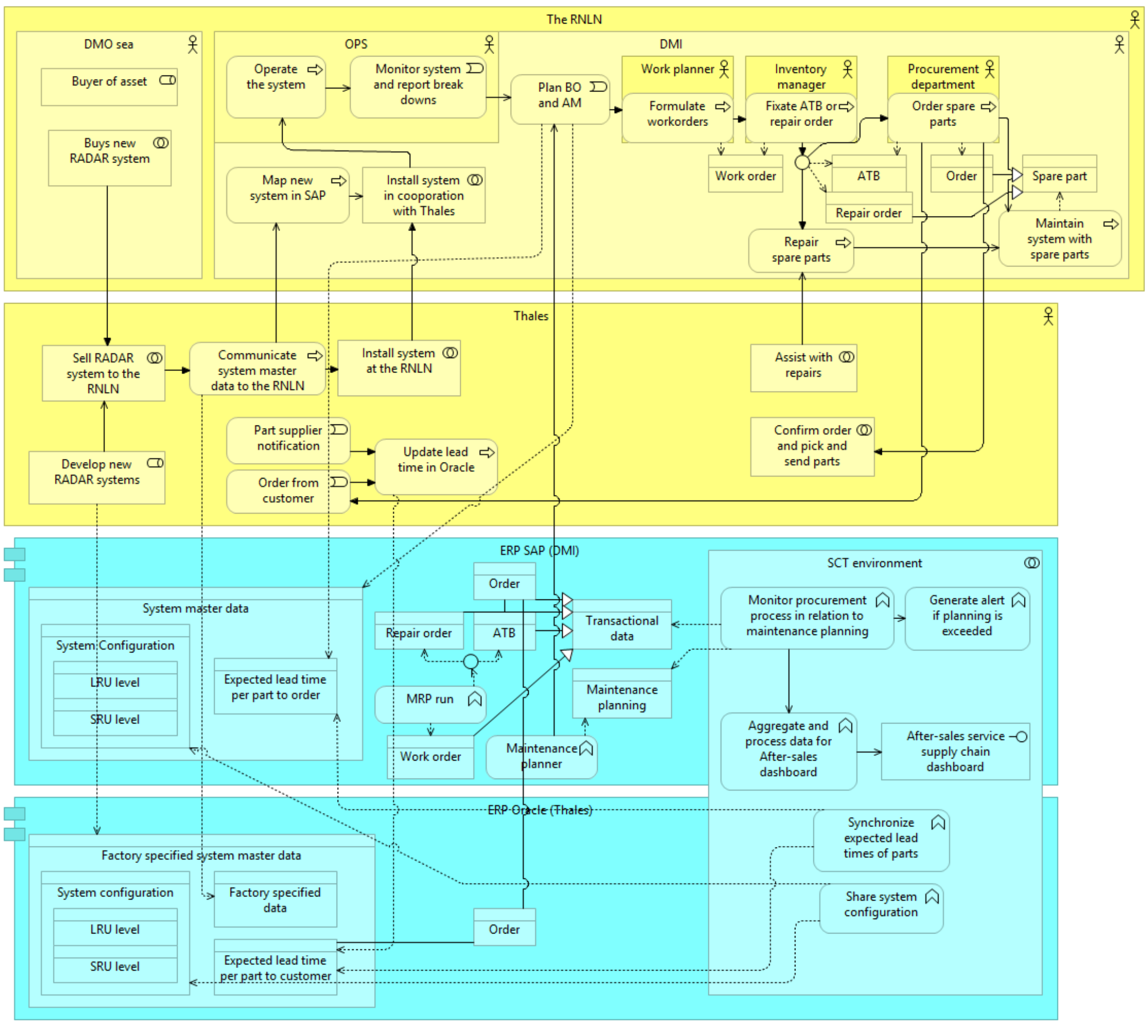


Figure 18: A new proposed procurement process of spare parts

6.2 Obsolescence management

We now propose some functionalities for the SCT that support obsolescence management. In Section 5.2 we discussed some of the issues encountered concerning obsolescence management and about the different agreements regarding the systems that fall under the In Service Support (ISS) contracts, and those that do not. The functionalities we propose are mainly focused on increasing the data communication between Thales and DMI, and the data registration at DMI. This is because most of the problems we encountered with the current obsolescence management process concerned these topics.

6.2.1 Opportunities and solutions

Sharing obsolescence data within the SCT environment

We propose that obsolescence data becomes standardized and integrated within SAP. The change that we propose is that from the registration of obsolescence as string of text within a miscellaneous data field ("OBSO" in the long text), to a selectable status of obsolescence, linked with a date of discontinuance in a new data field. We delineate how we propose this to be integrated in the business and information architecture section. Here we explain what the potential benefits would be.

Integrating obsolescence data as a standardized and registerable data type in SAP does multiple things for the service logistical processes. First of all it allows the long text to be used again for other notes about the item. This makes working with the SAP interface easier and allows for less room for human error.

Second of all it allows the SCT to gather workable data about obsolescence. Currently it is very difficult to monitor obsolescence of a system, since you have to specifically search for OBSO notifications in order to view obsolete items. If obsolescence is expressed in agreed upon data types, the SCT could easily extract this information. This would make monitoring obsolescence issues of a system easier, and would allow for better decision support and feedback on obsolescence issues. KPIs could be constructed, such as obsolescence notifications per system per month, length between obsolescence notifications and the introduction of technical alternatives, actual obsolescence against predictive models, etc. In any case, the data has to be collected and registered before it can be analysed.

Thirdly, making obsolescence a data type allows for better future communication between DMI and Thales' ERP system. If data about obsolescence is standardized throughout the supply chain, this data could be accessed and communicated within the SCT environment. The sx000i initiative we discussed in Section 4.4 has standardizing obsolescence data as one of its goals. Thales already has a team of employees that are looking into sx000i as a way to standardize data from certain after-sales processes (Jongebloed, 2020). We suggest that DMI joins these investigations with a team of supply chain managers, to see where cooperation is possible. If agreements can be made about the standardization of obsolescence data, the SCT would be able to share this data within the supply chain, allowing for more coordinated after-sales services.

Demand more detailed obsolescence descriptions from supplier (LRU to SRU)

In the current ISS contracts, obsolescence notifications are limited to obsolete LRUs. Thales however could be asked to also communicate the obsolete SRU that is responsible for the obsolescence of the entire LRU. This might reduce obsolescence induced costs, because sometimes alternative SRUs can be cheaper and more easily found than LRUs. The benefits of this would increase even more if the systems' configuration would be detailed up until the SRU level, as already suggested in Section 6.1. If a RADAR system's configuration is shared and registered on a SRU level, and information about obsolescence issues is communicated on a SRU

If both the system configuration, and the information about obsolescence issues is shared down to the SRU level, the real impact of obsolescence on a system would become more visible, and therefore easier to mitigate by the entire after-sales service supply chain. It would become easier for example to search for a technical alternative to a obsolete SRU than for a obsolete LRU.

It could also make doing repairs more advantageous. From old broken LRUs, for example, obsolete SRUs could be cannibalized. Having well documented obsolescence data is a prerequisite for this. We therefore propose that this SRU level configuration is shared within the SCT environment.

Improve LTB accuracy by sharing historical data

When obsolescence occurs and Thales makes the decision to place a Last Time Buy, it has to calculate the optimal size of the order. An order which is too large, brings with it unnecessary costs. While an order that is to small brings with it the risk of not being able to suffice the customers demand, resulting in expensive redesigns or a system not reaching its End Life Of Type. Thales currently calculates the size of the LTB based on their MTBFs and their customers' order history. These values however are not completely accurate as the observed failure rates by DMI might differ from the MTBFs that Thales mandates. On top of that, order history does not take failure modes (why a part broke) and failed components that have been repaired in to account. We therefore propose that this data is shared when LTB calculations have to be done, in order to make them more accurate. This could be beneficial to both parties. The OEM can provide a better after-sales service, while the asset owner is less likely to run out of spare parts during the life cycle of the asset.

Monitor impact of obsolescence on maintenance planning

This recommendation is an extension based on the recommendation given in Section 6.1. We already proposed that within the SCT environment, transactional data is tracked to monitor the adherence to the maintenance planning. To add to this, we suggest that the influence of obsolescence issues on the maintenance planning is monitored as well. Under the ISS contracts, DMI receives some information from Thales about the status of the resolution of obsolescence issues. Estimations or norms could be set by supply chain managers, indicating how long certain steps of the obsolescence management process should take. The SCT could give the maintenance crews at DMI an indication of when a obsolescence issue will be resolved, it can give supply chain managers insight in how effective the supply chain resolves obsolescence issues, and it can warn work planners when obsolescence issues are going to influence the maintenance planning, so that adjustments can be made to make the planning adherable.

6.2.2 New business and information systems architecture

We remodelled our business and information systems architecture in Figure 19 to place these recommendations in the perspective of the SCT environment. In this model obsolescence issues are still encountered by the same two ways as described in Section 5.2. Namely via the ISS contracts, or via orders placed by DMI. Although proactively receiving obsolescence notifications allows for much better obsolescence management, we do understand that not every asset can be covered by the ISS contracts. This makes the occurrence of reactive obsolescence management very difficult to avoid. To help avoid this however, we propose the automatic sharing of obsolescence data as a function of the SCT. Under the ISS contracts, Thales is already receiving information from its sub-suppliers about discontinuance dates of parts. It currently manually communicates this data to DMI in periodic obsolescence reports.

In our new model we propose that obsolescence data is standardized and shared within the SCT environment. Firstly DMI has to start registering obsolescence data within SAP. This way information about obsolescence can be analyzed, but also automatically communicated by Thales via the use of APIs. We refer to our literature review in Section 4.4 for more depth on the technicalities of this. The

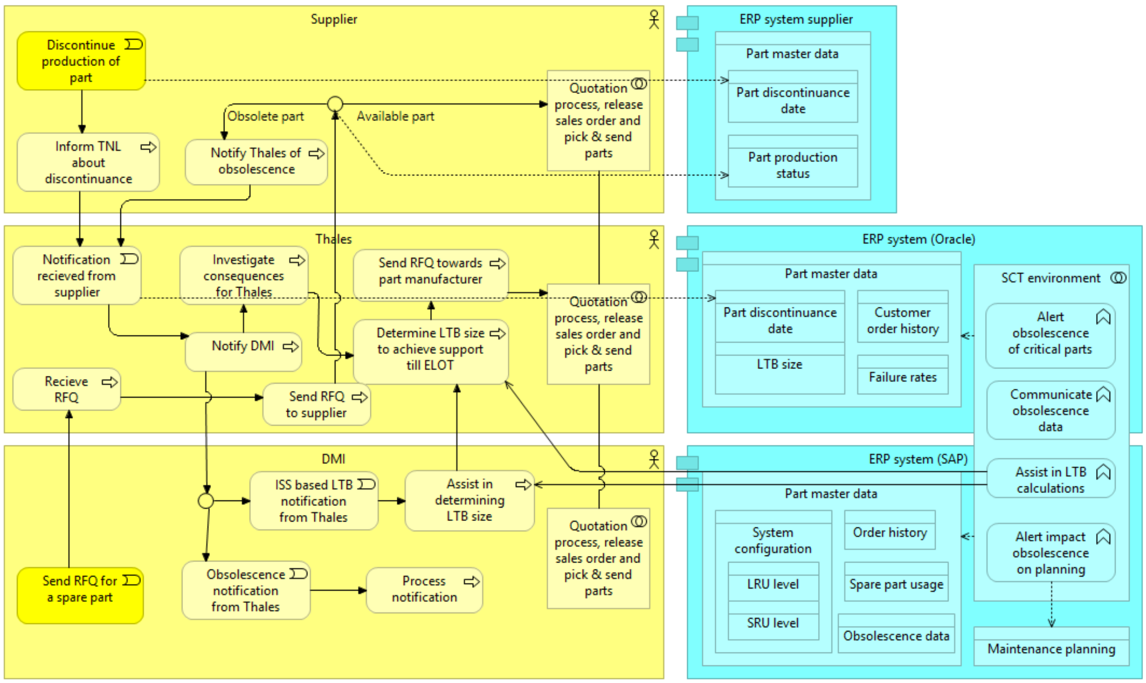


Figure 19: A new proposed obsolescence management process, supported by the SCT

simplest form of implementation would be the addition of a check box within SAP in which employees of DMI could mark a part that they received an obsolescence notification on from Thales. We suggest that in addition to this check mark it becomes possible to also log a part's discontinuance date in SAP. This allows for more coordinated planning, and the generation of alerts within the obsolescence management strategy. Currently this data is registered within the long text of a part, however this will not suffice if DMI wishes to do more effective obsolescence management. We see integrating and communicating this obsolescence data as a fundamental step towards conduct more information driven obsolescence management. By communicating this data, other SCT functionalities could be supported.

In a future state, for example, even more information can be integrated and communicated between both parties their information systems. Seuren (2018), in his paper, proposes a decision support tool to assist with obsolescence management. To operationalize this tool he proposes four categories of obsolescence data that might be use full for conducting more information based obsolescence management. These categories are (i) part identification data, (ii) item criticality data, (iii) data to estimate obsolescence resolution consequences, (iv) data to estimate the likelihood of an obsolescence issue. An abstracted version of the data types that he proposed are shown in Table 4

Seuren (2018) attributes standardized, often numerical, values to the data types described in Table 4. To exemplify this, we excerpt one data type from this study, namely item complexity. This data type is described as: *"What is the relationship between modules and the function that the modules perform?"*. This data type is then is numerically defined as: *"Response: low complexity (i.e. has modules that independently support a function) (0); Some complexity (1); Moderate complexity (2); High complexity (i.e. has highly dependent modules that support a variety of functions) (3)."*

All of these values combined are then used in a decision support tool, which determines the optimal obsolescence management strategy per part. For a part that, for example, is very complex, is only produced by a single manufacturer with which DMI has a limited relation with, is seldomely ordered, has a low technology life-time, etc., a proactive obsolescence management strategy is preferred over

Table 4: Examples of data types that could support obsolescence management. Abstracted from Seuren (2018)

Data category	**Useful for**	**Examples of data types**
Identification	Identifying a part.	Indenture level, article number, item name, item description, manufacturer.
Item criticality	Failure criticality analyses	Item's contribution to the system performance, mission criticality of item, safety criticality of item, item complexity.
Obsolescence resolution consequences	Obsolescence costs analyses.	Resolution consequences, support availability, type of item, item complexity, expected resolution time/cost, procurement price, supplier relationship.
Likelihood of obsolescence	Obsolescence risk analyses.	Expected months of unavailability date, probability of obsolescence, type of item, current life cycle stage, relationship manufacturer, technology type, number of manufacturers, successful repair probability, operating conditions.

a reactive one. For a part produced by many suppliers, with low obsolescence resolution costs, a reactive obsolescence management strategy might suffice.

When this model was applied to the SMART-L, Seuren (2018) found that for 10% of the parts considered in his case study, a proactive obsolescence management strategy was the most optimal strategy. By determining the optimal strategy beforehand, costs could be reduced, as the supply chain can respond more quickly and better prepared to occurring obsolescence issues. In this study, it was estimated that by the use of this tool obsolescence management costs could be reduced by 25%. This is of course only a case study, but it functions as an example of the possibilities that sharing and registering obsolescence data could bring for information driven obsolescence management.

6.3 Order Tracking

For the order tracking process we also modelled a new business and information systems architecture. In Section 5.3 we encountered and described two main issues concerning the order tracking process. These were the cumbersomeness for employees of DMI to review placed orders for any delays, and the issues with communicating said delays throughout the supply chain. The cumbersomeness of reviewing order status had to do with the way Thales communicated updates about orders towards DMI.

To put this into perspective of the SCT maturity grid, this influenced the level of maturity of monitoring and feedback. Orders were visually inspected to check the order status, and the feedback was based on ad hoc checks. We aimed to solve the current issues encountered by supporting these processes with SCT functionalities. We modelled this in the following subsection.

6.3.1 Opportunities and Solutions

Automatic updates about delays

Changes in the expected arrival date of an order are crucial to process within the planning of the SCT. If a product is e.g. two months late, the work order has to be moved towards a new date. Otherwise time and effort is wasted trying to do maintenance with parts that turn out to not be available on the day the maintenance is planned. We propose two new ways that delays could be processed within the SCT environment.

Firstly, the easiest solution would be to ask Thales to process this data before sending it to DMI. Simply asking the OEM to mark orders where changes have occurred, would make the work of DMI employees much easier. Thales could, for example, start by highlighting the orders on which a delay has occurred within the Excel file that they send towards DMI. This would make the task of manually searching for delays within said file, easier for the procurement department.

The second option would be to automate this process, and make it part of the SCT functionality. Instead of sending an excel file towards DMI employees, the SCT would pull information from the customer portal by the use of an Application Programming Interface (API). It could then compare the order status with the information registered in SAP. If it detects any differences, it updates the information within SAP and notifies the employees at DMI that an order has been updated.

Alert generation by delays

The second problem we encountered was that even when a delay was registered in SAP, mechanics and work planners were still often not aware of this delay. Therefore we suggest integrating alert generation as a function within the SCT environment. The data required to generate alerts would be the maintenance planning and the order status. If an order is delayed, DMI should be notified. If an order is delayed to the measure that the maintenance planning can no longer be followed, i.e. parts arrive later than the date their maintenance is planned, an alert is generated by the SCT alarming and informing all affected parties. This way the order can be expedited, or the planned maintenance can be moved to another date.

6.3.2 New Business Architecture and Information Systems Architecture

Figure 20 describes how these solutions can be implemented within the SCT. This new model builds on the model illustrated in Figure 14, but has an SCT environment that supports the after-sales service process of tracking orders. What we can see from the proposed architecture is that the SCT can pull information about the order from the customer portal and from SAP. We modelled this order information as the order status, stating whether for example the order has been processed, is waiting to be delivered or is underway, and as the expected delivery and arrival date. The SCT can compare this information and see if it matches. If the information in SAP matches with the information displayed in the customer portal, then we know that DMI is working with up-to-date information about their orders. If however DMI has a earlier expected arrival date than Thales' expected delivery date, then DMI should be notified that there has been a delay on the order. The SCT can now do two things. Firstly it will update the expected arrival date and notify the procurement department of the delay. If the delay is excessive, meaning that the maintenance planning will be influenced by delay of the order, then it can generate an alert within the after-sales service supply chain. It will alert the procurement department, allowing them to act on the alert by e.g. expediting the order. The SCT can also make this alert visible to other departments within DMI, such as the work planners and the mechanics. Implementing these functionalities within the SCT environment makes the SCT more mature on the monitoring and feedback scale, as the APIs provide relatively continuous feedback on the order status and delays no longer have to be visually inspected but are proactively shown via alerts.

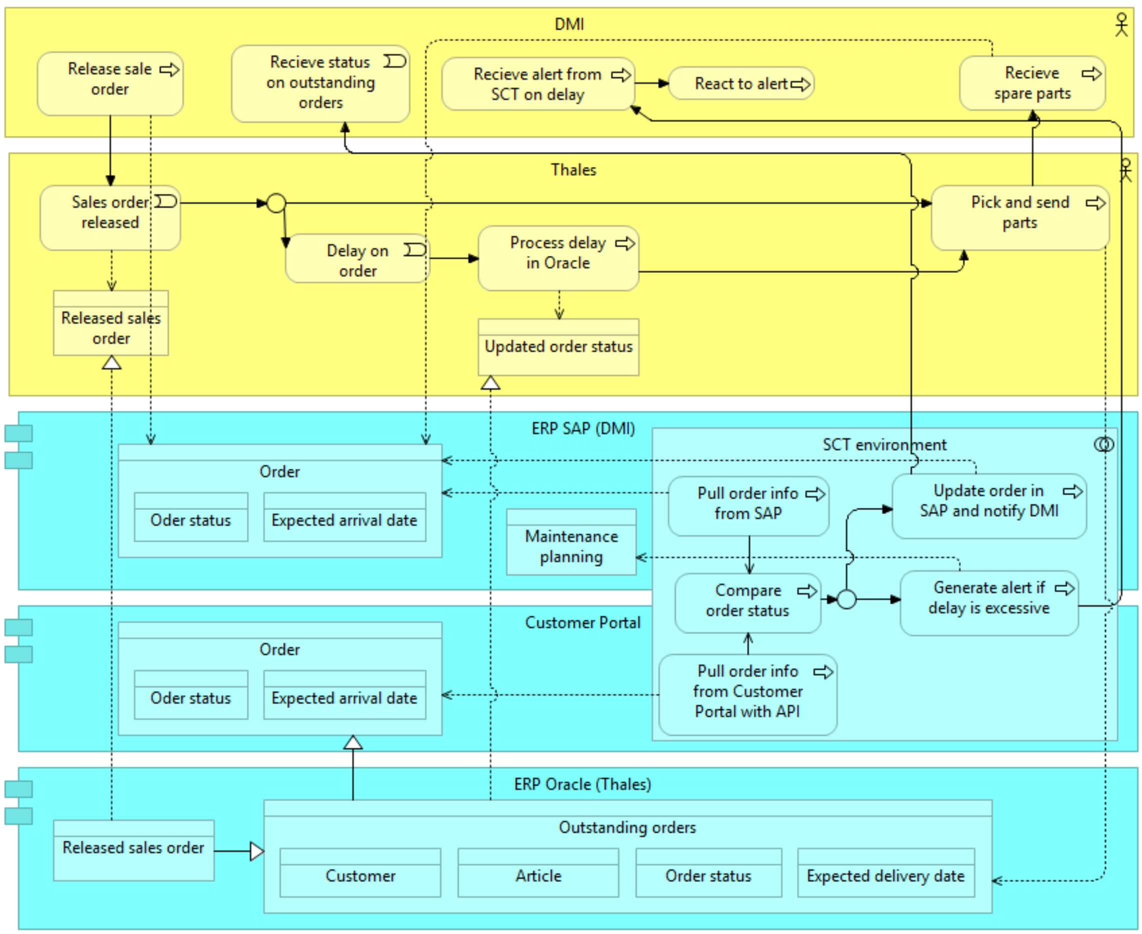


Figure 20: A new proposed order tracking process, supported by the SCT

6.4 Asset Monitoring

On the topic of asset monitoring we again focus on how data management and communication between Thales and the RNLN can be improved. In all of our previous sections we identified ways in which the sharing of certain data within the SCT environment could help support certain after-sales processes. For asset monitoring this is no different, but where in other sections we mainly focused on the data generated during the enactment of after-sales processes (transactional data, data about outstanding orders, the better registering of obsolescence data), we focus here on the data that is generated while operating and maintaining the asset. We already described the data that is currently being generated throughout the life cycle of the asset in Section 5.4. In this section we propose how, why, and when certain data might be interesting for the supply chain to share.

We wish to add that the RNLN is currently working hard to implement Information Driven Maintenance (IDM) for the year 2030 (see Section 2.1 for more information about this). Asset monitoring will play a large role in this, as data about functioning of the system can in the future determine when maintenance should be conducted. This also means that in the future a lot more usage data will be recorded about the systems on board the RNLN fleet. In the future this might offer even more possibilities for sharing usage data with the OEM. In a future state for example DMI might be able to better predict when a part will brake. Sharing this information within the SCT environment can give Thales the opportunity to already stock the part, before the order is placed. This could increase fill rates and the response time to breakdowns.

6.4.1 Opportunities and Solutions

Sharing usage data of the asset

There are a variety of reasons why it might be beneficial for the after-sales service supply chain to share usage data of the system. For the OEM, for example, receiving (customer) feedback in the form of historical operational data can be of much value for the design of future RADAR systems. We will give some examples now to support this. Data about how the system functions in certain weather conditions can aid the OEM with future design choices for new systems. The same goes for failure modes. If certain parts of the RADAR systematically break or fail because of a reoccurring reason, designers at Thales can take this into account for future designs, but also for redesigns and repairs. Failure rates and spare part operating hours can also give insights in whether or not their predictions for the MTBFs were accurate, helping them generate more accurate predictions for future systems. If DMI makes adjustments to the pre-written maintenance plan, such as reevaluating the set hours after which maintenance should be conducted, this could be interesting to share with the OEM and with other users of the same system.

However, not only the OEM would benefit from sharing usage data. In turn, sharing this data could help the OEM to provide better after-sales service towards the RNLN. On the topic of obsolescence for example, evaluating the factory data, specified during the design phase of the asset, with the historical usage data could support with making more accurate LTB calculations. We already discussed the possibility of sharing historical failure rates an failure modes in part in Section 6.2. We wish to reiterate that currently Thales only gets to see the order history of spare parts. These are not as informative as the actual failure rates observed by DMI. This is because some failures can be repaired in shop, which Thales would have no idea of. Sharing failure rates in a future state would therefore be an interesting addition.

In addition to this Thales could also be asked to share more usage data from its other clients. Determining a last time buy is assisted by looking at historical use of the spares. Most systems DMI maintains, exist in few numbers on board other vessels. Over the entire navy for example, there are only four SMART-L radars. This means that if an LTB has to be done for a certain spare part, the size of this LTB is based on a relatively small sample size. DMI could improve the accuracy of this LTB if Thales would share some (anonymized) usage data from its other clients. Then an LTB can be based on the historical data of e.g. twelve SMART-L systems, instead of four. This would triple the sample size, resulting in more accurate LTBs.

To conclude we suggest that within the SCT environment the discussed data is shared in order to help the decision support surrounding e.g. last time buys. This would help Thales gain more insights into their own systems and how they function when actually operational.

Linking system configuration between Thales and DMI

Both Thales and DMI currently have a system configuration described in their respective ERP systems. DMI has this system configuration detailed up till the LRU level, while Thales has a much more detailed system configuration described up till the SRU level. The SCT could allow for the communication of a systems configuration whenever a new system is procured. It might also be interesting for Thales to see the configuration of the systems installed at its customers. If DMI for example refurbishes a part, or keeps running a part that has exceeded its recommended operational hours, it can be interesting for Thales to see the effects of this on the system's performance. In short, linking these data sets could lead to a more detailed configuration from Thales' ERP system, allowing DMI to see the SRU configuration and Thales to see any modifications or repairs done by DMI on their system. We think that this would be valuable information for both parties.

Make agreements about data sharing

In order to actually share the discussed data, the data has to be processed so that it can be used an communicated throughout the after-sales service supply chain. We therefore recommend that a team is drawn up with employees of Thales and employees of multiple branches within DMI to review how and where the discussed data is currently stored and how it can be processed to be made useful for the other party. In Section 4.4 we already discussed the sx000i project that aims to standardize logistics support data and we learned from interviews that Thales is currently working on integrating this standard. We think that it would be beneficial for the RNLN to see what the possibilities for implementing this standard.

In any case, agreements should be made on which data each party is willing to share, how it should be shared and when it should be shared. We learned from interviews that the RNLN for example is not very keen on sharing operating data as this can sometimes contain classified information (e.g. where a ship has been and what it has been doing). We think however that there are ways to go around this by for example only sharing historical or declassified data. On the issue of when certain data should be shared we suggest that within the SCT environment triggers are installed that instigate the sharing of said data. Whenever Thales, for example, has to do an LTB calculation of a spare part that the RNLN uses, it can trigger the request of the updated failure rates, failure modes, MTTRs, spare part demand, spare part operating hours and inventory levels. With this information, a more accurate LTB calculation can then be done. When, for example, Thales starts the design of a new RADAR system, this can trigger the request of data about DMIs maintenance plans, maintenance strategy, failure modes, user experience, and maintenance logs. On the issue of how the data should be shared we suggest the possibility of using APIs. In Section 4.4 we discuss the technicalities of this in a bit more depth, but in short an API can send a request to a system, in this case the information system of DMI and then returns the requested data to the information system of Thales. Within this interaction, data can be encrypted so that it is communicated safely between both parties. The technicalities on how this API should be programmed is something we recommend further research to investigate.

6.4.2 New business and information systems architecture

In our new business and information systems architecture model we model the SCT environment as a environment where decisions could be made about what information either party wishes to share. This could be part of future ISS contract negotiations. When it is decided which and when data should be shared, the SCT could extract this data from either SAP or Oracle and share it with the respective ERP system. Here we see some large benefits for the OEM, as it receives operational data for the asset owner. In return, Thales would share a more detailed configuration of the system, up on to a SRU level. We modelled data types that we deem interesting to share.

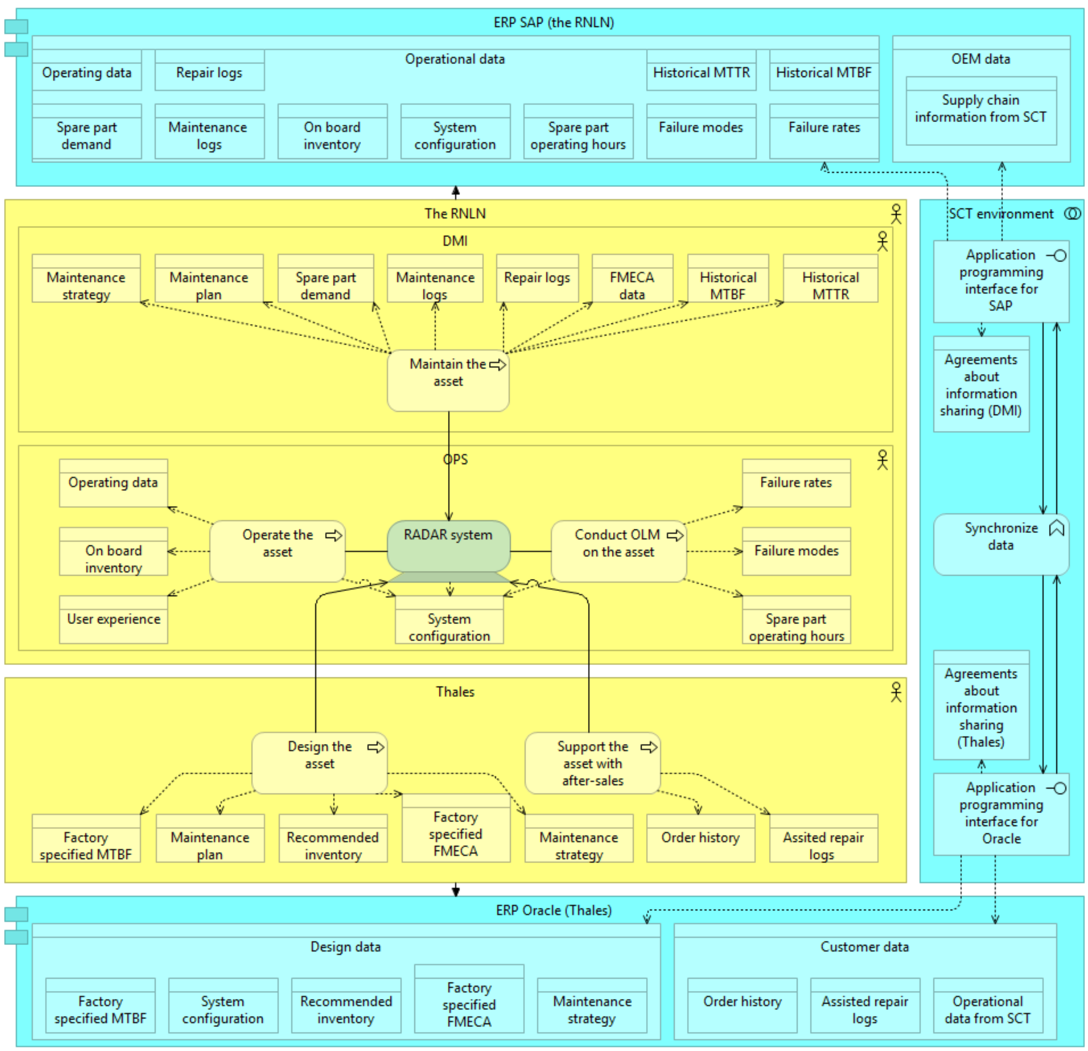


Figure 21: The new asset monitoring process. Describing what data is monitored and collected during the lifetime of an asset

In this model, APIs are constructed that can communicated between the ERP systems of Thales and the RNLN. Based on agreements made between these parties, data from these ERP systems can be extracted and synchronized. This way Thales gets e.g. synchronized failure rates, while DMI can synchronize their system configuration with the high level configuration of Thales.

6.5 New Technology Architecture

As part of the future enterprise architecture we now model a new technology architecture. In this technology architecture we added the SCT environment on top of the old architecture described in Figure 16. We have discussed previously what our view is on the physical manifestation of an SCT and in the new technology architecture shown in Figure 22 this is visualized.

As we mentioned before, we do not see an SCT as a stand alone entity. We rather see the SCT as an environment within the existing business, information systems and technology architecture in which after-sales service processes are monitored and supported by the five gradients given in the maturity grid in Figure 5. For the technology layer this means that for both DMI and Thales the SCT environment can be relatively easily constructed. We identify four elements required. Firstly there has to be an ERP zone communicator, which can extract data from the information system of either party. This can be done in the form of an API. This data can then be placed on a Service Control Tower server. From this server the data can then be communicated via the Service Control Tower communicator. Lastly, trough the passing of each environment, firewalls should be installed so that data can be safely transmitted and decisions on what data can be shared and requested can be upheld.

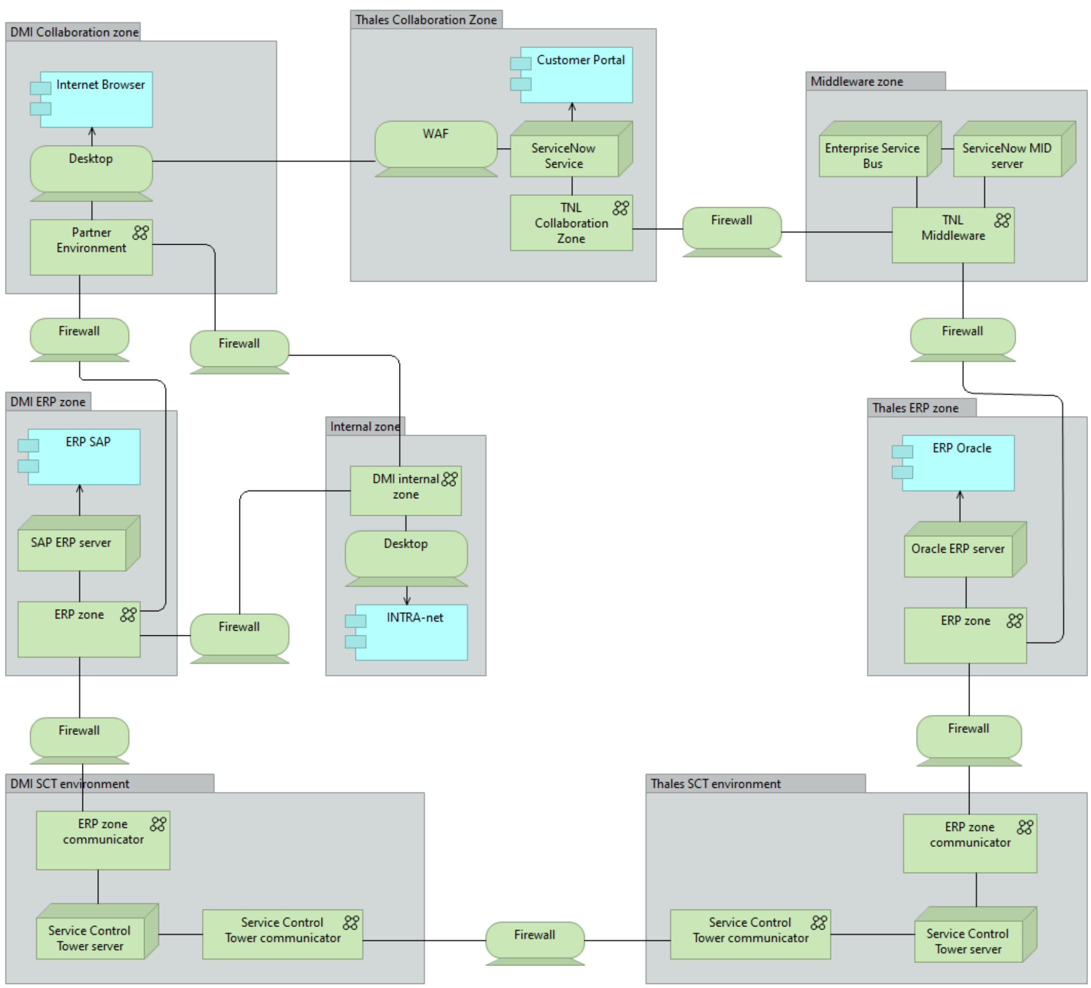


Figure 22: The new technology architecture, containing the SCT environment.

6.6 New Maturity of the SCT

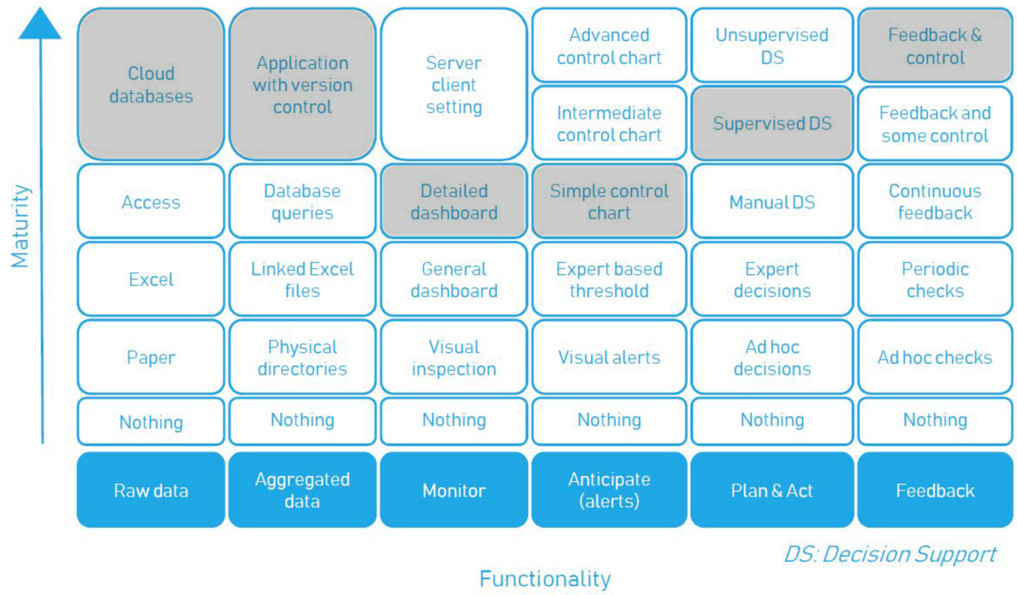


Figure 23: New maturity grid for a service control tower. Retrieved from Driessen & Keizer (2019)

Raw data

On the topic of raw data not many improvements can be made. the RNLN already stores much of its data in cloud data bases and this level was already graded fully mature. There are however still some processes which are not always properly documented by DMI, such as cannibalization of parts, and MTTRs. This could be improved and we wish to stress the importance of proper data registration for the entire after-sales service supply chain.

Aggregated data

On this topic not much can be said about improving this in the SCT perspective. It was graded fully mature and it has therefore not been a mayor focus point of this research.

Monitor

We did focus however on the maturity of monitoring within the SCT environment. In Section 6.1 we proposed the generation of a detailed dashboard within the SCT environment, which could display personalized data to departments in the supply chain. We aimed to improve this, as the current process of monitoring the supply chain performance is cumbersome and not easily accessible for departments, other than supply chain managers, at DMI. By the introduction of this dashboard we would grade the future state of the SCT as almost fully mature, on the detailed dashboard level.

Anticipate (alerts)

We proposed quite some recommendations on the implementation of alerts within the supply chain. By increasing the maturity of the monitoring aspect of the SCT environment, these alerts can now not only be based on expert thresholds, but also on control charts that flow out of the detailed dashboard. We think that these alerts would add a lot to the monitoring and anticipation of the after-sales service processes as explained in the previous sections. By basing these alerts on charts, we can increase the maturity level to simple control charts. Through time intermediate and even advanced control charts might be used, but we believe that the transition from expert based thresholds towards the use of simple control charts is an already big enough step to take on its own.

Plan & Act

On Plan & act, the maturity level was not raised. The existing level of plan & act was quite high. On the topic of LTBs however we did suggest better decision support, by communicating valuable data which could improve the LTB accuracy. This decision support will however remain supervised, which is in line with the wishes expressed by the employees of the RNLN.

Feedback

A huge leap is made on the maturity level of feedback. We identified in this research that little feedback was integrated within the information systems of the RNLN. Recommendations such as the tracking of transactional data and generating alerts when time frames are exceeded improves this level of maturity. The same goes for feedback about orders, which is currently manually processed. Automatically receiving feedback on these status is a huge leap. A level of control is added by implementing a function in the SCT which would allow an employee at the procurement department to expedite an order, or to inform a work planner that a maintenance planning has to be delayed.

6.7 Extra recommendations

Implement monthly (or weekly) meetings between service logistical parties

One of the main problems that recurred in every interview we conducted, was the poor internal communication between departments at DMI. We aimed to improve this by sharing more information within the SCT environment in the new enterprise architecture. However we propose that this is done in a broader sense than that of sharing information in the SCT environment. Employees from different departments at DMI had very infrequent contact. Complete departments are separated at the base by being stationed in different buildings, resulting in occasions were fifteen minute transits are required to visit a colleague from a different department. Therefore we propose to reintroduce monthly or bi-weekly meetings between the action holders of the service logistical processes. Most important for these meetings would be the presence of work planners, inventory managers, an employee of the procurement department. For issues that influence the spare part availability on board of a ship, we would suggest that an employee from OPS, responsible for the spare part inventory on board, is also included of that respective ship. This could be a chief of the mechanical staff. Also this base could be expanded with the presence of system engineers, when technical problems and obsolescence problems arise. These meetings don't have to be lengthy, and if there is little to discuss, that would only mean that the service logistics are doing well. However, once problems do arise they can be acted on quicker and the entire supply chain is informed of the issue. Now, they are often too contained in the department that they occur in. With periodical meetings, problems can be discussed more quickly and openly, and the supply chain feels more connected with one another, and more aligned in their common goal of supporting the operational vessels of the RNLN.

Guide correct usage of SAP by employees

Correct data collection is the foundation of good data communication within the SCT environment. However, during this research we found that employees are not always fully fulfilling their SAP related duties. Some processes are misused, or even skipped, resulting in incorrect data for the SCT. DMI should look at the possibility of enforcing correct usage of SAP by guiding or training employees if necessary. Another approach to this problem could be to task SAP as a service provider to make the use of their ERP system more foolproof. Further research could be done to investigate the possibilities to improve the system.

7 Conclusions and discussion

7.1 Conclusion

To conclude our research, we answer our main research question. We will then shortly discuss the answers to the sub-research questions, and reference where we answered them in this Thesis. Our main core research question was:

How can a service control tower support the coordination of the after-sales service logistical processes?

We defined coordination as the act of properly combining a number of objects (for instance data) for the achievement of the chain goal (see Section 3.1.2 for more depth). We limited our research scope to four after-sales service processes, namely procuring spare parts, obsolescence management, order tracking, and asset monitoring. We mapped these four processes within Archimate and investigated functions that could be integrated in the SCT environment to support these processes. We discussed these in depth in Section 6, but in short we can answer the research question as follows:

Within the after-sales service supply chain there was little back and forward communication between departments. Each department seemed to operate on its own "island", limiting the throughput of useful data for the other parties involved. This resulted in a low coordination of the after-sales service processes. New and valuable information about placed orders, for example, was not properly communicated with the supply chain. This resulted in a maintenance planning that could not be adhered and in uninformed employees that were unaware of delays or changes made to the maintenance planning. For obsolescence management this issue of coordination presented itself in parts that turned out to be obsolete after they had been ordered, and delays caused by obsolescence not being communicated throughout the supply chain. On the topic of asset monitoring valuable information was not properly registered or communicated with the Thales, the Original Equipment Manufacturer. This data however could be used to provide a better after-sales service.

So, how can a Service Control Tower improve this coordination? The SCT can function as a collaboration environment in which data can be shared throughout the supply chain. In the SCT environment Application Programming Interfaces (APIs) can be programmed which can request and transfer information throughout the supply chain. Multiple types of data have been identified that would be interesting to monitor internally at the RNLN such as the transaction data generated in the procurement process, allowing for better monitoring of the execution of the process. We also identified data to share outside of the information system environment of the RNLN. Lastly, we constructed functionalities that improve the coordination of the after-sales service by sharing data between Thales and the RNLN within the SCT environment. For obsolescence management, for example, more accurate Last Time Buys could be calculated by historical data about failure rates, user data can be communicated to aid Thales with the design of future systems.

All in all, we identified many functions for a future SCT environment that could support the coordination of the after-sales service processes. What these functions have in common is that they increase the communication of data within the supply chain and that they support the after-sales processes by combining the data from different departments, that was previously not shared. What we also tried to achieve by this research is to change the current perspective on data communication within the supply chain. Our recommendations can be used as a basis for discussion between the RNLN and Thales about the way the after-sales service is organized. They provide a starting point for developing a after-sales service supply chain with more open communication, but we commend both parties to continue to look for ways in which their cooperation and coordination can be improved, as we believe that we have provided sufficient evidence of its benefits.

7.2 Discussion

During this research we identified multiple ways in which a Service Control Tower could support the coordination of the after-sales service. Most solutions were found in the area of data communication within the after-sales service supply chain. By improved data communication, processes could be monitored in more detail and feedback on these processes could be improved. Also, cumbersome and error-prone tasks could be automated and standardized, such as the communication of delays on orders, and the registration of obsolescence.

We came to our results via two research methodologies, the Managerial Problem Solving Method (MPSM) and the Architecture Development Method (ADM). The MPSM was used to guide our research process, providing a research cycle to come to a solution for a knowledge problem. In this case the knowledge problem was about a future enterprise architecture, in which an SCT supported the after-sales service. In order to construc this new enterprise architecture we used the ADM. By using this cycle, we mapped the current enterprise architecture, identified opportunities and solutions for a new one, and presented the steps needed to be taken to migrate to this future enterprise architecture.

The analyses in our research were based mostly on interviews with actors throughout the entire after-sales supply chain. The interviews we conducted are summarized in appendix C. Although being our preferred method of research, we recognize that qualitative interviews do have some weakpoints. We discussed this in more detail in Section 3.2.3. Because of the limits of interviews as a sole information source, we did multiple things to minimize these risks. During the interviews we requested quantitative data from employees to substantiate their claims, resulting in appendix D and appendix E. Furthermore we interviewed employees of the many different responsible departments throughout the supply chain, to avoid gaps of information. This resulted in interviews with the system operator: OPS, a work planner, an inventory manager, a system engineer, a supply chain manager, a procurer, and on the side of Thales a product manager services. To extend our view on the cooperation with Thales, we connected with the Royal Netherlands Air force to see if their cooperation with Thales was comparable, and we contacted experts on the topic of Service Control Towers. Lastly, we tried to validate information given by one party, as much as possible with the other actors in the supply chain. This resulted in a confirmation of the current enterprise architecture on the side of Thales and the RNLN.

7.3 Further research

With the performed research, we have provided a clear framework for the SCT environment, and proposed many improvements to the after-sales service supply chain. To further build on this research, and to help make the proposed framework a reality, we have some suggestions for future research directions.

During our research, we mainly focused on the business and information systems architecture. The technology architecture layer was constructed from previous research done by de Vries (2020), and information given during interviews with employees of DMI. However, because of time constraints little quantitative research was done on the technology architecture at the RNLN. We therefore suggest that further research looks in to this with more detail.

We also suggest that in a future research project, more classified information is investigated and taken in to account when designing the technical specifications of the SCT environment. In this research, we were only allowed to view unclassified information. This sometimes limited our research as the more in depth reasons for the, for example, malfunctioning of a system required us to view classified information about how the system operated, which we were not allowed to. As discussed in Section 5.3, for example, it was unclear what halted the flow of information about a delay throughout the supply chain. It was clear that there was a bottleneck in the information flow, but in order to clearly identify where it lay, we needed a higher level of authority. Especially when researching the technical specifications required to, for example, construct the Application Programming Interface (API)s that would support the SCT environment, classified information will be required about the functioning of SAP and Oracle.

Lastly, we suggest that further research is done in the field of inventory management. This part of the after-sales service logistics is partially integrated in our SCT framework in the form of order tracking, the monitoring of on-board inventory and the calculations of LTBs. We do think however that there is are more opportunities within this field for the SCT to support the after-sales service, such as the improved communication and calculation of optimal stock levels of spare part.

All with all, we think that the research we conducted provides a good starting point for the improvement of the inter-organizational communication via the implementation of an SCT environment. Multiple solid improvements are proposed, that were recognized by all parties to be beneficial to the functioning of the after-sales service, and we are confident that our research can contribute to the conversation of what the after-sales supply chain of the future should look like.

8 References

Accenture. (2015). *Supply chain control towers in the high-tech industry.* Retrieved from `https://www.accenture.com/nl-en/insight-new-supply-chain-control-tower`

AeroSpace & Defence Industries Association of Europe (ASD) and Aerospace Industries Association (AIA). (2018). *International guide for the use of the s-series integrated logistics support (ils) specifications.* Retrieved from `https://www.sx000i.org/about-sx000i/` ([Online; accessed October 26th, 2020])

Bisschop, J. (2020, July 31). Interview.

Biswas, S., & Sen, J. (2016, August). A proposed architecture for big data driven supply chain analytics. *IUP Journal of Supply Chain Management*, *XIII*, 7-33. doi: 10.2139/ssrn.2795906

Cohen, M., & Lee, H. (1990, January). Out of touch with customer needs? spare parts and after sales service. *Sloan Management Review*, *31*, 55.

Condra, L., Anissipour, A., Mayfield, D., & Pecht, M. (1997, Oktober). Electronic components obsolescence. *Components, Packaging, and Manufacturing Technology, Part A, IEEE Transactions on*, *20*, 368 - 371. doi: 10.1109/TCPMA.1997.623032

de Vries, D. (2020, April). *Service control tower framework for spare parts service.* Retrieved from `http://essay.utwente.nl/80989/`

Driessen, J., & Keizer, M. O. (2019). *Smart after-sales services through the use of service control towers* (Tech. Rep.). Vonderweg 16 5616RM Eindhoven: CQM.

Guru. (2020). *Introduction to master data.* Retrieved from `https://www.guru99.com/introduction-to-master-data.html` ([Online; accessed September 8th, 2020])

Heerkens, H., & van Winden, A. (2017). *Solving managerial problems systematically.* Noordhoff Uitgevers. (Translated into English by Jan-Willem Tjooitink)

Hurib Visser. (2000, February). *Stichting signaalmuseum.* Retrieved from `https://www.holechistorie.nl/media/Nerg-uitgave-signaalmuseum-historiehollandsignaal.pdf` ([Online; accessed August 27th, 2020])

Jalil, M. (2011). *Customer information driven after sales service management: lessons from spare parts logistics* (No. EPS-2011-222-LIS).

Jimenez, V. J., Bouhmala, N., & Gausdal, A. H. (2020). Developing a predictive maintenance model for vessel machinery. *Journal of Ocean Engineering and Science*. Retrieved from `http://www.sciencedirect.com/science/article/pii/S2468013320300279` doi: https://doi.org/10.1016/j.joes.2020.03.003

Jongebloed, B. (2020, August 7). Interview.

Keizer, M. O. (2020, July 23). Interview.

Kloosterziel, B. (2020, August 3). Interview.

Koning, M. (2020, June 22). Interview.

Kumar, P. (2014, March). Master data management (mdm) – strategies, architecture and synchronisation techniques..

Kumar, R. S., & Pugazhendhi, S. (2012). Information sharing in supply chains: An overview. *Procedia Engineering*, *38*, 2147 - 2154. Retrieved from http://www.sciencedirect.com/science/article/pii/S1877705812021716 (INTERNATIONAL CONFERENCE ON MODELLING OPTIMIZATION AND COMPUTING) doi: https://doi.org/10.1016/j.proeng.2012.06.258

Lotfi, Z., Mukhtar, M., Sahran, S., & Taei Zadeh, A. (2013, December). Information sharing in supply chain management. *Procedia Technology*, *11*, 298-304. doi: 10.1016/j.protcy.2013.12.194

Macrotrends.net. (2020). *Netherlands military spending/defense budget 1960-2020.* Retrieved from https://tradingeconomics.com/netherlands/military-expenditure-percent-of-gdp-wb-data.html ([Online; accessed September 19th, 2020])

Marineschepen.nl. (2018, May). *Koninklijke marine in cijfers 1945 - 2018.* Retrieved from https://marineschepen.nl/dossiers/marine-in-cijfers.html ([Online; accessed August 27th, 2020])

Marineschepen.nl. (2020). *Vervanger m-fregatten (nederland en belgië).* Retrieved from https://marineschepen.nl/schepen/nieuwe-fregatten-2023.html ([Online; accessed July 7th, 2020])

Ministerie van Defensie. (2019). *Aantallen personeel.* Retrieved from https://www.defensie.nl/onderwerpen/overdefensie/het-verhaal-van-defensie/aantallen-personeel ([Online; accessed July 7th, 2020])

Mokashi, A., Wang, J., & Vermar, A. (2002). A study of reliability-centred maintenance in maritime operations. *Marine Policy*, *26*(5), 325 - 335. Retrieved from http://www.sciencedirect.com/science/article/pii/S0308597X02000143 doi: https://doi.org/10.1016/S0308-597X(02)00014-3

Molenaar, L. (2020, June 9). Interview.

Moon, Y. (2007, January). Enterprise resource planning (erp): A review of the literature. *Mechanical and Aerospace Engineering*, *4*. doi: 10.1504/IJMED.2007.012679

Nederlands Instituut voor Militaire Historie. (2010, April). *Leeswijzer marinegeschiedenis.* Retrieved from https://www.defensie.nl/binaries/defensie/documenten/brochures/2010/04/15/leeswijzer-marinegeschiedenis/leeswijzer-marinegeschiedenis.pdf ([Online; accessed August 28th, 2020])

Nederlandse Organsiatie voor Wetenschappelijk Onderzoek. (2019, April). *Maritime remote control tower for service logistics innovation (marconi).* Retrieved from https://www.nwo.nl/en/research-and-results/research-projects/i/49/32849.html ([Online; accessed August 28th, 2020])

Öner, K., Franssen, R., Kiesmuller, G., & Houtum, van, G. (2007). *Life cycle costs measurement of complex systems manufactured by an engineer-to-order company.* Technische Universiteit Eindhoven.

Ozkan, B., & Bulkan, S. (2016, Augustus). Cots parts obsolescence management of sustainment dominated military systems.. doi: 10.14339/STO-MP-SAS-OCS-ORA-2016

Pecht, M., & Das, D. (2000, April). Electronic part life cycle. *Components and Packaging Technologies, IEEE Transactions on*, *23*, 190 - 192. doi: 10.1109/6144.833060

Petersen, L. (2000). The use of commercial components in defense equipment to mitigate obsolescence. a contradiction in itself? In *Rto meeting proceedings 72 on strategies to mitigate obsolescence in defense systems using commercial components* (pp. 23–30). D-69046 Heidelberg: ACM.

Pollmann, B. (2020, May 27). Interview.

Ranjan, S., Jha, V., & Pal, P. (2016, January). Literature review on erp implementation challenges. *International Journal of Business Information Systems*, *21*, 388. doi: 10.1504/IJBIS.2016.074766

Rojo, F., Roy, R., Shehab, E., & Wardle, P. (2009, January). Obsolescence challenges for product-service systems in aerospace and defence industry.

Schallmo, D. (2018, July). Clarifying obsolescence: Definition, types, examples and decision tool clarifying obsolescence: Definition, types, examples and decision tool..

Seuren, T. (2018). *From reactive to proactive obsolescence management: a guide for implementing proactive obsolescence management within the dutch maritime industry* (MSc. thesis). University of Eindhoven.

Simatupang, T., Hun, B., & Sridharan, R. (2002, Augustus). The knowledge of coordination for supply chain integration. *Business Process Management Journal*, *8*, 289-308. doi: 10.1108/14637150210428989

Singh, P., Sandborn, P., Geiser, T., & Lorenson, D. (2011, Oktober). Ijams electronic part obsolescence driven product redesign planning. *Internat. J. Adv. Manufacturing Systems*, *7*.

Sluijter, P. (2020, June 23). Interview.

Sturm, R., Pollard, C., & Craig, J. (2017). Chapter 11 - application programming interfaces and connected systems. In R. Sturm, C. Pollard, & J. Craig (Eds.), *Application performance management (apm) in the digital enterprise* (p. 137 - 150). Boston: Morgan Kaufmann. Retrieved from http://www.sciencedirect.com/science/article/pii/B9780128040188000115 doi: https://doi.org/10.1016/B978-0-12-804018-8.00011-5

Thales Group. (2008, Oktober). *Integrated mast.* Retrieved from https://www.thalesgroup.com/en/innovation/integrated-mast ([Online; accessed July 16th, 2020])

Thalesgroup.com. (2019). *Defence in netherlands.* Retrieved from https://www.thalesgroup.com/en/countries/europe/netherlands/defence-netherlands ([Online; accessed August 27th, 2020])

The Open Group. (2007, July). *Service-oriented architecture (soa)* (Tech. Rep. No. W074). 44 Montgomery St. 960 San Francisco, CA 94104: The Open Group. Retrieved from https://publications.opengroup.org/w074

The Open Group. (2018, April). *Togaf version 9.2.* Retrieved from https://pubs.opengroup.org/architecture/togaf9-doc/arch/ ([Online; accessed July 27th, 2020])

Tinga, T., Tiddens, W., Amoiralis, F., & Politis, M. (2017, June). Predictive maintenance of maritime systems: Models and challenges. In (p. 68-68). doi: 10.1201/9781315210469-56

Topan, E., Eruguz, A., Ma, W., van der Heijden, M., & Dekker, R. (2020, April 16). A review of operational spare parts service logistics in service control towers. *European Journal of Operational Research*, *282*(2), 401–414. doi: 10.1016/j.ejor.2019.03.026

Veenstra, W. (2016). *Royal netherlands navy future fleet capabilities: A continuation of rational thinking.* (Unpublished master's thesis). Netherlands Defence Acadamy, The address of the publisher.

A Interesting figures about the RNLN

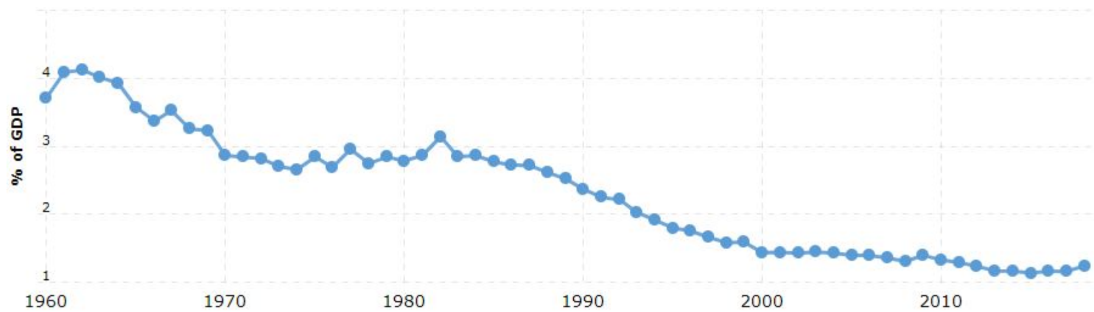
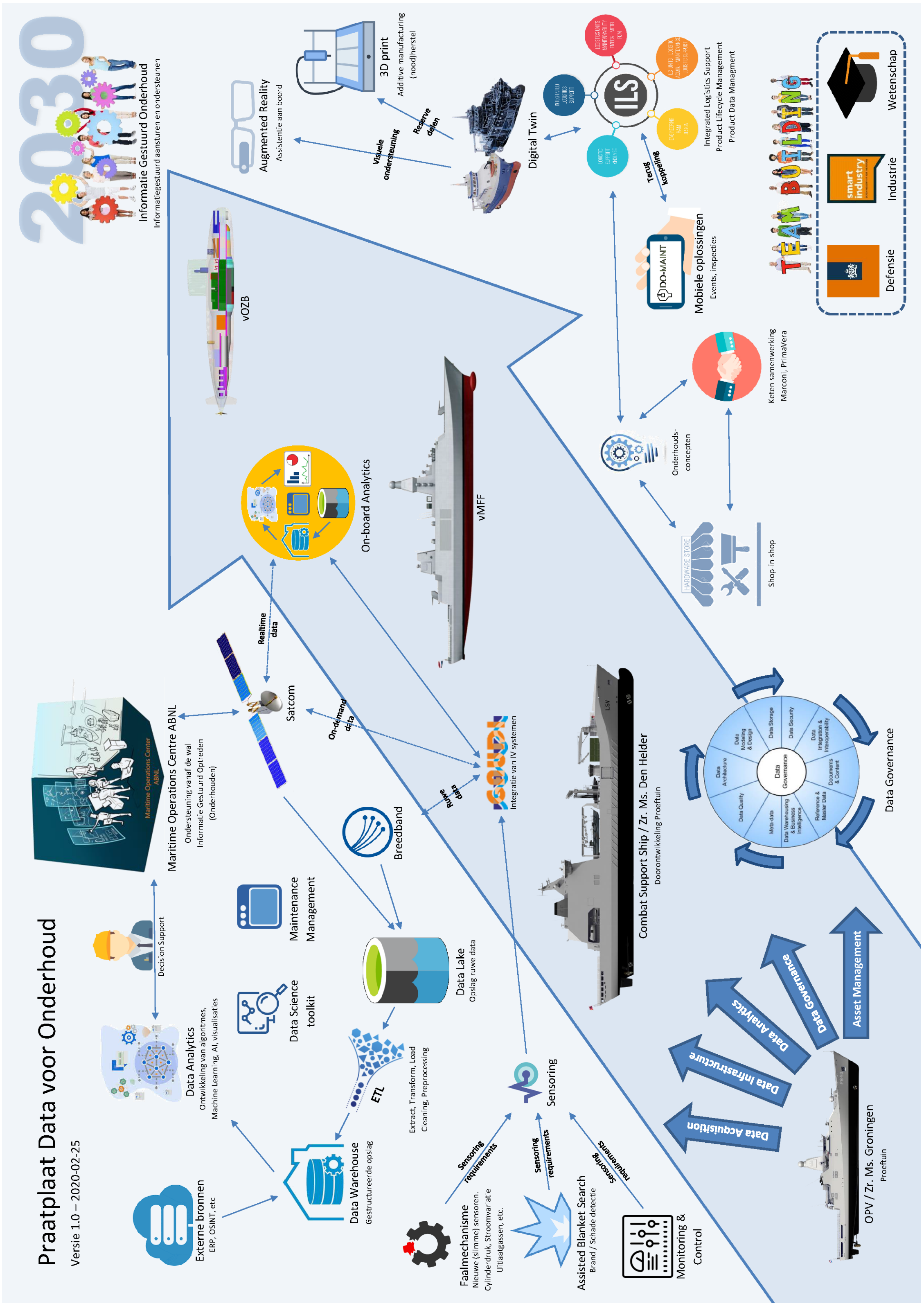


Figure 24: Military expenditure of the Netherlands in % of GDP. Abstracted from Macrotrends.net (2020)

Figure 25: Current fleet of the RNLN.

B Roadmap for information driven maintenance



C Interview summaries

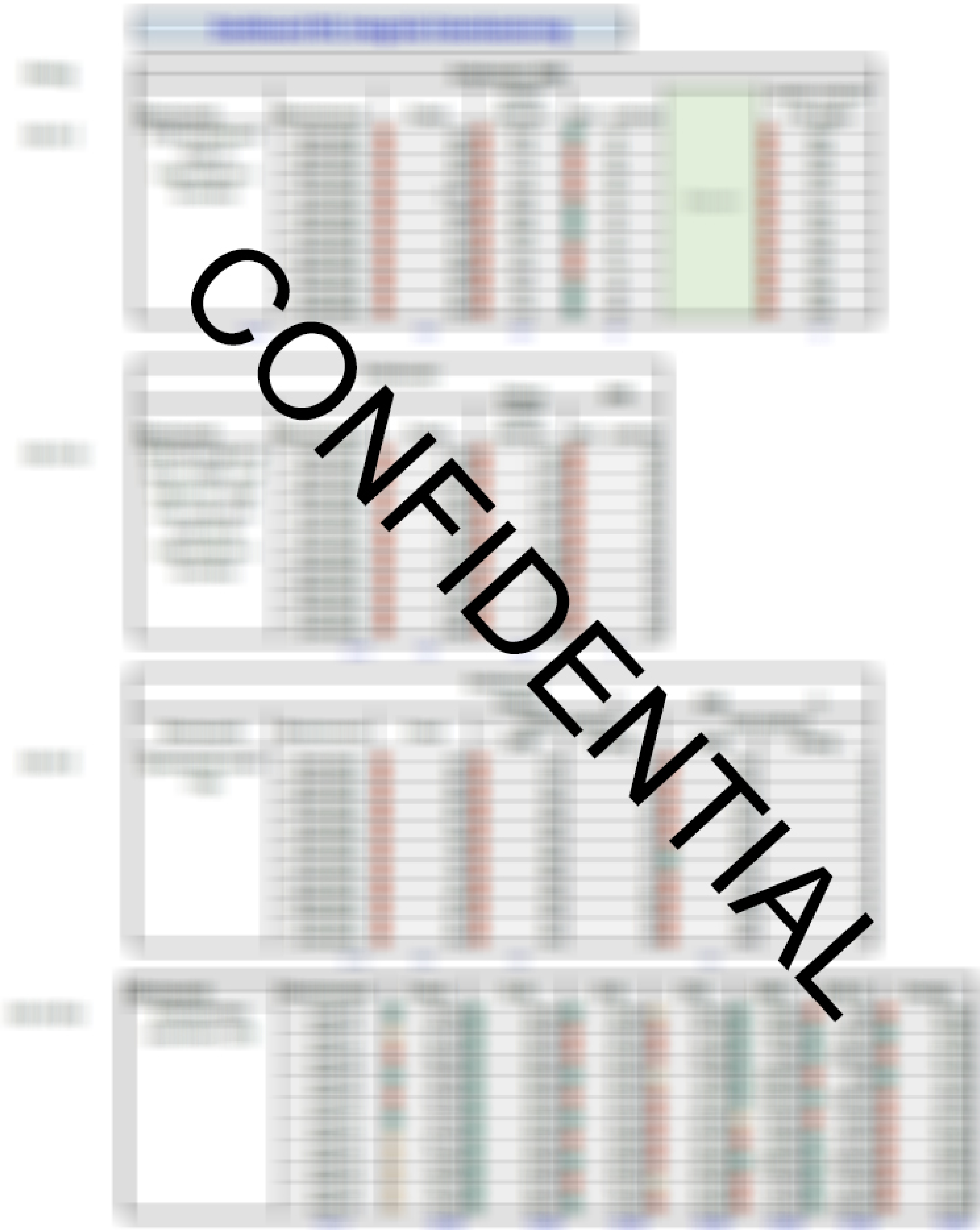
Date	Who	Location	Summary
9th of June	Leen Molenaar, Marcel Koning, Peter Sluiter, Marcel Gosler	DMI	This was our introduction interview, which lasted approximately two and a half hours. The four employees I spoke with were respectively the system engineer for the APAR, an inventory manager, a supply chain manager, and a work planner. From this interview i learned the main concerns that all four parties had regarding the after-sales service, providing the research with a good direction to search in for solutions. The main topics were obsolescence management regarding the ISS contracts and the systems that did not fall under these contracts, and the issues regarding spare parts not being delivered on time without informing the mechanics.
22th of June	Marcel Koning	Noorderkroon	Based on previous interview we sought contact with Marcel Koning, who is an inventory manager at DMI. We had previously learned some of the troubles that employees at DMI were experiencing on a day to day basis, but we had little insight in what a regular day looked like. Marcel gave us a very clear description of all the actors within the supply chain and how the spare parts required for the maintenance are eventually procured. We learned about ATBs, the planning function of SAP, the MRP run, the difference between BO and ILM. We also learned how in SAP currently obsolescence is registered and acted upon. Marcel stated that there was no real obsolescence management strategy in place for the systems that do not fall under the ISS contracts. All cases were managed on a case by case basis.
23th of June	Peter Sluijter	Via a mobile conference	We contacted Peter, the supply chain manager, in order to get quantitative data about the supply chain performance. We learned from previous interviews what issues were encountered, yet we had no real data to substantiate these claims or to show the size of the problem. Peter gave us insights into the dashboard described in appendix D. We discussed this dashboard, but Peter could not tell us what details made up these eventual numbers. We were for example interested in knowing the percentage of unfixated ATBs caused by obsolescence. Unfortunately we found no answer for this, so we had to nuance this in our research. We were happy however that we could finally support and scope the problem by quantitative data.

Date	Who	Location	Summary
1th of July	Jan Beest, and multiple crew members on the van Speijk	While sailing with the van Speijk	We got the opportunity to join the crew of the van Speijk, a multi-purpose frigate for three days on a mission in front of the Dutch coast. Here we interviews Jan Beest, a chief of the mechanical staff on board of the frigate was responsible for registering the spare part usage of the sensors and weapon systems. This included the RADAR systems on board of the ship. We mostly discussed how spare parts are stored on board of the ship and how they make a ship operational when they are required to go on a mission. From this we learned about the ease of thought on cannibalization of spare parts. Crew members on board openly discussed that if the parts were not delivered on time, the only real solution to make the ship operational was to take the spare parts of other frigates. This was badly documented within SAP.
6th of July	Weapon system support crew of the Royal Netherlands Air Force (RNLAF)	Logistical headquarters in Woensdrecht	We contacted the RNLAF in order to find out how their cooperation with Thales was, regarding the after-sales service. Our thought behind this was that the RNLN was not the only (governmentally instituted) customer of Thales, so maybe other defence organizations had interesting agreements in place that the RNLN could learn from. On the phone this sounded very promising, however when we arrived it quickly turned out that the RNLAF simply did not have the same problems that the RNLN encountered. This was because the RNLAF only had 1 active radar installation from Thales which was fully covered under their ISS contracts. Their contracts spanned even further, not even allowing the RNLAF to conduct any maintenance on the RADAR. Basically they paid for the coverage of the RADAR. It was a very interesting meeting, but it unfortunately did not provide us with any insights that we could adapt at the RNLN.
7th of July	Berend Jongebloed	A mobile conference	Berend Jongebloed is a product manager services at Thales. He is deeply involved within the MARCONI project and is in regular contact with the RNLN. With Berend, we had many talks about validating how we were told the processes at Thales were constructed, and about sparring what functions of the SCT could benefit Thales as well. We learned that Thales was very interested in details about failure rates and failure modes, in order to make their LTBs more accurate. Besides these insights we mainly validated the Thales side of our enterprise architecture

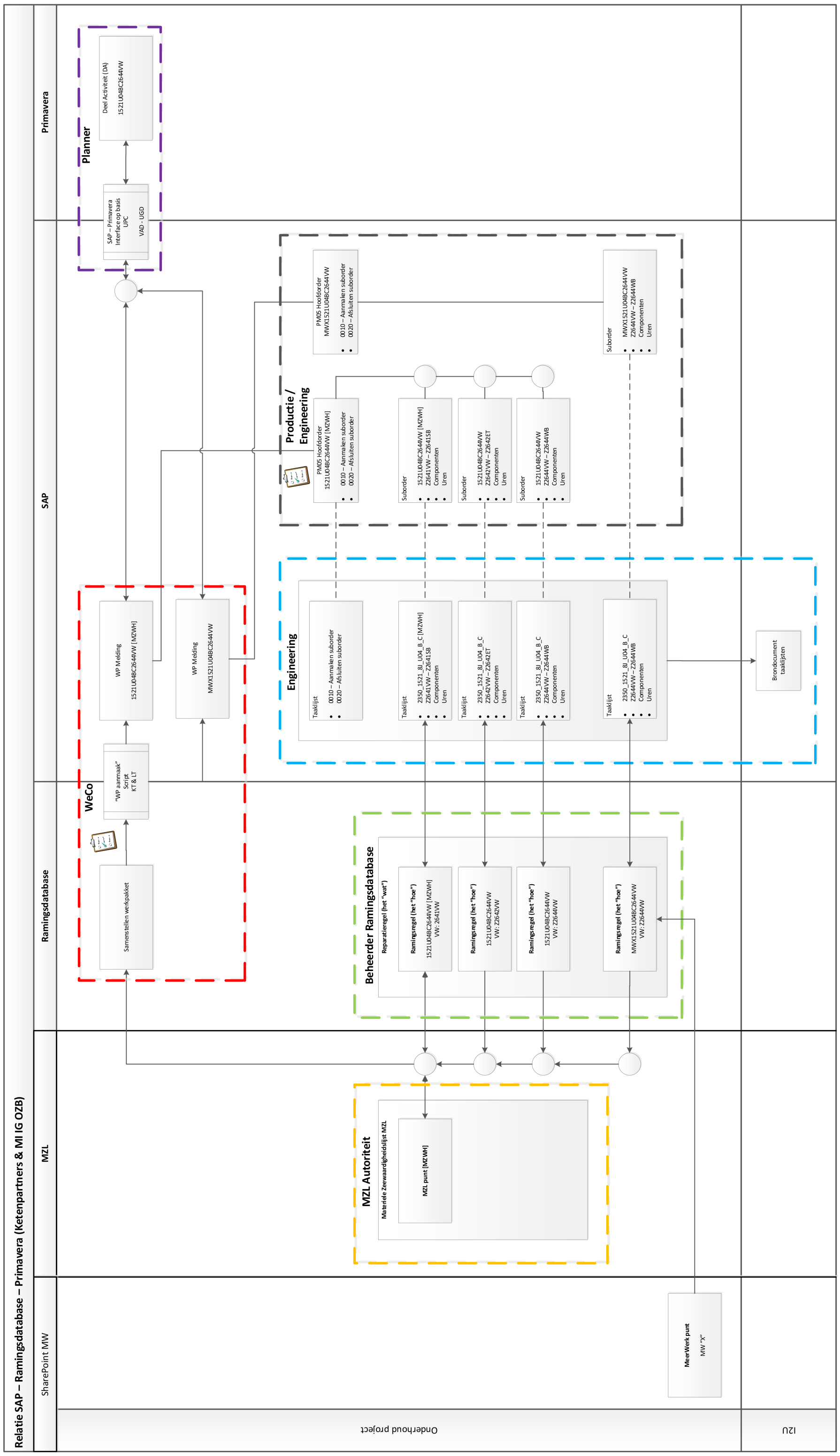
Date	Who	Location	Summary
23th of July	Minou Olde Keizer from CQM	A mobile conference	Minou is the expert on the topic of SCTs that we approached during our research. We found her white paper in the literature and decided to seek contact with her as some things from her white paper still seemed unclear to us. We are very thankful for her contribution, as our view on SCTs changed dramatically after speaking with her. We got rid of the idea that an SCT has to be a rigid seperate entity outside of the existing information system of an organization. In contrast, we learned to see the SCT more as an environment that allowed parties of the supply chain to send and request data that they could use for their own analyses. We saw this as a huge improvement, as now difficulties such as ownership issues were out of the way. The only limits were the agreements made between parties about data sharing.
31th of July	Jelger Bisschop	A mobile conference	We were put into contact with Jelger Bisschop, another system engineer for the submarine division of the RNLN. We were advised to take up contact with Jelger, as he was one of the first system engineers to actively combat the problem of obsolescence within his department. He had a very proactive stance on obsolescence management and strove for better documentation of obsolescence issues. From our interviews we learned about the "fietsendrager-methode" and the issues of improperly registering data within the maintenance processes. Jelger stressed the importance of data standardization and the feedback of the system when employees did not properly fulfill their tasks surrounding data management.
3th of August	Bert Kloosterziel	Noorderkroon	Bert Kloosterziel is an employee at DMI that works within the procurement department and as a head contract manager for the ISS contracts. He is therefore often in contact with Thales and provided us with a lot of insights on how the actual communication with Thales went. From this we learned for example about the unsorted excel files DMI received from Thales concerning their order status.
6th of August	Berend Jongebloed	A mobile conference	We again spoke with Berend to validate the new insights we got about the interaction with Thales from DMIs perspective. Also we discussed our vision on the SCT. Berend was interested in how this idea of an open data sharing environment could be extended to sub-suppliers of Thales.

Date	Who	Location	Summary
26th of August	Minou Olde Keizer, Bart Pollman, and Jan from CQM	Teams	CQM was interested in our progression with the research and sought contact with us and Bart Pollman from DMI. No real new topics were discussed, we only sharpened our view on the interpretation of the SCT environment.
19th of October	Berend Jongebloed	Microsoft Teams	To finally validate all of our Archimate models, we contacted Berend once more to walk through these models. He could confirm that what we modelled was accurate. He requested to make the models even more personalized, indicating what actor is precisely responsible for what activity within the after-sales service supply chain.

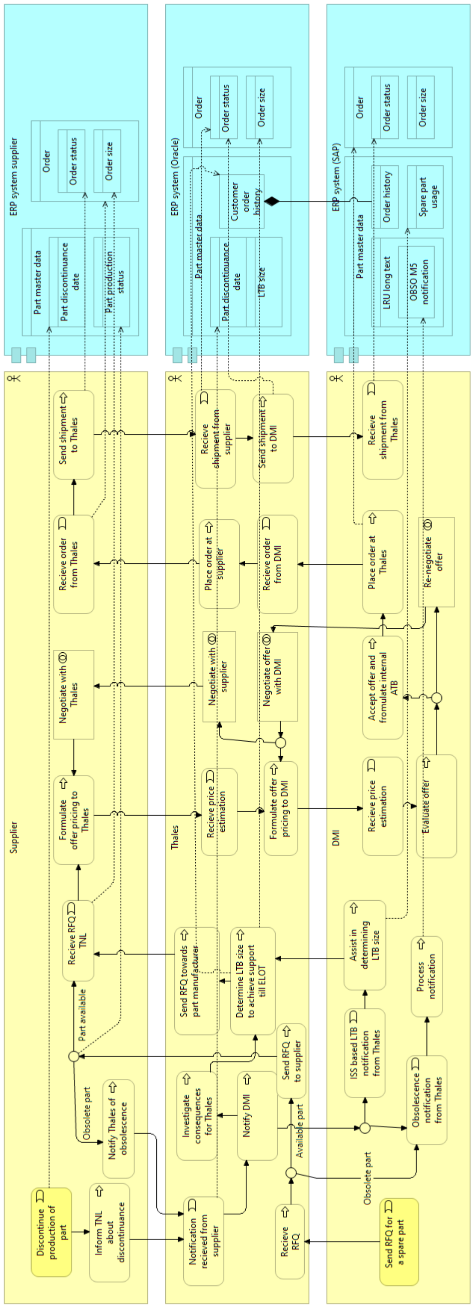
D Dashboard supply chain performance of the RNLN



E Information system interaction within the RNLN



F Obsolescence management architecture (long version)



G Systematic literature review

In this Appendix one Systematic Literature Review (SLR) is completely described, in order to give an insight in the methods we used in this research to find the cited literature. For this SLR we will try to answer one of the knowledge problems. We choose the research question: What processes fall under the scope of a Control Tower? This is an important question to answer, because it gives perspective on the possibilities of the Control Tower architecture. This is also a knowledge question that can be solved by doing a SLR.

Included in this scope will be papers that:

- List design approaches concerning a control tower architecture.
- Talk about the types of integrated processes in a control tower.
- Compare functionality between existing control towers.
- Propose functionality for future control towers.

Excluded from this scope will be papers that:

- Articles that only focus on coding aspects.
- Articles that are not written in Dutch or English.
- Talk about actual physical (air traffic) control towers.

Method
To do this SLR, I will be using the databases Scopus and Web of Science. I choose these two databases because all of the content is peer-reviewed, and their focus is multidisciplinary. I want peer-reviewed articles only because they increase the credibility of the source, and I want a multidisciplinary focus, because a control tower is often an integration between departments. This eliminates PsycInfo (behavioral focused), Business Source Elite (management, economics focused) and Google Scholar (contains non-peer reviewed articles). It is possible that by searching in both engines, duplicates are found. These will be noted and reduced to single articles.

Search strategy
The detailed process of searching for the articles can be found in appendix A. Here I will briefly discuss my search strategy. I started with the keyword "control" & "tower". This was to broad, so I limited it to "control tower". This narrowed down the entries. A lot of articles discussed physical (often air traffic) control towers, so I added logistic(s) in the search. This resulted in a manageable amount of research papers.

Conclusions
The resulted articles and their summarized findings can be viewed in appendix A. The articles gave quite some insight on the knowledge question. One article (Topan, E., 2020) proposes the implementation of spare parts service logistics as a function of a service control tower. In a different article (Ji, S.-W., 2013) a more analytical perspective is taken on the information handling of a control tower and puts forward the idea of a quality control aspect within the control tower. This could be translated towards the navy with KPI's specified for the performance of their maintenance process. Two articles ((Baumgraß, A., 2015) and (Hofman, W., 2014)) propose the functions of monitoring resources and tasks, and exception handling. To answer the research question, most functionalities attributed to control towers, consist of monitoring and visualizing of real time inventory, process performance, recourse and job data. It also has functionality in the handling department, allowing users to receive real time advise and intervene on tasks, when necessary. With this SLR we have answered the knowledge question.

Article name	Author	Year published	Author Keywords	Key concepts
A review of operational spare parts service logistics in service control towers.	Topan, E., Eruguz, A.S., Ma, W., van der Heijden, M.C., Dekker, R.	2020	Operational planning, Review, Service control towers, Spare parts, Supply chain management	Identifies needs of control tower in practice, by surveys.
Study on supply chain information control tower system	Ji, S.-W., Tian, Y., Gao, Y.-H.	2013	Double-loop feedback control, Information control tower, Supply chain	Discusses Real time information visibility within an information control tower system.
Dynamic resource allocation with the arc control tower	Filipčič, A., Cameron, D., Nilsen, J.K.	2015	Control towers, Distributed computer systems, Dynamics, Employment, Job analysis, Middleware, Resource allocation, Software design, Software engineering	Describes dynamic resources allocation, and job management preformed by a control tower
A software architecture for transportation planning and monitoring in a collaborative network	Baumgraß, A., Dijkman, R., Grefen, P., Völzer, H., Weske, M.	2015	Collaborative networks, Control tower, Transportation, Transportation management system, Transportation planning	Presents software architecture for transportation control towers.
Control tower architecture for multi - and synchromodal logistics with real time data	Hofman, W.	2014	Agent technology, Decision support, Information and communication technology for supply chain management, Multimodal and synchromodal logistics	Presents a first draft of control tower architecture that can handle real time data for exception handling and transaction coordination.
Enabling improved process control opportunities by means of logistics control towers and vision-based monitoring	Alias, C., Kalkan, Y., Koç, E., Noche, B.	2014	Control towers, Decision making, Design, Distributed computer systems	Presents three application examples for a visual control tower tool

Figure 26: SLR Articles found

Database	**Search input**	**Scope**	**Date range**	**Entries**
Web of Science	"Control tower"	Topic	All years	6820
Web of Science	("control tower" AND "Logistics") OR ("control tower" AND "architecture")	Topic or Title	All years	25
Web of Science	"control tower" AND ("Field" OR "range" OR "scope")	Topic or Title	All years	34
Scopus	("Control tower" AND "logistics") OR ("Control tower" AND "architecture")	Title, or abstract, or keywords	All years	141
Scopus	"Control tower" AND ("range" OR "Scope")	Title, or abstract, or keywords	All years	100
Total Papers				**300**
Removing duplicates				42
Excluded based on relevance				181
Excluded with reasons for exclusion				62
Selected for review				**15**

Figure 27: SLR Databases used