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The improvements in inventory management with a service control tower

THALES NETHERLANDS
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This thesis was written to be used by Thales Netherlands and for the examiners at the University of Twente.

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Preface

To whom it may concern,

This is my bachelor thesis. It was conducted at Thales, although most of it was done at home due to the Coronavirus pandemic. It was only one month during which I was able to establish contact with stakeholders inside Thales, and the rest was conducted at home. During this short time I was surprised by the openness Thales showed in comparison to the large amount of bureaucracy that preceded the research. The colleagues with which I had the honour to work together were very accepting of me and open to any request I made. Even after having to work from home, none were unwilling to schedule a call or share their screen to explain something.

Special thanks go out to four people at Thales. First and foremost, Berend Jongebloed, who continually provided me with valuable feedback and helped motivate me throughout the difficult times I faced. Without his constant guidance, I would not have been able to produce any of the results I now have. Maree Govaarts, who first showed me around Thales and supplied me with a list of contacts. She assured that the one month I was able to spend in the office of Thales would be a productive one. Maaike Groot-Dengerink, who supplied me with a dataset through which I was able to get a clearer view of the spare parts relevant to this research. She assisted with the understanding of how inventory would be organized and explained the difficulties inventory faced. And finally, Bert Untied deserves special thanks for giving me a short introductory course of both Togaf and ArchiMate. Without Bert, I feared my models would not have been anywhere near readable and my research would have only contained text.

An additional special thanks go out to Rogier Harmelink at the University of Twente, who was not only extremely kind and helpful, but also patient with the delays my research faced due to the sudden lockdowns. Without his near weekly feedback I would have lost all my motivation and fallen still, waiting for the lockdown to pass. I hope I was able to provide you with the same enjoyment I had during the moments our meetings became less serious.

To all who helped me I would like to say: thank you very much.

Abel Keijzer

Executive summary

Besides selling radar systems, Thales offers a service for supplying spare parts for these radar systems. The MARCONI project has been researching a method which can improve this service: a service control tower. For this research, Thales and DMI were selected as research subjects to see how this control tower would interact with them. However, in addition to a service control tower, Thales is also in the process of establishing inventory. Where all parts used to be produced on-order, some will now be sold from inventory, in order to be able to supply more accurately. Both have the goal of improving the service that can be delivered. So in order to assure that both can be implemented simultaneously and help each other, the following research question was posed:

How does a SCT impact the levels of different inventory locations of spare parts intended for DMI at Thales?

To answer this question, the Methodology of Heerkens & Van Winden (2016) was used. Specifically, the research cycle that is proposed by this book. In addition to the research cycle, the baseline structure of TOGAF is used as well, although this methodology has some aspects that are irrelevant to answer for now.

Since the MARCONI project focusses their research on Thales and DMI, this research will follow in its footsteps and negate the other customers of Thales. First, the research zoomed in on existing literature as well as previous research by Van der Plas (2020) and De Vries (2020), who researched a similar subject prior. Here the key finding is the inventory management METRIC, that uses complex calculations in order to determine the investment cost per inventory location and the expected service level yield of said inventory locations. It does this by looking at the expected chances of failure (MTBF) and the expected chances of repair for each part at each location through the supply chain. A variant of this method is used by Thales to calculate their inventory levels. In addition to this method, Thales has developed their own tool to calculate the optimal inventory levels. The difference is that their own tool is more practical and based around historical orders. The dataset of their own tool was used for calculations throughout the rest of the research. A weakness of the tools is that one required a lot of data to function, and another suffered from data inaccuracies, specifically an inaccurate MTBF. Additionally, the number of orders per year at Thales is so low that forecasting is very difficult.

Analysing the data resulted in determining that Thales is inaccurate in delivering orders on time. Based on the difference between the expected processing time and real processing time, it was clear that spare part orders often had to be scheduled far in advance in order to be delivered on time. In addition to this, spare parts were often noted to have an increased risk of being delivered late.

So to help the long lead times and increase the availability of items, Thales is going to establish inventory. The service control tower can be used as a supporting entity for inventory. It can supply data that Thales could use in their tools, as well as monitor inventory upstream and downstream, in order to support order forecasting. It can use KPIs that it extracts from the databases of Thales to calculate the risk of certain spares in the supply chain, so that the reliability of deliveries increases.

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Abbreviations

-	DMI	Directie materiële instandhouding
-	IMS	Inventory management system
-	MPSM	Managerial problem solving method
-	MTBF	Mean time between failures
-	SCM	Supply chain management
-	SCT	Service control tower
-	SLA	Service level agreement
-	TDQ	Typical demand quantity
-	TNL	Thales Netherlands

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1. Introduction

The MARCONI (Maritime Remote-Control tower for Service Logistics) project was set up by multiple universities to determine the value of a networked service control tower (SCT). The control tower is known for its function in aviation, where it operates as a mediator between airports and airplanes to guarantee a safe take-off and arrival. According to an archived website of the Federal Aviation Administration, the intent is to "prevent a collision between aircraft operating in the system and to organize and expedite the flow of traffic"[1]. It does this while the airport focusses on more permanent changes, such as new leisurely locations. In recent years, the control towers have seen a more broad application in supply chain management (SCM), where they take the same role as an overseer as at the airports. Control towers look at the execution of the operational planning, while the company focusses on strategic and tactical decisions. MARCONI researches the application of this SCT in a maritime setting. Two of the companies involved in this project are the Royal Netherlands Navy (RNLN) and Thales. The project looks at the current state of the supply chain and looks if a SCT could be influential enough to warrant implementation.

1.1 Thales

Thales is a company that specializes in researching and developing radar systems. They are located worldwide, with the Dutch headquarters located in Hengelo. The products Thales produces are complex and require a lot of specialized knowledge to understand the specifications of these products. This knowledge of developing radar systems can be considered as one of the greatest assets of Thales. The products Thales supplies are serviced according to a maintenance schedule or when the need arises. For example, whenever an item malfunctions and needs to be replaced or repaired. These spare parts are bought as a set and replenished on-demand, meaning that the spare parts are replenished in a short-term setting. Whenever a radar system is purchased from Thales, a 'starter pack' of spare parts will be included, with which the system can be maintained properly until scheduled maintenance.

Thales currently offers a wide variety of services to their radar systems, which they offer through a customer portal. Here, the customer gains access to a profile that they can customize. From this profile they can open a case where they request a spare part or other forms of maintenance. Thales will receive this case and start the handling process. Both parties communicate back and forth, until there is enough information available to resolve the issue at hand. This servitization is maintained through the lifecycle of the supplied system.

1.2 DMI

One of the Dutch customers of Thales is Directie Materiële instandhouding (DMI). The people at DMI maintain the systems that Thales supplies and provides services for. DMI supplies spare parts to CSZK-OPS, who will use these spare parts in the field when the radar system needs reparations. Both of these parties (DMI and CZSK-OPS) are under the umbrella of the Royal Dutch Navy, so they work closely together. Since these systems are very complex, CZSK-OPS or DMI is not always able to specify their exact needs. This means that Thales has to investigate the issue themselves in some instances.

DMI is knowledgeable about the items they purchase from Thales. In an interview, it was mentioned that DMI deconstructs the radar systems when requiring repair and always tries to repair the radar themselves. The performed repairs are done at their own location, near their inventory of spare parts on shore. Should an item need to be replaced, a request for repair is sent to Thales and the

[1] www.faa.gov/air_traffic/publications

repairs continue after receiving the spare part. Currently, almost all required parts are purchased through Thales, whenever the need arises. Even items that could be sourced differently at a much lower price, are purchased through Thales, which makes the replacement parts much more expensive. For example, a small metal part that has limited impact on the functions of the radar system is purchased through Thales. Since Thales does not keep a supply themselves, they have to purchase exact amounts from their own supplier. This process is unnecessarily increasing the administration costs of Thales and the purchasing costs for DMI because of the small purchasing volume. Since Thales has to dedicate their time to negotiate the prices with their supplier, report said prices and order, they are eager to limit the items they can sell. Currently, Thales is thinking of ways they can limit the items they sell to customers without causing issues.

1.3 Spare parts

In this research, the difficulties of supplying spare parts is the main focus. Thales offers an initial spare parts package with their radar system, but since electrical systems are known for their long lifespan (Basten, 2014), additional spare parts must be supplied occasionally. These spare parts influence the service level that Thales offers. These levels are determined through what is called a service level agreement (SLA). In this SLA, Thales agrees to supply a certain level of function from their items. Should this level not be achieved, the customer can penalise Thales for failing to reach their agreement. These penalties can be substantial, so achieving this service level has a high priority throughout the company.

Spare parts can either be procured from the original equipment manufacturer (OEM) or is produced by Thales themselves. An interviewee mentioned that a rough 80% of items are purchased. All of the items are currently purchased on-demand, without an inventory acting as buffer. However, this system is in the process of being changed and a new inventory management system (IMS) is being researched. This inventory is placed to be more accurate in delivering spare parts and reaching the SLA. According to De Vries (2020), an average 60% of items is shipped on time. This doesn't directly indicate that the service level offered is only 60%, since items could also be purchased pre-emptively. Only when a system does not work due to the lack of availability of a spare part does it affect the SLA.

From interviews, it becomes clear that the demand for spare parts is extremely low. The high value parts are bought very infrequently and the average demand for many items is around one unit a year. This makes demand prediction very difficult to do. Combined with a long lead time, supplying spare parts is difficult and requires constant monitoring. Additionally, the spare parts have a chance to become obsolete once a new version of that item is available. Should a spare part become obsolete, the OEM should send a notification to Thales, letting them know that there is a last time buy opportunity before the sale completely stops. This will allow Thales to notify the customers that need that part and let them decide whether or not restocking their inventory is necessary. In reality however, suppliers do not always send Thales a notification and it has happened that Thales was unable to purchase an item because of obsolescence.

1.4 Service control towers

A control tower in a supply chain increases visibility in a supply chain by functioning as an overseer (Trzuskawska-Grzesińska, 2017). Control towers are implemented in some industries, where they take over one part SCM. The difference between a normal control tower and a SCT, is that the need for an SCT comes from complexity of SCM and servitization (De Vries, 2020).. It primarily focusses on the implementation of the tactical planning (Topan, 2019). For Thales, this would mean that a SCT can pre-emptively identify demand, so that Thales has enough time to procure the parts. It would then expedite the outstanding orders and have near-constant updated information. DMI would be able to more closely follow the orders and in turn receive the items earlier, meaning the possible downtime would decrease for the ships with these systems. However, these are only two small gains for large institutions. Unilever uses their control tower for ensuring optimized transport and a constant stock for customers in Europe (Bleda, 2014). This is a substantial task and one of high importance. Stockout would directly impact the revenue and combining transportations would directly lower the costs of transportations. So their SCT directly impacts the value generation of their products. If MARCONI wants to implement a SCT between Thales, it is important to know how it would impact the current supply chain and the stakeholders. That is what this research is primarily about.

2. Research methodology

The first step of the research is to determine the core topic. Two researches have been conducted prior. Daniel de Vries (2020) had researched the general application and architecture of the SCT at Thales and Ian van der Plas (2020) has researched these at DMI. The research of Daniel will be used to determine the research topic, together with interviews with employees at Thales. The research of Ian can be used to verify assumptions about DMI. For the methodology of this research, the Managerial problem solving method (MPSM) by Hans Heerkens (2014) will be applied. It will be combined with the TOGAF method, to model the architecture needed for the propositions.

2.1 The Applied methodology

The MPSM is a methodology that uses a simple eight step method to determine the core problem of any issue. It is a simple method that any researcher can customize to fit their research (Heerkens, 2016, p. 16). It can be seen as a framework where the methodology can be built upon. The MPSM differentiates between two problems: action problems, where there is a discrepancy between reality and expectation, and research problems, where there is a lack of knowledge about a certain issue. From the introduction, it is clear that there is a lack of knowledge about the implementation of control towers. The problem of this research is therefore a research problem. You could say that the MARCONI project researches the main (research) problem and that this research attempts to supply knowledge needed for that problem.

To solve a research problem, the MPSM defines a cycle for gathering knowledge. This cycle follows the same structure every time, allowing consistency and a somewhat easier execution. The cycle is broken up in eight consecutive phases. All of the phases have a clear goal, that should be achieved, before moving forward. The eight phases of the research cycle of the MPSM are:

1. Define the research goal
2. State the problem
3. Define the research questions
4. Define the research subject
5. Operationalize the research
6. Measure the subject
7. Process the data
8. Conclude the research

The first step of the research cycle is to define the goal: why does this topic need to be researched? The request of Thales for this research was to help find why a SCT is necessary. In the first interview in appendix A, there was a certain scepticism towards implementing a SCT. The interviewee noted that inventory is more important at the moment. So, the goal is to find what Thales can add and gain by having a SCT.
The second question is the problem statement. This is more difficult, since issues rarely exist in a vacuum. Problems are related and the effect one solution has to another has to be clear before any significant change can be implemented. For this research, it is important to see what the effects are of implementing a SCT. This is still unclear at this point in time and has to be researched. This will be done by looking at the business architecture of Thales and seeing what a SCT will change.

Since the methodology is only a framework, some additions and changes can be made to better fit the research. Additionally, Thales has stated that previous research with this methodology has created friction between student and supervisors, so they prefer a different problem solving method. The core of the research cycle will remain the same. The main addition to the research will be to apply the TOGAF structure to the research. TOGAF is designed for problems related to business architecture, IT and technology. This means the methodology is made to structure business problems that affect all of these, which is the case with a SCT. The business adapts to the new structure, changing their current function descriptions. The IT has to adapt to the information offered by the SCT. Finally, the applications need to allow access if the SCT wants to gather information, so this has to change somewhat as well.

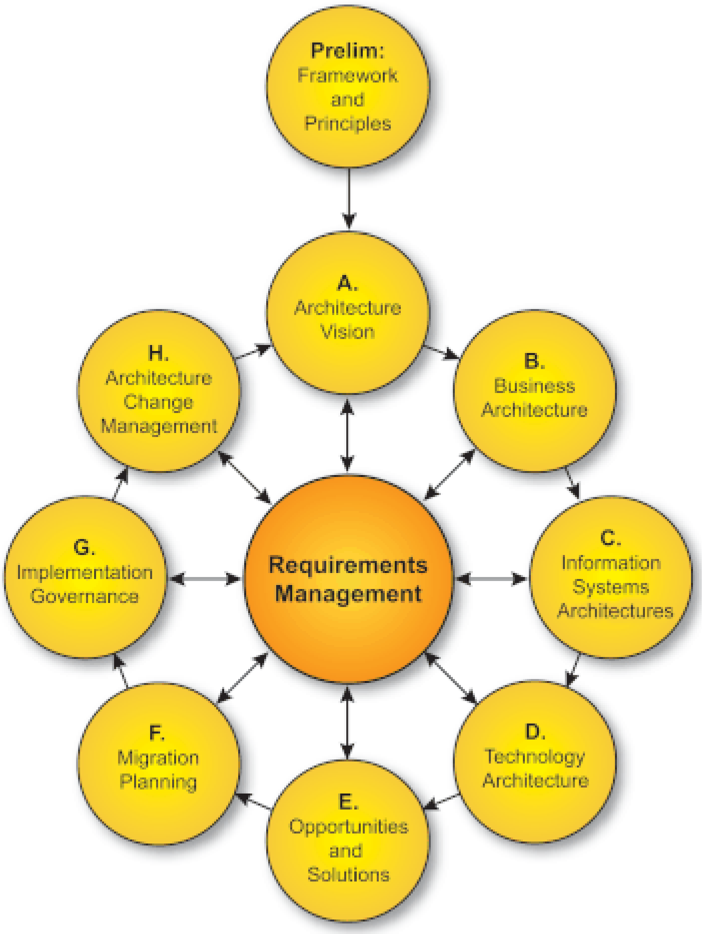

Figure 1: The TOGAF methodology

In figure 1, the different steps of developing architecture are shown. The research subject of the research cycle can be seen as the preliminary idea and the architectural vision that accompanies it. The one thing that is missing in this cycle however, is a literature review that can help generate the opportunities and solutions. In the research cycle of Heerkens (2014), this falls under operationalizing the research, so the literature review will be conducted before starting with modelling the business architecture. Phase E is where the opportunities and solutions are determined through the business architecture, which is a clear link to reporting the measurements in the research cycle. After this, processing the data encompasses planning, governance and the architectural change management. The conclusion will be drawn after determining the changes that will have to take place in the current business architecture.

The research is set to be conducted in a timeframe of ten weeks, from start to end. Fully researching architecture of the SCTs is therefore difficult and some restrictions need to be put in place. These restrictions will be based on the advice from the previous research and interviews that are conducted with the stakeholders of Thales. These restrictions will be discussed in a later chapter

2.2 Problem cluster

A problem cluster is a cluster where you try to find the roots of an issue. Since some issues are mere consequences of a problem, this cluster can help determine the relations between issues. This cluster would also be verifiable by stakeholders, who could look at the relations and give feedback where necessary. In this research, the core problem is reliant on three different aspects: the inventory implementation of Thales, the previous research and the MARCONI project. The MARCONI project's research attempts to solve a problem described broadly as: 'how can Thales and DMI benefit from a SCT?' This question can be rewritten as a problem, which will be at the top of the problem cluster. Then, surrounding this subject are the issues that came forward in interviews and by reading previous research. Some of these issues are irrelevant due to the scope of the research, or due to other factors. These topics have been listed in the table below the problem cluster.

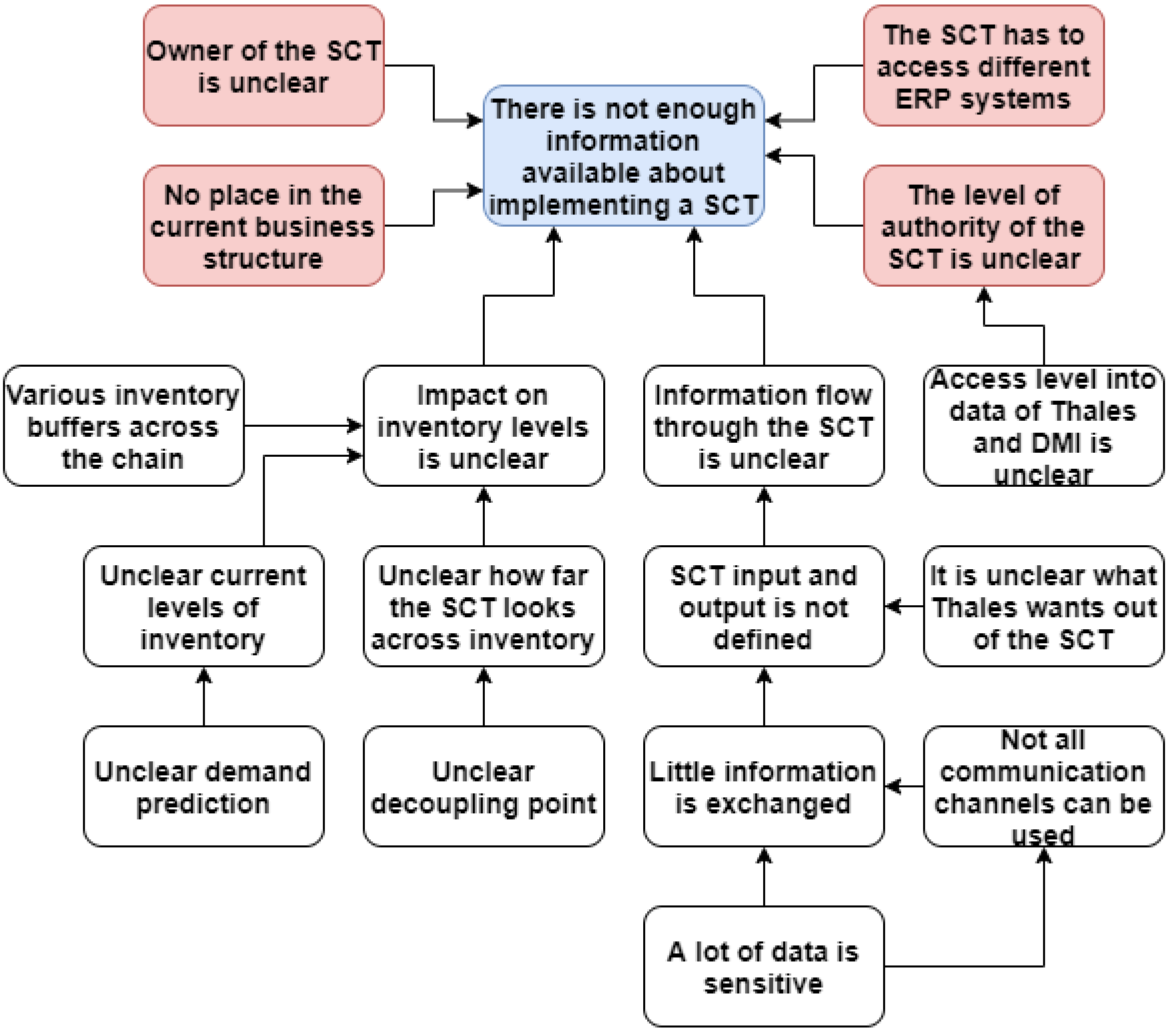

Figure 2: problem cluster of the SCT

Topic	Reason not a research topic
The SCT has access to different ERP systems	This topic is better suited for a later research
No place in current business structure	This topic has already been researched by Daniel
Owner of the SCT is unclear	The assumption will be made that both parties will completely cooperate with the SCT, so determining owner is not important
Level of authority of the SCT is unclear	The level of authority of the SCT in the supply chain should be determined in a later stage

Table 1: Non-core problems on the end of the problem cluster

The two main topics that emerged were the concept of the SCT, from the MARCONI project, and the topic of inventory, from Thales. The topic of inventory is very interesting at this moment, since Thales is in the process of implementing a new inventory management system (IMS). However, this makes inventory a very complex issue as well. Looking at how the IMS is currently set up and seeing what the SCT could do to improve the IMS is a great topic. Some more specific things like forecasting can be researched, but should be limited to forecasting the items of DMI. Other customers of Thales are outside of the scope of this research. Since the research still has to be linked to the MARCONI project, the research subject should be about the changes with an SCT. It is important to keep this in mind throughout the research.

Information flow is usually not a big problem in mass produced items, but when you deal with sensitive data, this issue becomes more pressing. When looking at the data DMI has access to, it can be argued that this data can infringe on national security. This could be one of the reasons why Thales and DMI do not freely share their data. It can be interesting to see what data is available at this moment and what is not. On the other side of the spectrum, Thales' main asset is knowledge of radar systems. Here, too, the issue can be seen as national security. If a foreign nation gains access to the workings of the radar systems, they could use this data to find flaws or exploits. Since an SCT would need to have at least some insight into the data of both, researching the flow of information and how to communicate is an important step. It can also show what limitations the SCT would have to deal with.

2.2.1 Core research problem

So, to define the issues located at the end of the problem cluster in one sentence:

How does a SCT impact the levels of different inventory locations of spare parts intended for DMI at Thales?

How this topic will be answered, will be discussed in the next chapter.

2.2.2 Reality and norm

This research of MARCONI is focussed mainly on the acquisition of knowledge, meaning that the core problem is a knowledge problem. This means that there is no real norm to achieve, but an unclear situation in which transparency is important.

What can be said is that the current SLAs are not always achieved, while they should be. The IMS is supposed to change this, but the question is if this will really have an impact.

2.3 Problem Approach

For the problem approach, limitations are just as important as goals. That is why the first step is to set the limitations of this research. Afterwards, the stakeholders of this research will be analysed and the required information for the research determined.

2.3.1 Limiting the research

Since this research is meant to be completed in ten weeks, it is impossible to look at all possible outcomes. For this research, the topic of inventory, how it is managed at Thales and how the SCT would be able to supplement any more information will be the key research topics. The inventory at DMI should be included in the research, but it should not be seen as a variable. The inventory locations will be mapped, but the inventory levels at these locations will be considered as rigid, meaning they cannot be influenced.

First of all, this research will mostly look at the connection between Thales and the SCT and less between DMI and the SCT. Both due to the time constraint and the other researcher at DMI, Thales will be the main point of contact for information and validation. Where possible, both sides will be examined, but it will not be considered a requirement for finishing the research.

Secondly, the research on the side of DMI will be considered relevant and not outdated. Since the other researcher is working on the same project and only recently finished, this assumption is not outrageous. Any mistakes in his research will be sought out as much as possible, but validating the data gathered from DMI would be too much work. The same can be said with the research of Daniel de Vries, with the exception of his parts looking into inventory.

2.3.2 Stakeholders

This research has multiple stakeholders, that will be influenced either during, or after the research is finished. These stakeholders can also be used to acquire information through interviews or surveys. To assure that all stakeholders will be taken into account while conducting research, they will be listed and their connection to the research explained.

Stakeholder	Influenced by…
Employees of Thales & DMI	The functions this SCT will have as a mediator between Thales and DMI
The supervisor at the UT	The results that can be used as a foundation for future research.
The supervisor at Thales	The functionalities of the SCT that are requested by the employees and changes in cooperation with DMI
The researcher at DMI	The adjustments he has to make based on my findings and possible improvements in lead times of spare parts.
All researchers of the MARCONI project	The results witch which they will further the development of their project.

Table 2: Stakeholders in this research

2.3.3 Research questions

The core topic still has multiple unknown factors that have to be researched prior to solving anything to come to an informed conclusion. The lack of information can be solved by creating research questions. These questions will also consider the entire relationship cluster and look through this cluster and determine what information is needed to progress with the research. These questions have a clear goal and solving structure in regard to solving the knowledge problem. Additionally, these questions will also keep the MARCONI project in mind. Since the research is conducted on behalf of the team of MARCONI, a clear connection between this research and their goal is very important. Finally, these questions will also give structure to the report.

The research questions will be:

1. How does the literature define a (service) control tower?
    a. How can it help inventory management?
        i. How would it be able to help the inventory of Thales?
        ii. What are its general functions in inventory management?
        iii. What constitutes the needs for a control tower?
    b. What are the requirements for setting up a control tower?
        i. What in- and outputs would a control tower need to function?
    c. What are some real-life examples of control towers influencing inventory?
2. What constitutes a part being a spare part?
    a. How are spare parts currently sourced?
        i. What are limits sourcing?
    b. What are the important KPI’s for Thales linked to inventory of spare parts?
        i. How accurate are these KPI’s?
        ii. What is needed to improve the KPI’s?
3. How does Thales determine inventory levels?
    a. On what data do they base the levels of inventory?
        i. How reliable is this data?

        ii. What data could supplement the accuracy of these forecasts?
   b. How is this system expected to perform?
        i. Is there any performance data?
        ii. What are the current flaws?
   c. Is the inventory of their customers / suppliers taken into account?
        i. Why or why not?
   d. What literature can be found for having inventory on slow moving items?
4. What data needs to be exchanged the most?
   a. What is exchanged between Thales and its customers?
        i. What available data would Thales' customers want?
        ii. What available data would Thales want?
   b. What data could the SCT use, as to improve the transparency in the supply chain?
   c. What are the biggest limitations for the SCT in data exchange?
        i. What could be done to overcome these limitations?
5. What can the SCT do to improve the levels of inventory at Thales?
   a. How much would it be able to improve for DMI?
        i. How much for other customers?
        ii. To what certainty can be said that the lead times will improve?
   b. What would an ideal situation look like?
   c. What obstacles would an SCT encounter in improving inventory?
   d. Would it be valuable enough to implement an SCT for all of their inventory?

Any other questions that arise during the research will be listed and solved in their respectable chapter.

3. Literature review

For conducting the research, some information about general topics is required that are not available at Thales. These topics will be specified as the literature research continues, from broad to more specific. Starting off is where a IMS is implemented and the reasons for implementing. Then there will be a part about inventory management that is most suited for spare parts, especially high value spare parts. Finally, there will be a short evaluation of what a control tower is capable of and where it is implemented.

3.1 Supply chain management

A supply chain can be defined as a system through which organizations deliver their products and services to their customers (Trzuskawska-Grzesińska, 2017). It can be defined as a network of organizations that are involved, through upstream and downstream linkage in different processes that add value to the final product (Mentzer, 2001). These supply chains can become complex whenever product stops are performed by third parties or the product is more complex.

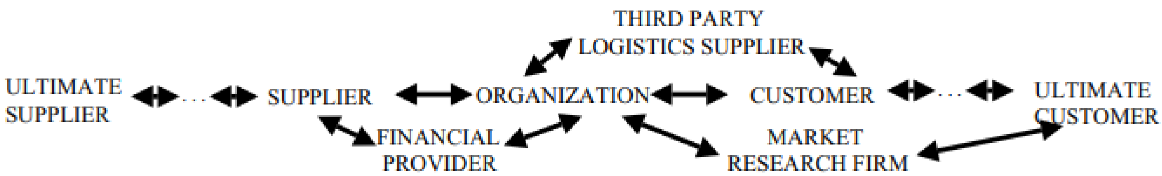

Figure 3: A more complex supply chain - retrieved from Mentzer (2001)

In figure 3, you can clearly see how some steps can increase the complexity of a supply chain. In a well-organized supply chain, interdependent organizations mutually and co-operatively work together to control, manage and improve the flow of materials (Trzuskawska-Grzesińska, 2017). The goal of every supply chain should be to maximize the overall value generated (Chopra, 2016, p. 15).

To achieve this goal, you need supply chain management (SCM). SCM can be defined as the management of the relationships and flows between the string of operations and processes (Slack, 2016, p. 399). It encompasses the planning, organization and controlling of all activities involving sourcing, conversion and logistics (Trzuskawska-Grzesińska, 2017). These aspects could be divided into three main categories: strategic-, tactical- and operational planning. Figure 4 shows these different levels of planning and their timespan.

Figure 4: The different levels of planning

Strategic planning is all about planning far ahead in your company. It sets goals and attempts to forecast for a long period of time. The tactical planning is about organizing the planning to fit in the year or months ahead. It encompasses choosing which supplier you use for raw materials and negotiating contracts for a the near future. Finally, the operational planning is about controlling the supply chain on a day-to-day basis. The operational planning is about tracking orders and crisis intervention to make sure the tactical planning is followed. Chopra (2016) defines six different supply chain drivers: facilities, inventory, transportation, information, sourcing, pricing. The facilities are not relevant. The production site is irrelevant to this research and the storage site too. Since an IMS is in the making, a storage site is not yet present. Transportation is irrelevant to this research, due to the limited scope. Pricing falls outside the scope as well, since investigating the pricing methods would cost a lot of time and effort. So, of the six drivers only three are relevant for the rest of this research: Inventory, information and sourcing.

3.1.1 Inventory in the supply chain

One method for controlling a supply chain more efficiently is implementing inventory. Inventory is implemented whenever there is a mismatch between demand and supply (Chopra, 2016, p. 61). It affects the costs incurred, assets held and responsiveness in the supply chain. Typically, inventory levels are determined on a tactical level. In the US, the value of inventory has increased from $400 billion to $640 billion between 2000 and 2010 (Bleda, 2014). Setting up a buffer inventory can be a great way to improve a companies' responsiveness to uncertainty (Slack, 2016, p. 437). However, inventory also includes many new costs. One especially relevant is the costs of obsolescence. These costs are a rate at which an item loses its value as it deteriorates in quality or relevance (Chopra, 2016, p. 284). At the same time, a common problem with inventory is that the (computer) IMS are based on what is called the perpetual inventory principle, where data inaccuracies are detrimental to the effectiveness of inventory (Slack, 2016, p. 462).

3.1.2 Information

Good information of a supply chain can help improve the utilization of assets and the coordination of supply chain flows to increase the responsiveness and reduce costs (Chopra, 2016, p. 65) (Chopra even states that sharing information is "crucial to the success of a supply chain"). In a more traditional supply chain, the information is exchanged in a linear fashion. The customer requests information from the distributor who requests information from production, which makes information exchange slow (Carpal Fleet, 2018). Additionally, this form of sharing information can result in a mismatch between forecast and reality, making the upstream supply chain more susceptible to large fluctuations in demand (Chopra, 2016, p. 265). Recent technological development have increased the channels through which information can be efficiently shared, with the SCT obviously being one of the more recent examples. This in turn has allowed for better visibility in the supply chain (Bleda, 2014).

3.1.3 Sourcing

Sourcing is deciding who will perform what particular supply chain activity, which could also include the management of information and location of inventory (Chopra, 2016, p. 57). Sourcing strategy can often differ per item, since some items are critical to the function of a product, while other items are more easily acquired. Sourcing has become more important due to the increase in out-sourcing products in low cost geographic locations, which brings more complexity to the supply chain (Bhosle, 2011). Sourcing can also be helpful tool in risk sharing and value creation. By aggregating parts of customer and supplier, the total surplus of the value created in the supply chain can increase (Chopra, 2016, p. 447).

3.2 Inventory management of spare parts

Inventory management to satisfy demand and inventory management for spare parts can almost be seen as two completely different techniques. The methods of managing demand are split in the item approach and the system approach . The item approach is more traditional and calculates the inventory based on costs and expenses, which is associated with selling high volume products. The system approach attempts to offer a certain system availability, which is more often associated with spare parts (and which is more in line with the SLAs that Thales offers their customers). Achieving the service level is an important part of business, since failing to reach this service can lead to sanctions. Rustenburg (2016) has a list of the most common complications related to high value spare part demand:

1. An ever increasing technical complexity of the assets, resulting in not always comprehensible failure patterns
2. Smaller installed bases of production systems, resulting in lower demands and thus more complicated demand patterns
3. Increased obsolescence due to fast product improvement
4. Customers demanding higher and more differentiated performance levels
5. A much stronger focus on working capital
6. Reduced knowledge and experience in the field of spare parts management

It could be valuable to determine what the impact of inventory would have on these issues. Problem 2 notes the more difficult demand patterns. This issue is also shared in other papers (Jaarsveld, 2013, p. 77) . The consequence of this problem is mainly that it causes difficulties of predicting demand. Predicting demand is more difficult and holding costs can increase rapidly. Besides difficult forecasting, obsolescence is an additional issue that the inventory of spare parts face (Van der Plas, 2020). Obsolescence increases the holding costs by reducing the value of spare parts more rapidly than normal. This makes inventory management of spare parts difficult and the methods limited. The most common and extensive method is known as the METRIC method.

3.2.1 METRIC

For inventory management of slow moving spare parts, the method of Sherbrooke (2004) is the most commonly used. This method is called the METRIC method. It can differentiate between both single- and multiple-echelon and single- and multiple-indenture systems. METRIC can also apply different demand distributions if needed (Sherbrooke, 2004).

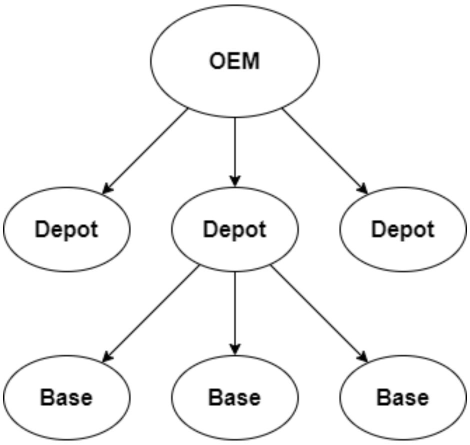

Figure 5: A multi-echelon model

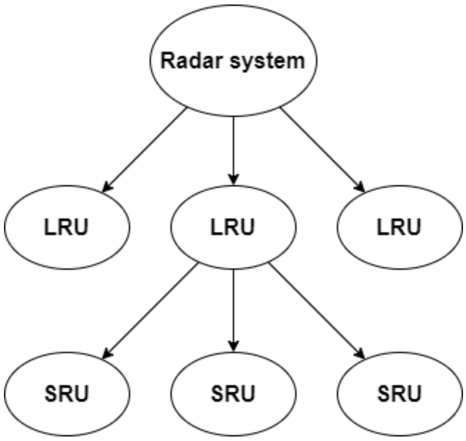

Figure 6: A multi-indenture model

In figure 5 and 6, a multi-echelon and multi-indenture model are described. The bases describe the location where the system is in use. They are similar in design, but encompass completely different parts of the METRIC model. A single-echelon model would be a 1 OEM that delivers to 1 depot (or one base). A single-indenture model would be a model where a system has only level in which a part can be replaced. For example, a radar where only LRUs can be replaced. Note that the multi-indenture model can also go deeper in terms of layers. A smaller part of the SRU could be broken, instead of the entire unit, meaning that the SRU can be repaired as well. This often happens higher up in the supply chain, because of the high level of expertise required to repair that part.

To determine the demand of the LRUs, METRIC uses a Poisson distribution to describe an item demand (or a negative binomial distribution in the VARI-METRIC model) (Sherbrooke, 2004). Unfortunately, the effectiveness of this assumption has not been researched thoroughly enough, according to Constantino (2017). The METRIC's aims consist of defining the minimum stock level for a set of items that satisfies system's availability constraints. Even though it may indirectly offer some measure of increasing supply chain performance, it is meant to propose metrics in accordance with the decision maker's perspective (Constantino, 2017). It does this by using the queueing theory. By computing expected usage with certain stock levels, it attempts to find the optimal stock level which still satisfies the service level.

The following assumptions allow the METRIC model to work (Sherbrooke, 2004, p. 47):

1. The decision as to whether a base repairs an item does not depend on stock levels or workload
2. The base is resupplied from the depot, not by lateral supply from another base
3. The (s-1, s) inventory policy is appropriate for every item at every echelon.
4. Optimal steady-state stock levels are determined

It would be interesting to see if these restrictions are taken into account at Thales.

3.3 Control towers in supply chains

Control tower generation	*Key new functions*	*Reason for emerging*	*Constraints*
First generation	- Logistics and transport control	Visibility for third-party logistics	- Lack of verifiability - Only reactive
Second generation	- Operational control	New technology emerging (GPS tracking)	- Manual processing - Lack of uniformity - Information overload

Third generation (current)	- End-to-end visibility - Data analytics	Better integration of data and insight	- Lack of adequate IT infrastructure - Manual intervention
Fourth generation	- Increased scope - Better analytics - Proactive	Rapid technological development, AI systems	- Speculative - Lack of uniform IT infrastructure

Table 3: Different generations of control towers (shorted & combined tables of Sainathan (2019))

Control towers have different uses depending on the type of tower and the place it is used. Some use the term supply chain control tower to describe a central hub that monitors and manages operations (Sainathan, 2019). For after-sales service support, the term service control tower is more well-suited (Topan, 2019). The use for control towers in a supply chain has only recently been popularised. Sainathan (2019) differentiates four different generations of control towers, whose characteristics can be found in table 3.

The current generation monitors the operational planning and any inconsistencies will be to the planning will be spotted (Topan, 2019). Bleda (2014) names three key concepts that have enabled supply control towers to become important in SCM: the generation, availability and oversaturation of data. The extreme generation of data has allowed for a lot of opportunities in analysing data and forecasting (Bleda, 2014). These analyses would be conducted from a SCT. The need for a SCT seems to come from a level of servitization, combined with a level of complexity of the supply chain (TKI Dinalog, 2019). The first step of servitization is argued to be selling spare parts of an already sold product (Jovanovic, 2016), which could mean the SCT was originally intended to be implemented in this area. The reason why the SCT became important, however, was to minimize the negatively impacting business events, like supply disruptions, demand spikes or even natural disasters (Trzuskawska-Grzesińska, 2017). Since the item approach attempts to reach a service level, these negatively impacting business events would harm the offered service level. So, an SCT would allow for a higher offered service level.

The SCT works by processing available data and using that data to improve transparency in the operational planning and increase the visibility in a supply chain (Bhosle, 2011). This increased visibility and better control can help cost efficiency of the supply chain. Since a SCT has this panoramic view over the supply chain (Trzuskawska-Grzesińska, 2017), a SCT can easily spot parts of the supply chain that do not follow the tactical planning. It can then send notifications to the stakeholders when intervention is required. Topan (2019) even states that it is essential to have standard responses to many of the automated messages from the SCT. This means that protocols can be easily followed once a disruption in the tactical planning has been discovered, reducing variance in the offered service.

Additionally, some SCTs create unforeseen advantages. The supply chain control tower of Unilever, for example, has allowed them to improve the their customer service and lower their carbon imprint, while its original function was to improve transport efficiency (Bleda, 2014). Furthermore, the SCT can improve the data quality that is available to the user. Since many companies use a form of integrated tactical and operational planning (Topan, 2019), the SCT can supply the data from the operational planning that the that the tactical planning uses.

3.3.1 Control towers from literature

Dell uses a control tower that is completely focussed on monitoring their service and making sure it all happens smoothly (Cooke, Q3 2012). In the example shared with Bleda (2014), Dell uses their tower to respond more quickly to customer requests and spare parts logistics. In this case, the tower would try to predict when a customer is more likely to have the need for a spare part, based on the failure rate. This is very similar to the function that this tower would need to have in the case of Thales, though Dell’s items use much smaller/cheaper parts. The article from Cooke (2012) states that the Dell tower provides five key things:

1. Provide situational analyses for recommendations (during a crisis)
2. A location for experts from both Dell and their continued customers
3. Mapping programs for every (emergency) situations
4. Real-time tracking for management of incidents, technicians and parts
5. News and weather updates to identify problems that can cause delays

The mapping program helps Dell allocate the closest distributor for providing spare parts to the customer, meaning they are able to supply extremely fast customer service (Bleda, 2014). Besides allocating a distributor and technician closest to the customer, they will also be able to estimate the arrival time with extreme accuracy. Because they keep an eye on the news and the route the item or service takes, they will know instantly if there is an issue with the delivery process. This makes the supply chain extremely streamlined and gives Dell an advantage over their competitors in regards to their service level. At the same time, the variance in delivery quality is lower.

Another example is Unilever. This tower is actually an office located in Poland (Kleinhempel, 2015). This control tower is not as much focussed on reducing risk, but more focussed on streamlining the transport throughout Europe (Bleda, 2014). They reduce costs and carbon emission by centrally managing all of their transport. According to the presentation given by Kleinhempel (2015), Unilever has 65 factories, 100 distribution centres and >250,000 customer locations. Outsourcing transport would be very costly and managing per country or region would be confusing, due to the 40,000 transports per month, so they implemented a system called UltraLogistik (Kleinhempel, 2015). This system improved three key elements: The customer service (partnership approach, end-to-end visibility) Carbon efficiency (more efficient transport, less distance travelled) and reduction of costs (cheaper transport) (Bleda, 2014). What is most incredible however is that now, 99,5% of their shipments are delivered on-time (Kleinhempel, 2015).

4. Current situation

For this part of the research, the current situation of Thales will be evaluated, phase 5 of the research cycle. The general supply chain will be visualized, for both the current situation and after implementing the IMS. Then the inventory will be analysed, how it is calculated and how it is supposed to function. At the end, the current issues of implementing inventory will be pointed out and discussed.

4.0.1 The available data

For this part, the available data in an Excel tool was used to look at the orders to find any consistent issues regarding the delivery of orders. These issues could show why inventory is necessary and if a SCT can be a valuable addition. This data consists of all completed orders for spare parts, spanning from [REDACTED]. This means that the data for [REDACTED] is somewhat incomplete, since some of the spare parts are known to have a lead time that exceeds one year. There were three dates for each order: the creation date of the order, the promised shipping date and the real shipping date. By taking the difference between the creation date of the order and the shipping date, the real lead time of each order can be deduced. By looking at the difference between the promised shipping date and actual shipping date, the times an order was shipped late as well. The requested quantities of the spare part of the order was also included. In a different list in the same tool, the item specifics were listed. It included a value for each spare part that was called the processing lead time. This lead time is the cumulative total lead time. This lead time can be seen as the expected lead time for a certain spare part. Besides the lead times, the item was listed as either 'buy' or 'make', differentiating between items that were sold through Thales or produced in their production department.

4.1 The SCM of Thales

Thales has a complex supply chain due to the type of items it supplies. Thales differentiates between three types of items. These items are currently almost always sourced through Thales. In the table below, you can see what item types are currently offered by Thales. The rest of this chapter will mainly discuss spare parts, but the distributor parts will occasionally be mentioned. The special items will be unmentioned from here on, since these will remain on-order only and the orders are too rare or specific per customer. The specials are items that are, for example, not assumed to ever malfunction or made to fit a customer's specific need, thus not included in inventory calculations and will remain on-demand only.

	TYPE OF ITEM	AVERAGE LEAD TIME	ITEM COMPLEXITY	AVERAGE DEMAND
SPARE PART	SRUs and LRUs	Long	Medium/High	Low
DISTRIBUTOR PART	Small and sometimes mass-produced items	Short/medium	Low	Low/medium
SPECIAL ITEMS	Made to fit specific needs	Very long	High/Very high	Very low

Table 4: The different item types

Figure 7 is a simple visualization of how the value chain of a spare part is formed.

[REDACTED]

Figure 7: Broad view of the supply chain

This visualization is based around supplying a spare part to DMI. There are more stops between the supplier and the ultimate supplier, but for the sake of brevity, these stops have been excluded. Since the spare parts are often complex, the supply chain would go back significantly and branch out often. Additionally, the other customers have been excluded as well, since this research will only focus on the relation between Thales and DMI.

Thales sources their items more often from suppliers than that they produce the part themselves. According to De Vries (2020), an approximate 80% of items are bought from suppliers and the other 20% are made at Thales (for example, Thales produces all of its own wiring). In a dataset supplied by Thales, these numbers were lower, at roughly [REDACTED] purchase and [REDACTED] production (as seen figure 8). The reason these numbers differ so much, could be because the previous research had to use estimations instead of accurate data. Additionally, since this dataset only focusses on spare parts, the distributions might be somewhat different as well. In figure 8 and 9, the item origin is listed for the item database and order database respectively. There is another category of items called 'unclear'. These items are slightly different versions of the already existing types and can either be buy or make. As can be seen, purchase items make up [REDACTED] of the item type database. However, these items were less often ordered, only [REDACTED] of all orders.

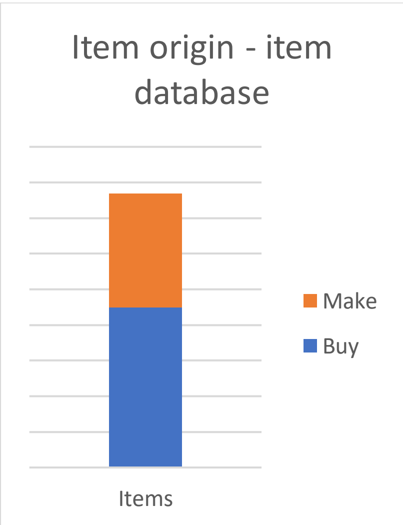

Figure 8: Buy or make - item types

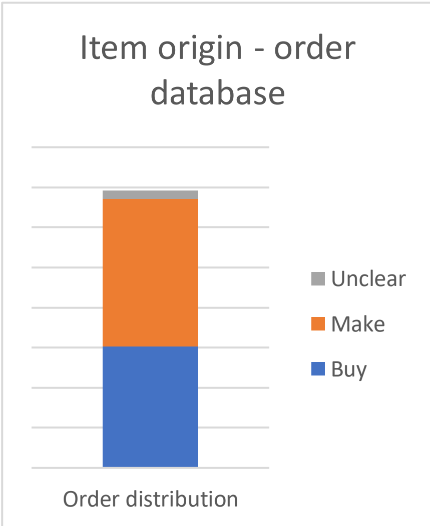

Figure 9: Buy or make - distribution of orders

In the supply chain, Thales itself serves two main functions: 1) develop new radar systems (to sell) and 2) to supply spare parts for the radar systems that are currently in use. The key process is the service of supplying spare parts. This process is what the MARCONI project is attempting to change and where a SCT could help streamline the flow of items.

RNLN is noted to have two main inventory locations, on-shore and on-board. The inventory on-board is carefully selected based on the mission for which the system is needed. As stated in interview 3 in appendix A, the more important the mission, the more spare parts that are taken. The other inventory is located on land at Den Helder. This inventory location is where Thales supplies the requested items to. In addition to the spare parts, at this location, radar systems are serviced and taken apart by DMI, should a part malfunction. If possible, DMI will always repair the part themselves. This means that not all malfunctions require a new part. Since the radar systems follow a maintenance schedule, they are taken apart at least once every number of years. This scheduled maintenance is to better estimate the lifecycle of the item and service any items that need to be serviced.

The SLA is the key collaboration between Thales and DMI. This agreement dictates what service level Thales must achieve by supplying spare parts. Since most customers have their own SLA, their influence towards each other can almost be negated. A SCT could be used to monitor the SLA to see if there is a possibility of either party failing to live up to the agreements. It can then notify either stakeholder to allow them to improve. Should they still fail, they will be penalized.

4.2 SCM with inventory at Thales

[REDACTED]

Figure 10: The number of late orders

Historically, Thales is not accurate in their on-time-delivery. De Vries (2020) notes that an estimated [REDACTED] of orders get delivered on-time. Using a dataset of historic orders, it was calculated that [REDACTED] of orders were shipped later than the confirmed shipping date, as can also be seen in figure 10 and 11. This is similar to the [REDACTED] that De Vries had indicated, with the difference coming from raw data instead of personal accounts. From an interview, it was mentioned that the main problem inventory should help to solve is the volatility of their supplied service level. Both these things indicate that the service level Thales can offer is low. Offering a low service level, means that Thales cannot ask a high price for their service, lowering the revenue. By implementing inventory, the supply chain gains another buffer and is less susceptible to unexpected orders, possibly increasing the expected service level that Thales delivers. This can only be realized by implementing an IMS. The changes in the supply chain can be seen in figure 12. The differences have been given a gradient for clarity.

[REDACTED]

Figure 11: The total number of late orders

[REDACTED]

Figure 12: The new supply chain with inventory and alternative supplier

Should the new IMS be implemented, the supply chain would look a little different, as seen in figure 12. The two changes have been given a gradient to show the difference. First of all, the suppliers of earlier in the chain now supply to the inventory of Thales instead of supplying through Thales. The buffer can help Thales react to unexpected business events. It can help supply items when in a pinch, so that Thales does not have to suffer the fines agreed in the SLA. They could also opt to keep their inventory at their current level and still supply directly from the supplier. This way, Thales can spread the impact on the service level over different customers and keep their inventory as an emergency supply. As Rustenburg (2016) mentioned, an issue of supplying spare parts is that customers tend to ask for different service levels in their SLAs. The problem could in this case be spun into an advantage. Of course, the SLA needs to have room to allow for these options, which is not a guarantee.

Secondly, another supplier was added. Since Thales differentiates between item types, only spare parts will be kept on-hand. This new supplier will now supply distributor parts to DMI, instead of supplying through Thales. Excluding certain items will help to limit what Thales has to consider when implementing inventory. These parts are small and are not as important to the function of the radar system as the spare parts. In an interview, it was stated that these parts can include things like cleaning cloths and small metal caps. De Vries (2020) also mentions that some smaller (distributor) parts should not be purchased through Thales, since this would increase the cost for the customer. Would the customer purchase these items themselves in bulk, it would be much cheaper and you would never have to depend on Thales to supply these items. This limitation is important when implementing inventory, so that Thales is not obligated to keep inventory for all distributor parts of their radar system. It will limit the possible items considered for inventory to the most important ones, without risking a lower service level.

4.3 Inventory tools

To implements the IMS, the costs have to be determined and the inventory levels established. For these two things, Thales uses two different tools. For determining the investment per item, the use a tool called OPUS10[2]. For determining the levels of inventory, they use an Excel sheet with selected data of historical orders.

4.3.1 OPUS10

OPUS10 is a tool for companies that would like to accurately estimate the possible supplied service level based on many different KPIs. This tool is commercially available for any company that decides to purchase it. OPUS10 models the spares inventory to obtain the maximum logistic availability with the available budget. It is restrained by budget and encompasses both initial and resupply of spare parts. The tool works using a variation of the METRIC method proposed by Sherbrooke (2006), which was discussed in the literature review. This Vari-METRIC works in almost the exact same way, with the only difference being a negative binomial distribution for the demand instead of a Poisson distribution. The other workings of the tool are the same as discussed in the literature review. The system requires a lot of specific values related to the inventory of repairable spare parts, e.g. MTBF, repairability, lead times etc. The depth of this tool makes it accurate in determining the service level returns at the current stock level, while being less susceptible to data errors. The goal of this method is to 1) investigate the expected availability of an item, 2) optimise the safety stock and 3) grant insight into critical items. These critical items are the items that either increase the investment disproportionally or have a higher impact on the delivered service level. The items that have a larger impact on the service level of the Technical system in which they are placed, should be first to be evaluated in regards to keeping inventory.

The way OPUS10 works, is that it first calculates the optimal supply curve. This curve is an inverse exponential function, where the investment (on the horizontal axis) is placed against the achievable service level (on the vertical axis). Then, the current logistical availability is calculated for Thales at the current stock level at that certain location. When this logistic availability is below the optimal supply curve, it is clear that the current stock level is not optimized in regards to the investment. This logistic availability should be increased by replenishing current stock levels (at their respective echelon) while also determining the budget of replenishment. Relocating stock to a different echelon can also be considered when attempting to increase service availability. This will cause the availability to go up, but requires more communication to realize. A visualization of a run of OPUS10, can be found in appendix B.2.

The largest advantage of OPUS10 is that is focusses on the most impactful items. The cost drivers and the availability killers are quickly determined. This allows for an analysis into what drives the costs up or what makes it so important for the availability of the system. When using, say, statistical

[2] www.systecongroup.com/uk/software/opus10-more-spare-parts-optimization

analyses for analysing demand of parts, the focus is often generalized. The items are treated with equal attention and the recommendations on inventory are usually based on expected values instead of real values. With OPUS10, the focus is clear from the start.

Additionally, METRIC is a very complex calculation. It uses many different KPIs (see the end of the next chapter) and is therefore accurate, even if one of those KPIs be unreliable. Due to the many different aspects of items that are taken into account, the estimated achieved service level is often accurate. This, for Thales, is one of its biggest advantages. In an interview, one employee mentioned how reducing variance is more important than anything else. Since Thales is penalized when their SLA is not achieved, a high variance in the calculations are very risky.

4.3.2 The second tool

Since the MTBF is not always known as well, Thales uses a second tool to support their inventory levels, more based around historical orders. It is an Excel sheet that Thales has created themselves. This tool is not based on any existing spare part inventory theory, unlike OPUS10. In this sheet, the spare parts are evaluated based on their MTBF and average demand per year. It takes data of historical orders and uses this to see what items are at risk of running out of stock. It uses a Poisson probability curve to determine the expected number of sold units. When there is insufficient data to reliably determine the probability, they resort back to the typical demand quantity (TDQ). This number is the number of items that is typically ordered per year. In the case of the tool, the inventory should at least cover 75% of all the orders of the TDQ. There is no distinction made between customers, only between the different types of items. The tool tries to use as much data as possible to determine stock levels, but it often resorts back to the instinct of the product teams. These teams are more invested in the items in the field and their estimates are often taken over the results of the tool. The creator of the tool even stated that the tool is used to scientifically support the instinctual choices that the product teams make.

The way this tool works, is that it looks at the lowest inventory level at which the agreed service level is still achieved. According to this tool. Thales' required levels of inventory are often low, since the number of spare parts sold per year are low as well. This makes the tool sensitive to small increases in inventory. It also means that an inventory of zero is often enough to reach the service level agreement. However, keeping most of the inventory levels at zero is not much of a change compared to the old method (on-demand spare part delivery). The inputs of the tool are often debatable as well. The Mean time between failure (MTBF) is a highly unreliable input. Since there are so few instances of items in the field, the demand differs between customers. The quality of maintenance is not the same for all customers, the technological knowledge varies and the type of usage could vary heavily between customers. This makes it that the MTBF is often taken as an estimation of the product teams (though this value is often not reliable either).

In appendix C.1, a short table with the most important KPIs per tool is placed.

The key difference between OPUS10 and the Excel sheet is that OPUS10 is more scientific, but less concrete. Where OPUS10 shows where to resupply or relocation of stock to realize the highest available service level, the Excel sheet is only focussed on determining the required inventory levels for Thales. In figure 13, the relation between OPUS10, the Excel tool and other calculations are visualized.

[REDACTED]

Figure 13: The process of determining inventory

In figure 13, the process of establishing inventory at Thales is visualized. As seen here, the OPUS10 run is only a small part of the entire process. The tool is mainly used to determine what the current expected service levels and investment costs are. The function of the Excel tool is even more limited, with its only function being supporting to the final decision.

4.3.2 The reliability of the calculations

The tools that are currently used to determine the inventory levels in the future are not at all perfect. First of all, OPUS10 has some flaws.

The first is that the tool is very data hungry. To illustrate how data hungry the tool is, an model is shown in appendix B.2. The most important decisions in the tool are based on the data that is available, of which it needs a lot. This makes the tool a lot less accurate when the datasets it uses are seriously lacking or unreliable. When only one single variable is unreliable, it is not an issue, but when dealing with such a low demand, the data this tool can use quickly runs out. This causes the chance to have multiple variables be unreliable. However, how unreliable the data might be, the overall cost-availability curve should always give some reliable indication of the achievable levels of service, as Sherbrooke (2006) himself states.

The MTBF of the spare parts is not always known, and for expensive technical systems with a high lifecycle (Basten, 2014), the MTBF is very unreliable. Additionally, new items do not have a MTBF yet, unless it is an estimate given by the design team. Not only are these estimates not always reliable, the MTBF can be influenced by the quality of maintenance per customer. This will skew the results of OPUS10 the wrong way, since OPUS10 assumes a reliable (or constant) MTBF. Additionally, in an interview with DMI, it was stated that requests for spares are sometimes bundled together. Broken parts are accumulated in the repair shop, sometimes without realizing, until a new spares are needed. This makes calculating the MTBF more difficult.

The METRIC tools offer a limited number of actions to increase service level. OPUS10, although detailed for determining flaws in inventory levels, has a very limited scope. Besides restocking certain echelons in the supply chain, there are plenty of alternative actions to achieve a certain service level. While OPUS10 is great to compile the optimal inventory levels, its recommended action is not guaranteed to be optimal. Sherbrooke (2006) himself mentions that item deterioration (or obsolescence) has not been included in the METRIC system. Since obsolescence is an issue that causes the value of spare parts to decrease, how can you include this factor into OPUS10? When do you stop stocking a part because of obsolescence?

The scientific validity of assuming a Poisson distribution for the demand is not supported. As said in the literature review about the METRIC tool, the assumption of demand being Poisson distributed has not been researched enough (Constantino, 2017). This makes the scientific support somewhat weaker for both tools. Especially the Excel tool, that was made just to support an assumption, is not as scientifically sound as might seem at first glance. The variance in this tool is not included and the risk of failing to deliver is not included either. Should the consequences of failing to reach the SLA be high, than the variance should be as low as possible, and the other way around. This is also in some form true for OPUS10. Even though this tool does include the variance of the demands, the risk of failing the SLA is not included (partly because it is different for each customer).

The Excel tool uses probability and historic data to determine what the optimal inventory levels are. This makes one of the risks the variance of the expected service level delivered. Since variance is the biggest factor of risk in the SLAs, any calculation that faces variance should carefully consider what the consequences are with said variance. This tool attempts to solve this by asking the design teams what their instinct says about the number that is presented. While this might help eliminate the feeling of doubt, the scientific accuracy of this tool can certainly be called questionable.

4.4 The problems of keeping inventory

Like in the literature review was mentioned, implementing inventory for spare parts is not easy. The list from the literature review (Rustenburg, 2016) are a few of the common issues of inventory. These issues are all recognizable, although some are not influenceable, while others are less important. From an interview at Thales, it was said that the biggest problem of an IMS lies within the variance of orders. In this chapter, some important influencers of this variance are evaluated.

4.4.1 Difficult demand patterns

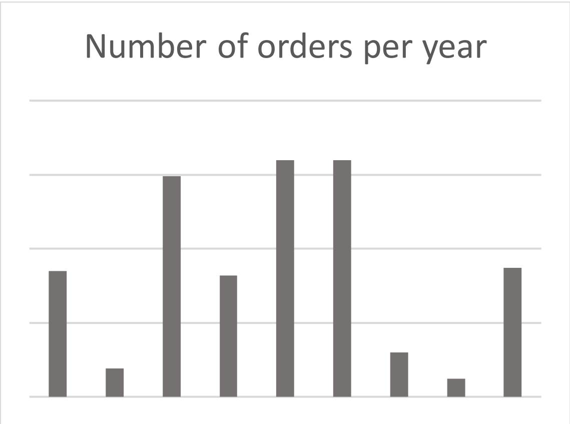

Figure 14: The number of orders per year

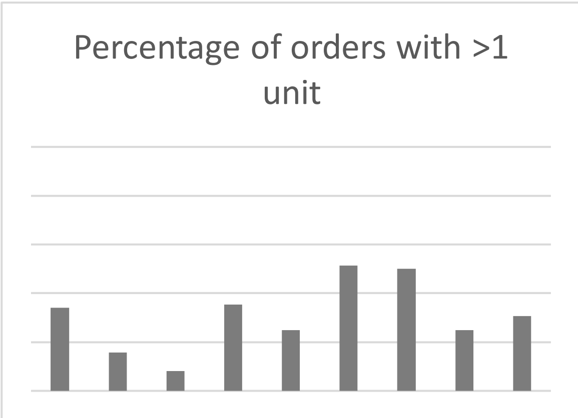

Figure 15: Orders consisting of more than one unit

In figure 14 and 15, the demand per year and the number of orders with more than 1 unit is visualized. It immediately becomes clear that the demand quantity varies heavily per year. Even though 2018 and 2019 are incomplete, their total is still set to be under average. Not only is the number of orders Thales receives inconsistent, the number of spare parts in these orders is often very little. In the other graph are the percentage of orders that only consisted of one unit shown. Here it can be seen that on average, roughly [REDACTED] of orders only consisted of one item. This indicates a high variety of items and a hard to predict demand. Forecasting based on historical orders is therefore difficult, so predicting demand has to be based around the MTBF. However, the MTBF reliability is poor due to two main issues. The first is that the MTBF is often based on an estimate, since basing order history is not reliable enough. These estimates are known to be unreliable, as was mentioned in an interview. The second is that there is some difference in the quality of maintenance that the customers perform. Some customers of Thales were said to only perform maintenance when the item malfunctions and not when there is a scheduled moment of maintenance. So only using the MTBF for forecasting is not reliable enough either. Forecasting the demand is therefore difficult, irregular and varies per item and customer. This is in line with the statement of Rustenburg (2016), of spare parts having an irregular and hard to forecast demand (pattern).

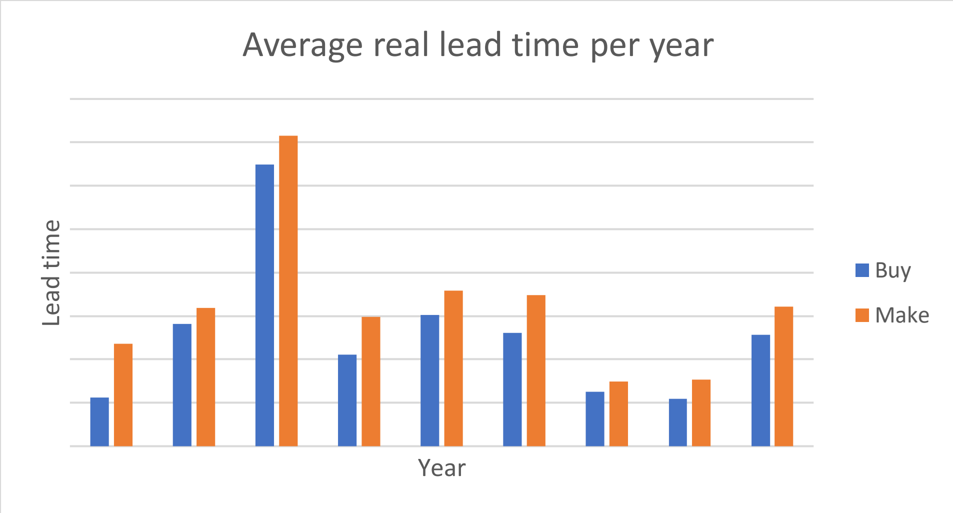

Figure 16: The real lead time per year

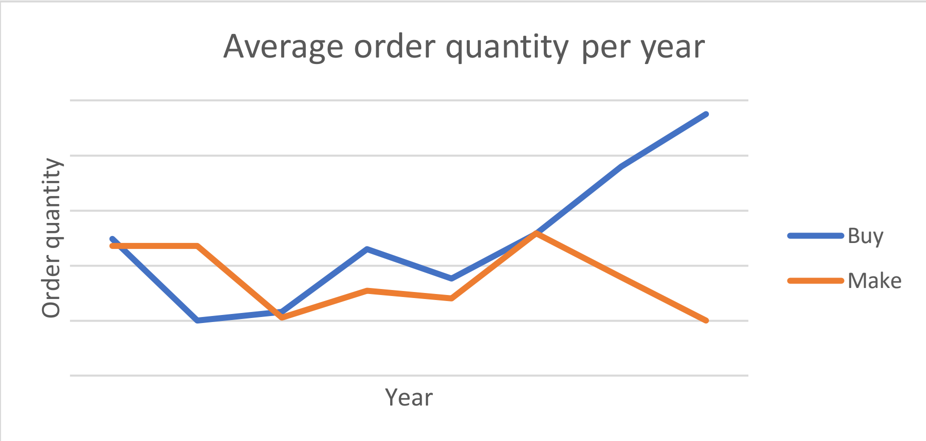

Figure 17: The average order quantity per year

In figure 16 and 17, the average order quantity per year with the lead time is shown. It should be noted that the graph is not complete. For 2018 and 2019, some of the orders placed are not yet complete and therefore not included. This is because the lead time for some items exceeds two years and the already completed orders are likely to have been completed under the normal processing time. This might also influence 2017 and 2016, but it would be a much smaller change due to the large number of orders already fulfilled.

From these two graphs, it seems that the low number of items per order in 2014 might have attributed to the unusually high lead time. As clear from figure 14, 2014 had the smallest number of orders with multiple units, with only [REDACTED] exceeding one unit. This can indicate a high variety of item demand, making the orders more difficult to process than initially thought. This could be why the years 2016 and 2017 have a higher expected lead time, but not as high as 2014 (since the number of orders in these two years was somewhat similar).

From this graph, you can see that the lead times increase as order sizes become smaller, with an exceptionally high lead time 2014. In this year there were a large number of orders in that year. This could have caused a congestion at suppliers and at Thales' own production department. As seen below, the expected lead time was lower than average, but the real lead time was more than twice the average. This is a trend that became apparent in the dataset. Overall, the average real lead time of items was 88% higher than the processing lead time. Additionally, 2014 had the lowest average number of items per order, with only [REDACTED] of items exceeding one unit per order. In 2016, which had a similar number of orders, [REDACTED] of orders exceeded 1 unit per order, so it seems small orders are more difficult to handle. This confirms that the issue described by Rustenburg (2016) is present at Thales.

[REDACTED]

Figure 18: The expected and real lead time per year

4.4.2 Supplier delivery risk

As said by Chopra (2016), sourcing is an important part of supply chain management. Thales has a lot of different suppliers and the quality of sourcing needs to be considered before the possible effects of the SCT can be considered.

When looking at the dataset, there is a special column for the items that are prone to delays from the supplier. Here, the purchasing department indicates whether a supplier is reliable or not and if additional inventory has to be kept on hand in case the shipments are delayed. Figure 18 shows that [REDACTED] of the [REDACTED] purchase items are at permanent risk of being delayed. This does not mean that there will be [REDACTED] extra units on hand, since that will depend based a multitude of factors, like the TDQ of the items. However, it does mean that 38% of sourced spare parts have been known to be delayed. It makes sourcing unreliable and increases the variance of supply.

Figure 19: The items at risk of being late

That the sourcing items are at a higher risk of delay can also be seen in the lead times of the items. These can be differently interpreted. The first is the shown in figure 19, the average expected lead time and real lead time are put next to each other for both buy and make items. Here, it can be seen that both buy and make items have a much longer average real lead time than expected. When comparing differences, they are almost equal, with purchase items having a slightly larger difference in terms of days. This difference might seem insignificant, but looking at the percentual differences shows that sourced spare parts have a much higher difference. In percentages, production items exceeded their lead time by an average of [REDACTED], while purchase items exceeded theirs by [REDACTED]. This number is very high, which is likely due to orders being created before being processed. The reason can for example be that Thales anticipates a longer lead time than usual, ordering items before the order is processed. This is why the delays were also compared to the processing lead time, which can be found in appendix C.3. Here, it is shown that delayed orders exceed their promised shipping date by an average of [REDACTED] and [REDACTED] of their processing lead time for buy and make items respectively. Clearly, higher lead times can be somewhat anticipated, or these delays would have been high as well.

In appendix C.4, the delays are scattered per item. Here it can also be seen that the sourced spare parts are more volatile than their produced counterparts. It indicates that purchases are less likely to be fulfilled on short notice. All this indicates that the sourcing of Thales is difficult and pre-emptive action is required for proper order fulfilment.

[REDACTED]

Figure 20: The average lead times of buy and make items

[REDACTED]

Figure 21: The lead time differences in %

4.4.3 Degradation of inventory value

In the literature review, Chopra (2016) mentioned that inventory in a supply chain can cause the value of items to deteriorate. Rustenburg (2016) also mentioned this same problem in his list of issues of high value spare part demand. The difference is that Rustenburg specifically specifies technical obsolescence. He mentions that items degrade due to fast product improvements, which is part of technological obsolescence. Technical obsolescence reduces the value of a product the longer it stays in inventory, since this part is no longer state-of-the-art. It happens when a new radar system is developed, which consists of new parts, making the old part redundant. Additionally, when improvements are made to an already existing part, the old version loses value as well.

In the old supply chain, the degradation of value of inventory was irrelevant to Thales, since they had no inventory that could degrade. Mainly the customers of Thales had to deal with this problem. Van der Plas (2020) mentioned that obsolescence is especially costly for DMI. He mentions that visible obsolescence is only maintained at the LRU level at Thales. This means that obsolescence of SRUs is not monitored at DMI and can force them to purchase a LRU instead of a SRU. Should Thales implement inventory, this issue can affect Thales as well. Say that a part becomes obsolete, but they still have inventory of the SRU/LRU in which the part belongs. This would force Thales to decide to either replace the item in their inventory or not. Replacing the part would take time and money, but it could allow them to increase or retain the value of the item. If the old part will remain in the SRU/LRU, the value of the item will degrade, since it is not up-to-date anymore. Either way, Thales will be forced into a decision that can reduce the value of inventory.

Additionally, since customers have to occasionally purchase an LRU, when only an SRU is obsolete (like DMI stated in an interview), the data can show a higher demand for LRUs than there in reality is. This can in turn cause Thales to assume the MTBF of the LRU is lower than it really is, while obsolescence has caused an influx of orders. Since the MTBF and TDQ are both used in calculating inventory levels and influenced by this faulty information, this would mean that Thales would overstock on LRUs. These LRUs can in turn become obsolete and increase the costs/risks of keeping inventory.

5. Future situation

In this chapter, phase 6 and 7 of the research cycle will be handled. Here, the key difficulties of the last chapter will be set against the possible prospect of a SCT. Since no real tests can be run, the concept will remain hypothetical. After discussing the possible effects it can have on the supply chain. The requirements for each party will be discussed and how these parties will have to handle this new concept. Finally, the question whether the SCT is truly the ideal solution for these issues will be discussed.

5.1 Potential

As discussed in the literature review, the SCTs monitor the operational planning and notify stakeholders of any deviations of the tactical planning. It now becomes important to determine what this particular SCT can do to help the IMS of Thales. For this, the three drivers of Chopra (2016) will be used as a baseline structure: Inventory, sourcing and information. The weaknesses of the current IMS that were discussed in chapter 4, will be compared to the possible solution that the SCT can offer. In their respective chapters, the findings in this research will be compared to the previous research of both De Vries (2020) and Van der Plas (2020) to identify differences in propositions.

5.1.1 Inventory management

The key issues in inventory management were the long lead times that forced forecasting to occasionally be pre-emptive and based around things like the MTBF and historical orders, who were not always accurate. So, to help in forecasting, the first thing the SCT can offer is an aggregated view of inventory levels. By having Thales see exactly how many items DMI has left and in which state those items are, forecasting can become much more accurate. Thales can anticipate on other KPIs like current inventory levels, number of items in repair (and estimated repair times), number of hours used and number of spares on-board. This will make Thales less reliant on estimations or inaccurate data calculations.

In chapter 4, it was discussed that the lead time was often much higher than anticipated. The SCT can help these estimations by directly looking at the inventory levels of the supplier and the order progress. If the inventory of the supplier becomes critical, the SCT can look at the other inventory levels and determine the risk this low inventory poses. Similarly, closely following the orders of suppliers will decrease the possible delay orders might face.

Figure 22 shows what the SCT will look like in this scenario.

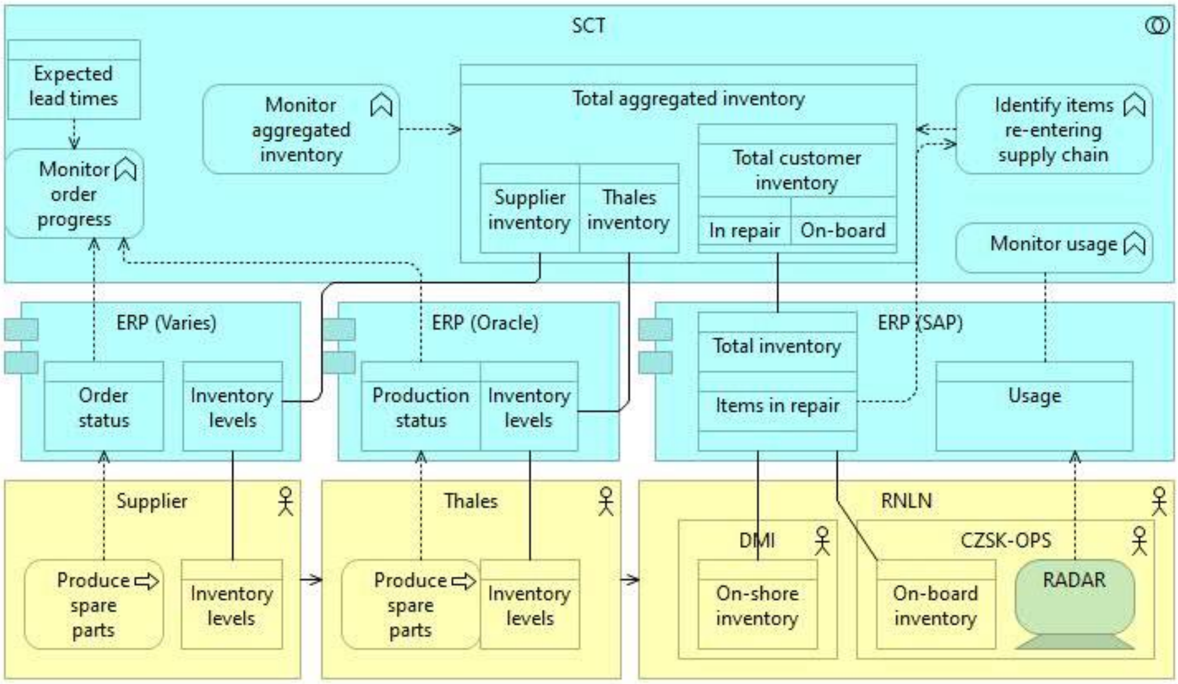

Figure 22: The SCT as a monitoring entity in inventory management

Topan (2019) mentions in his paper that many alerts are generated at the surveyed companies, but only a small portion is considered high priority. So, in addition to monitoring current inventory, the SCT should analyse the available data in order to determine the urgency of its warnings. These analyses can be based on several KPIs, some more easily calculated than others. Some simple KPIs of spares are lead times, expected hours of usage and chance of repair. These KPIs affect when a spare should be ordered, making them important for more accurate risk analyses. Promised service level can be included as well, so that the SCT can determine the impact certain deliveries have on the service level Thales delivers. Thales can then choose to let delays occur, whenever they are not too impactful to the SLA.

For more advanced analytics, things like the risk of failure on a mission or the level of strain of a spare part could be taken into account. The heavier the usage of a spare, the higher the chance of failure. However, these would be a lot more difficult to implement, due to the complexity of these KPIs. Strain, for example, comes in many different forms and does not impact spares equally, which impacts how reliable the calculations really are.

If the SCT finds that the risk is high enough, it will send a notification to Thales and DMI This process can be found in appendix B.1.

De Vries (2020) also mentions inventory management and how it could be implemented in the SCT. In his models, demand forecasting and inventory management were used to generate a RFQ when spare parts reached critical levels. The key difference with his models is that these models propose to include Thales in generating the alert for a RFQ. Instead of sending a RFQ to DMI, letting them decide whether to purchase or not, a risk report should be sent to both Thales and DMI. Not only could Thales use the data in this report, but they could also add any additional information that may be lacking in the current risk report, like an unusually high demand from other customers or an indication of obsolescence. It might also make Thales more responsive in sending a price quote, since they can prepare a response beforehand. Additionally, these models also attempt to include the inventory at Thales and the supplier for a more complete picture of the risk status in the supply chain.

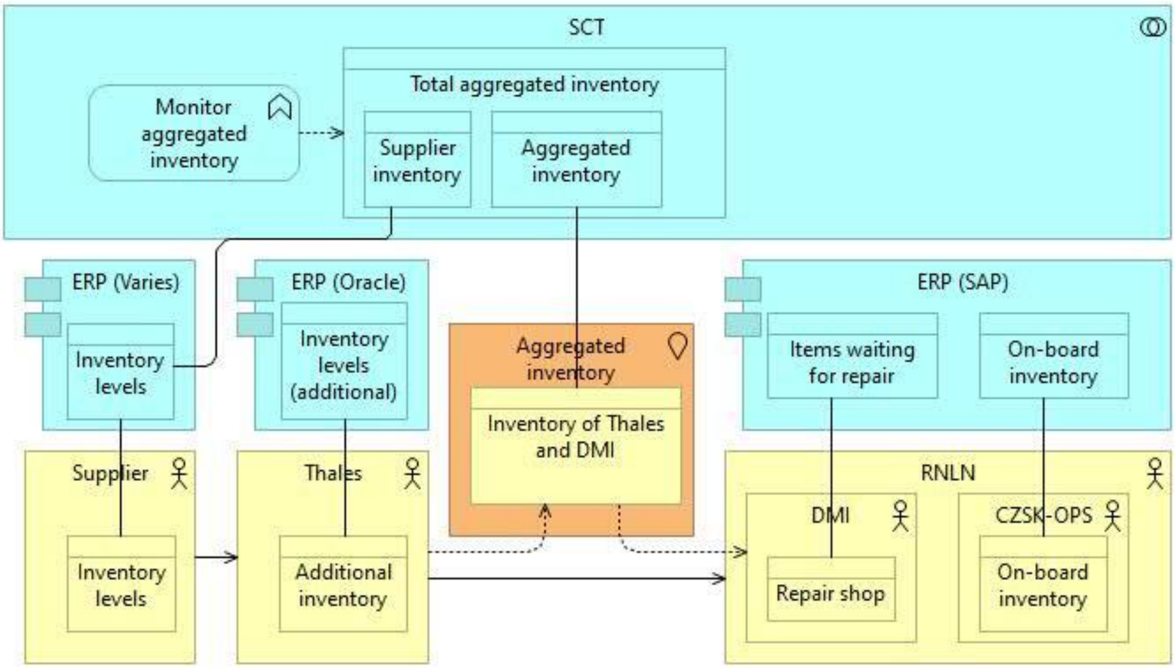

Figure 23: The SCT monitoring a completely aggregated inventory

The next level of inventory management would be to install a shared inventory location and let the SCT oversee this inventory. This combined effort will allow Thales to Supply DMI with more accuracy, while sharing holding costs. This could be expanded to include the supplier of the spare parts, but that would require more cooperation from the supplier than can be assumed. In figure 23, this option is visualized. For the sake of brevity, the other possible functions of the SCT have been excluded, even though it could still perform these in addition to the inventory aggregation.

For this complete aggregation to work, however, a lot has to be decided about the levels of access to the inventory. Ideally, Thales should be able to store all of their spare parts, even those that are not destined for DMI, so that their holding costs are low and there is some uniformity. It is unclear if DMI is willing to allow this. For DMI, it would be better for them to perform all maintenance and repairs in this warehouse, so that their parts on-shore will be in one location and they can access spares directly. That would mean Thales would have to let DMI have access to their inventory, which they might not want to. This option should certainly be researched further, before it should be implemented.

5.1.2 Sourcing

Topan (2019) states that the interviewed corporations have limited to no control over their external supply process. This was also determined to be challenging for Thales. As chapter 4 indicated, [REDACTED] of the [REDACTED] purchase items were indicated to be ‘at risk’ of delays. Additionally, the processing lead time was often exceeded. Inventory can act as a buffer, making these delays less impactful. As mentioned, however, forecasting is difficult and the items that do not have inventory space allocated will remain at the same level of risk. The SCT can take over expediting and start monitoring delivery risks. Should no inventory be left, it can notify the stakeholders about this, so that they can react accordingly. For this, it needs to extract some KPIs out of the ERP systems of the stakeholders in the supply chain, as can be seen in figure 24.

Like the alerts at inventory management, the SCT can use analytics to more accurately report the risk orders face, making the notifications more impactful. The SCT can use the supplier risk check to see if the supplier is expected to be accurate or not. The SCT can look at historical orders and calculate an expected delay and see if this delay would impact the repairs planned in maintenance planning of DMI. The SCT could also suggest the cannibalization that Topan (2019) mentions in his paper (which was not yet optimally used in the surveyed companies). If the spare is part of a LRU, for example, Thales could also salvage the spare from this LRU and later replace the salvaged part. Or alternatively, the LRU could be replaced in its entirety.
In the next step of analytics, the SCT could also monitor the current workload of suppliers, seeing if the orders are at an increased risk of being delayed. One of the issues with the delivery of spares was the difference between the expected and real lead times. This issue was present at both buy and make items, with buy items suffering a larger deviation from the expected lead time. By having the SCT monitor the workload, estimated shipping dates can be altered depending on the current workload. This can all help to increase the accuracy of the estimated lead time, which in turn influences the time at which an order has to be sent to the supplier.

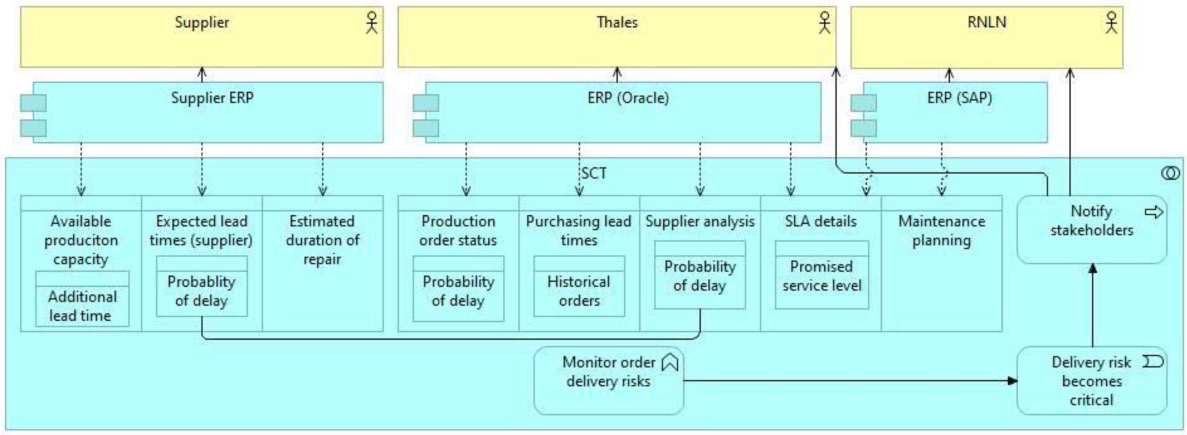

Figure 24: The SCT monitoring supplier risks

Order tracking has been mentioned in detail both in the research of De Vries (2020) and Van der Plas (2020). Van der Plas proposed to compare the data in the ERP of DMI to the data in the customer portal and see if a delay would cause issues. Due to the performance of suppliers, it would likely be better to relay these requests directly to suppliers instead of to the customer portal. Thales does not always have the most accurate delivery times in their system, so directly requesting order statuses from the supplier would yield more accurate information. An example of an information request for order statuses can be found in figure 26.

5.1.3 Information

In an interview, it was stated that there is very little information exchanged between Thales and its customers. This is not helping the efficiency of the supply chain. As stated in the literature review by Chopra (2016), good information exchange in the supply chain will increase coordination and responsiveness. For Thales, the required information for calculating inventory is not always readily available. One way in which this could be gathered is through asset monitoring. Both previous researchers, Van der Plas (2020) and De Vries (2020), mentioned that asset monitoring would be valuable to both Thales and DMI. The MTBF, which is now based on estimates, could be based on actual usage, making the calculations using this number more accurate. The SCT could then even expand this statistic to apply to the spares in use at other customers, possibly increasing accuracy for them too. However, this is mostly speculative since the MTBF is dependent on many different factors that are not always constant throughout customers. In figure 25, it is shown how Thales might request information from the SCT. In a future stage, calculations of the inventory parameters or MTBF could be done within the SCT itself, so that the process is more standardized.

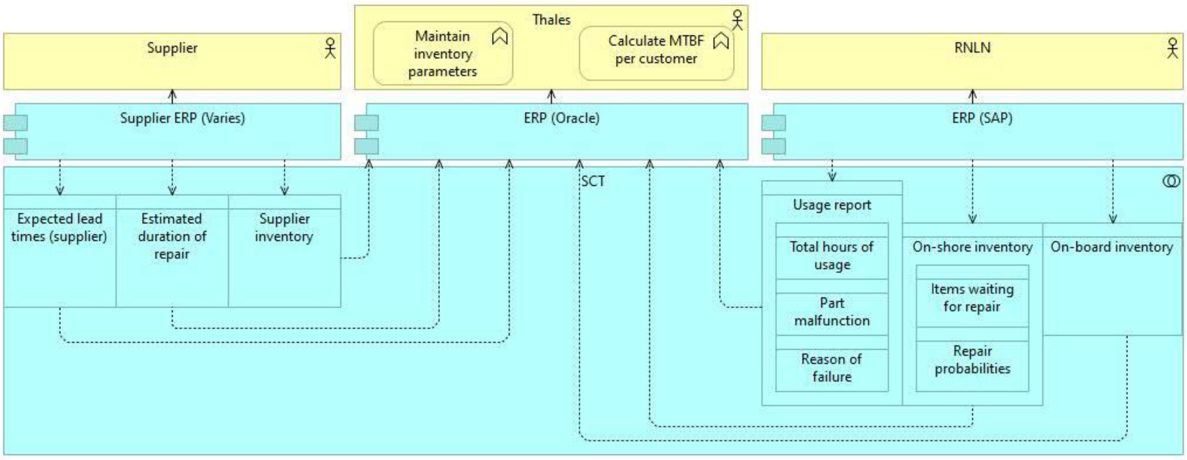

Figure 25: The SCT as an information hub for Thales

De Vries (2020) does not really goes in detail into information exchange, except that the SCT can use information to forecast demand and supply data to Thales. However, his models show that the SCT supplies data directly to the ERP of Thales. This research instead proposes that the data is used in the SCT for analytics and calculations and that the transformed data will be sent to Thales. This will reduce the workload of Thales and lower the chances of failed analytics due to human error. Additionally, DMI and Thales might be more open to share transformed data, due to the sensitivity of the data in their systems. This is also what Van der Plas (2020) notes in his findings. He specifies it to asset monitoring, but this could be expanded into inventory management and demand forecasting (especially since demand forecasting is in this case related to asset monitoring). Another addition is the supplier information, that can also be taken into account with important calculations. Should the supplier have data about the MTBF, it could make the calculations even more accurate.

Information about obsolescence can also be more effectively exchanged through the supply chain. Should the SCT notice that an item has become obsolete, it can read the current inventory status, identify any risk categories and notify DMI and/or Thales. They can then look at the item and its usage, compared to the MTBF or the expected lifecycle of the system it is used in and determine how many units are needed for maximum service level. Due to the aggregation of inventory, this expected number of units can be more easily determined, since both inventories can see how many usable units are still in the supply chain, without an inquiry upstream of the supply chain. The requirements for this were discussed in detail in the research by Van der Plas (2020). The difference is that here, the SCT can combine requests of inventory levels with obsolescence status directly from the supplier. This will yield more accurate information, as well as an expected remaining life of the spare. Figure 26 shows how this inquiry might look. Here, things like workload and inventory levels can be included, so that the supplier does not necessarily need to be part of the SCT collaboration.

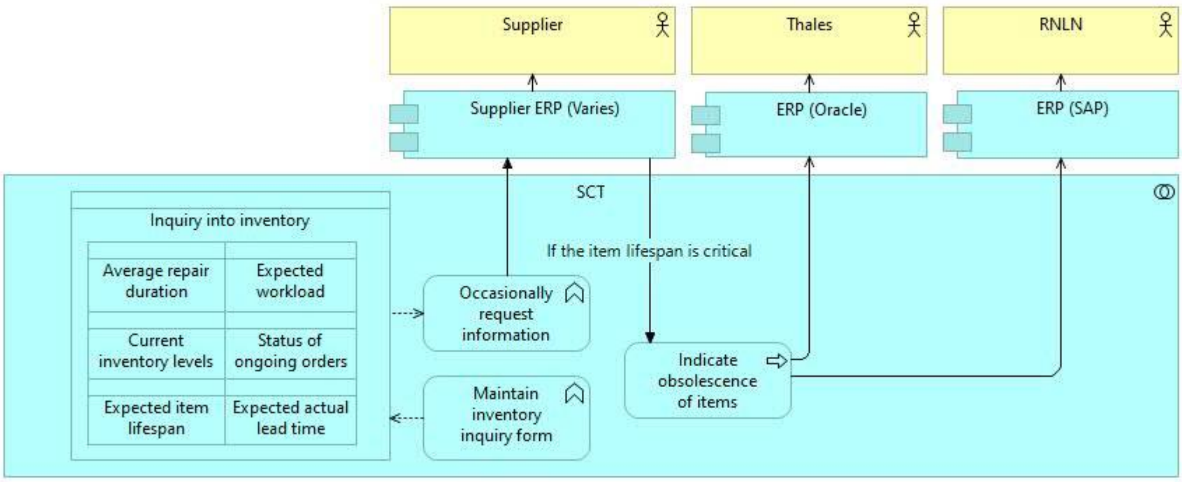

Figure 26: The SCT using its inventory inquiries to detect obsolescence

5.2 Limitations

Even though the SCT has many advantages, implementing it is not easy. It is not an isolated entity and in the literature, all other entities were only for one individual company instead of two. In this chapter, the main obstacles the SCT faces will be discussed. For these chapter, the same structure will be maintained as the previous chapter with inventory sourcing and information as key supply chain drivers.

5.2.1 Inventory limitations

The biggest limitation in inventory management is the select inclusion of items. Thales has many different items and each of these items have their own demand patterns. DMI is only one customer with a certain number of items, so only a small part would be covered by the implementation of the SCT between Thales and DMI. Due to the focus of the research, there is no guarantee that the same situation applies to the other customers. Where Unilever and Dell had the SCT takeover one part of their companies' logistics department, the SCT is assumed to only influence a limited number of items. This is not an issue for DMI, since they would still likely receive a better service, but this would mean that Thales has to split the operational activities in two: with and without SCT. This could be solved by having Thales gain authority over the SCT and allow them to include all of their spares and customers.

Similarly to Thales, DMI monitors entire frigates of which a part are the radar systems. Would the SCT be implemented, DMI would face similar issues to Thales, where they have to split their logistic chain in two. The difference here might be that DMI can outsource their logistics of radar systems entirely, effectively removing the expediting of one key system they have to monitor for the function of the frigates. However, this limitation needs to be researched before implementing the SCT.

5.2.2 Sourcing

One of the issues of the SCT with sourcing is the level of engagement from your suppliers. Requesting information from suppliers is one thing, receiving it is something else. Without a clear incentive, suppliers could neglect to keep the information in the SCT up-to-date, negating any advantages the SCT would have in this regard. Including all suppliers in the SCT collaboration is unlikely, due to the sheer number of stakeholders that would be involved in that case. It has also not been researched how well suppliers would respond to an incentive. Additionally, if the suppliers decide to offer order information, there is no guarantee that the information given will be accurate.

5.2.3 Information sharing

To solve the lack of information sharing, Thales could start by looking at smaller alternatives. The customer portal that Thales currently uses could be expanded to fit some of the suggestions given earlier. In its current state, the portal is only used as a 24/7 gateway for the customers. This could easily be expanded to include aspects of the SCT that were mentioned earlier. It could ask for usage reports on the radar system, which was suggested the SCT should do to increase the accuracy of the MTBF. This would include many more customers other than DMI, meaning the data quality would increase even more than with an SCT and could be personalized for each customer. Additionally, the customer portal can be used to monitor the inventory levels of the customers. Since aggregating inventory will be profitable for both Thales and its customers, the portal could offer customers this option for expansion of aggregated inventory. The customer can choose how much of their inventory they would like to show to Thales, so that Thales can pre-emptively stock on items in inventory. Using the customer portal would also be more easily implemented, since the system is already in use and would not require as much research.

For the exchange of information, there needs to be some form of uniformity in data, which is currently unclear. In the literature review, Sainathan (2019) mentioned that a common problem of current generation control towers is that there is no real data standard. The SCT as described earlier will have to deal with information exchange between two companies, making this issue more difficult to solve. If the SCT would actively monitor KPIs such as inventory levels, expected lead times and spare part strain, these need to be the same datatype to be easy to read. If not, the SCT risks compatibility errors and would require manual correction.

5.3 Implementing inventory

Even if the SCT is not implemented, the issue of proper inventory management is very important for Thales. That is why some remarks can be made that could be used in general to optimize inventory management, even without a SCT

The main issue with implementing inventory for Thales, is that the demand is extremely unstable. High inventory levels mean high holding costs and increase risk of obsolescence costs, so it has to be kept low, while also covering demand. This is where the SCT would have the most impact, but there are other things that can be done to smooth the demand curve, while not increasing inventory levels. One method is called vendor-managed inventory (VMI). This would method describes storing spare parts upstream, by the manufacturer. This manufacturer would hold inventory for the spare parts while Thales assures that their customers have enough inventory. This system would allow Thales to lower inventory holding costs, but due to the outsourced inventory they have an increased dependency at their supplier. This might not be preferable, seeing how reliable the suppliers are, but it is a method lowering holding costs. Additionally, the costs of obsolescence remain the same if not higher. Should an item become obsolete, Thales is forced to take all of their outsourced inventory. This would increase the costs of obsolescence.

A method to eliminate the risk of obsolescence is to offer call-of-contracts. In these contracts, customers 'purchase' a set of items that they can call upon whenever the need arises. Thales will hold the items in inventory until either all items are called off, or the duration of the contract ends. The main advantage is that the items in storage are guaranteed to be sold. This eliminates the risk of obsolescence, since all items in storage are guaranteed to go, while making the calculations of holding costs easier. It also means that the fluctuating demand is less relevant, since the customer is in this case responsible for their own estimations of demand. Additionally, some of the items that are held could be used to satisfy demand of other customers, depending on the risks of these actions. A disadvantage of call-off-contracts, however, is that the customer may end up with a large quantity of spare parts it does not need anymore. This might not be an issue for Thales, but it does give customers more negotiating power, possibly lowering profit margins.

Another opportunity for inventory is to combine efforts with DMI. Not implementing an SCT does not mean that aggregating inventory is not possible. Storing spare parts in a warehouse that is shared with DMI would allow Thales to share the holding costs and offer DMI a higher service level. DMI would have direct access to any spare part they need, so that they can repair LRUs without reorder delays. Thales on the other hand can increase standard stock levels, since the holding costs are lower in general, increasing their response time to unexpected orders.

6. Conclusion and discussion

In this final chapter, the conclusion in regards to the main research question will be given. This question, as it was named in the methodology, was: *How does a SCT impact the levels of different inventory locations of spare parts intended for DMI at Thales?* Besides a summation of how this question was answered, the final recommendations to Thales will be given, as well as some weaknesses with the SCT.

6.1 Findings

The supply chain of Thales could use some additional support, besides the implementation of inventory. The supply chain is complex and the behaviour of the spare parts might vary between customers. As mentioned in the literature review, a control tower can be a great method to take over a logistic part of the supply chain. One of the specializations of the control tower, the SCT could be implemented to help the service Thales offers its customers, depending on the function that is given to the SCT. If the SCT gains access to the inventory levels of the stakeholders, it can calculate important risks related to spare parts. It can then then use this information to inform Thales and DMI of any spares that require some intervention. This mediating function can help smooth out demand and lower variance. This would mean that the inventory levels can be kept lower, without suffering increased risk of stockout. A key addition to previous research, is that the sourcing of Thales might also need to be monitored for a real effect. Thales' suppliers are unreliable and only by monitoring their orders closely, it could already help the service that Thales can offer.

As was suggested by both Van der Plas (2020) and De Vries (2020), If the SCT would access company data from both DMI and Thales, it can increase the accuracy of calculations. This availability of data would on its own help Thales better estimate things like repairability at DMI, MTBF (for items at DMI) and hours of usage. The new data available can then increase the reliability of the calculations that the SCT (or Thales) can perform to improve forecasting, for example in their inventory level calculation tools. With enough data reliability, the function of these tools could be upgraded to have more impact than their advisory function that they have now.

6.2 Discussion

The key issue with the SCT as it was imagined in this research, is that it excludes spares Thales offers. Having to split the spares offered in two would not necessarily mean that overall service will improve, only service of a certain number of items, therefore making the implementation less appealing. Additionally, the dataset that was provided used all different spares that were to be considered for an inventory location. This means that the calculations and results of these analyses are more general and may not apply to the situation between Thales and DMI.

Additionally, Thales has a lot more customers than DMI. Since only DMI is part of this SCT, the yields of the SCT might be somewhat overvalued as well. As De Vries mentioned in his final chapter, the MTBF can depend on factors that differ for each customer. This makes the exchanged information only valuable to the calculations regarding DMI. It is possible that there is some consistency which the MTBF might follow per customer. This was out of the scope of this research, however, and can be a topic for follow-up research, since this would greatly improve the yields of the SCT.

6.3 Recommendations

Some intervention is required to help Thales support their inventory. OPUS10 is an extremely detailed tool, but makes some assumptions that harm the scientific validity. The variance of demand is one of the key problems for Thales, so anything that can help reduce this variance can help increase efficiency of the supply chain.

The main addition the SCT has to this supply chain is that it can provide more spare part data. This generation of data can already be implemented through another method, such as the customer portal. In its current form, it already provides more insight in the spares by being a 24/7 access point for customers. The next step can be to request detailed maintenance and usage reports. This alone might, besides offering a more accurate MTBF, indicate earlier on when items are starting to malfunction. Not only this, but the calculations of OPUS10 would also be more accurate, meaning inventory will also be more easy to calculate. This would require cooperation of customers, but it would increase the service that Thales can offer, therefore being an incentive to offer help. Of course, it is unclear how willing customers (besides DMI) are, so further research is required.

Additionally, Thales could more thoroughly examine suppliers. In the analysis of the current situation, data showed that some items suffered extreme delays compared to the expected lead times. A delay at suppliers is not unexpected, especially when the parts are rarely ordered. However, the scope of these delays were in some cases too high. Either the expected lead times need to include a buffer period, so that the lead time is less variable, or the suppliers need to be more involved in these delays. Being able to accurately predict when an item can be delivered will help to reduce the current supplier risk, making the need for inventory less pressing.

7. References

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Appendices

A. Interviews with Stakeholders

[REDACTED]

B. ArchiMate models

B.1 Determine stockout risk

[REDACTED]

B.2 OPUS10 run overview

[REDACTED]

C. Additional tables and graphs

C.1 KPIs for both inventory tools

[REDACTED]

C.2 Distribution of buy and make orders per year

[REDACTED]

C.3 The average delay compared to processing time

[REDACTED]

C.4 Difference between real and expected lead time

[REDACTED]