UNIVERSITY OF TWENTE. THALES

Radar system lead time reduction

Master thesis

Peter GJALTEMA

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External Report

"How can the lead time for radar systems be reduced, in particular, what are lead time consequences of design choices?"

Master thesis

Radar system lead time reduction

Author: P.B. Gjaltema

Study: Industrial Engineering and Management,

Production and Logistic Management specialisation

Committee:

Dr. P.C. Schuur (University of Twente)

Dr. M.C. van der Heijden (University of Twente)

Company committee:

Ir. J. van den Bosch

John Hof

Date: 23-01-2015

MANAGEMENT SUMMARY

Thales struggles with the long lead times for their radar systems. For large radar systems these lead times can approach three years. The radar system is made for a Marine ship, and these are built in roughly one year. This fact, and the competitive advantage when faster delivering than competitors, makes the reduction in lead time a must.

We will look for improvements in the lead time for new radar systems which are still to be designed. Thales wants to be able to make design decisions for new radars also based on lead time consequences. Therefore the research question we will address in this research is

> *"How can the lead time for radar systems be reduced, in particular, what are lead time consequences of design choices?"*

As suggested by our research question, the purpose of this research is twofold: (1) to design a model that clarifies the lead time consequences of initial design choices and (2) to reduce the total lead time of the radar by logistic measures, given the initial design.

An improvement can probably be made in the design phase of a radar system because in this phase the decisions for certain materials, production techniques and functionalities are made. These decisions imply consequences for the lead time of the radar system, for this we made a model. With this model the lead time of the radar system under design can be monitored, and design decisions can be made based on lead time consequences for the whole radar. The items that really are the cause of the total lead time are highlighted. Designers can reconsider these items, such that the radar will face a shorter lead time. For the case an item cannot be changed by re-design for shorter lead times, or when it would cost too much, we need other measures. These are logistic measures like sub item inventory and value stream analysis.

We investigated **Radar A** for lead time reduction. What strikes is that we only need to consider a few items and production steps (39) for achieving a significant reduction on the total lead time. These are the items that should be improved for reducing the lead time of the radar from 119 weeks 78 weeks, which is 1.5 year. This is a reduction of 35% in lead time. We investigated four Long Lead Items of Radar A for lead time reduction, because those LLI's are the main cause of the total lead time, and they also have the most reduction potential.

To find the best appropriate measure for improving those Long Lead Items, we need more information than only the lead time of these items. In cooperation with suppliers the information about the product breakdown structure, supply chain and value stream of those items became clear, such that we could make the best improvement measure. The results are shown in Table 0-1.

Table 0-1 Long Lead Item improvements

Long Lead Item	Started Lead time (weeks)	New lead time (weeks)	Improvement measure
1	92	37	Improvements at supplier, deleting waiting times. Four sub-items in inventory for low cost.
2	82	58	Synchronized LT information with supplier, two items in inventory for low cost
3	78	53	Two large items in inventory for high inventory cost.
4	94	40	Improvements at supplier, deleting waiting times.

We see large improvements can be made by aligning information and more cooperation with suppliers. Analysing waiting times for the LLI's led to serious lead time reduction. Cheap sub item inventory, some materials which cost in total only a few hundreds of euro's, also significant reduces the lead time. Sub items like in Long Lead Item 3, where we see expensive inventory cost, should be reconsidered by designers in the design phase. Therefore re-design should be a trade-off against logistic measures.

By analysing Radar A and the four Long Lead Items, we developed and used the **roadmap for lead time reduction** below, which can be used for radars in general.

0. The initial design is made by the designers.
1. Determine the relevant minority of the items. This are the items where the paths, longer than the lead time goal set by Thales, consist of (for Radar A 39 items, 2.5% of all the items). Make this subset visual.
2. Select the critical path of the radar system, verify its lead times, determine its sensitivity for reduction.
3. Re-design for lead time reduction:
    - Changing the product-breakdown-structure with as result a shorter lead time;
    - Using other production techniques with a shorter lead time;
    - Look for other suppliers with a shorter lead time;
    - Use standardized items, perhaps with re-design;
    - Involvement of suppliers in the design process.
4. If re-design is not possible or too costly, investigate the supply chain and value stream of the Long Lead Item in the critical path.
5. Work out the following logistic options for lead time reduction for making the best trade-off on lead time reduction and cost:
    - Sub item inventory;
    - Deleting wastes (mostly waiting time);
    - Pre-release.

The improvement potential of by re-design in the design phase of a new radar system is hard to quantify. Several examples like changing supplier or using a more standard design show however, that there are possibilities for lead time reduction in the design phase. With our research we can come up with the following **conclusions.**

1. *The lead time of a radar system can significantly be reduced by improving a small part of the total items a radar system consist of.* For Radar A we needed to consider 39 items, 2.5% of the total items from the radar.
2. *Monitoring these 2.5% important items with our model in the design phase, reveals the lead time consequences of design choices.* Now design decisions can be made on lead time consequences.
3. *Logistic measures have potential for significant lead time reduction with low cost.* Sub item inventory for only hundreds of euro's seriously reduced the lead time of Long Lead Items.

We urgently recommend the following **recommendations** to Thales.

1. *By this research we developed a roadmap that should be used for lead time reduction.* With the roadmap we have significant reduced the lead time of Radar A. This roadmap is applicable for every large radar.
2. *Thales should largely extent cooperation with key suppliers.* When having more than 50% of the production outsourced, cooperation with important suppliers is a necessity for reliable production plans.
3. *Closely monitoring the critical paths when really building the radar, is essential.* Critical paths deserve a lot attention for on time delivery and lead time reduction.

PREFACE

With a lot of pleasure I have executed this graduation assignment. For me Thales turned out to be a very interesting company, even more than I thought at the beginning. Besides the sophistication and innovativeness, the usefulness of their products really has my sympathy. I have learned a lot from the specific logistics of radar systems, and the challenging environment Thales faces. All together this period was a great experience to me.

I would like to thank Thales for giving me the opportunity for executing this graduation assignment, with perfect working conditions. The helpfulness from, and informal relations with a lot employees, especially the whole industrialisation department and several logistic planners, made this graduation assignment a very pleasant period.

In particular I would like to thank my supervisor at Thales, J. van den Bosch. His expertise and time he invested in me, has given me new insights en sufficient challenges during this period. I thank both the supervisors from the university for giving me valuable feedback, such that I was able to eventually come up with this report about which I can be satisfied. With relief I end my study by this graduation assignment, which made me very confident for entering the working area.

Peter Gjaltema

INHOUDSOPGAVE

LIST OF ABBREVIATIONS

BOM: Bill Of Material
BTO: Build-to-order
CODP: Customer Order Decoupling Point
CPM: Critical Path Method
DFA/M: Design for Assembly & Manufacturing
EDC: Effective Date of Contract
EPM: Electronic Parts Manufacturing
FA: Final Assembly
FAT: Factory Acceptance Test. Here the T&I phase ended
FOC: First Of Class
LLI: Long Lead Item
LT: Lead time
MRL: Manufacturing Readiness Level
MTO: Make-to-order
PBS: Product-Breakdown-Structure
T&I: Test and Integration
TOC: Theory Of Constraints
TRL: Technology Readiness Level
V509: FA phase ended
VSM: Value Stream Map

1. INTRODUCTION

Thales Netherlands is a company which designs and assembles advanced radar systems for marine ships. For the competitiveness of Thales, it is a necessity to reduce the lead time of radar systems. Thales believes, improvements for the lead time can be made in the design phase of a radar system. Therefore they requested the design of a model, making it possible to base design decisions on lead time consequences. Also logistic improvements are considered for total lead time reduction.

This research is a master thesis from a student studying Industrial Engineering and Management, with the production and logistics direction, at the University of Twente. An in-depth logistic analysis is conducted for this assignment.

In this chapter we further introduce the company for which the research is performed in section 1.1. The research problem is outlined in section 1.2. At last in this chapter, the way this research is performed is discussed in section 1.3.

1.1 THE COMPANY THALES NETHERLANDS

In 1922, Holland Signaal Apparaten (also known as *Signaal*) was founded for making naval fire control systems for the Royal Netherlands Navy. After being taken over four years by the German Army, the factory came in the hands of the Dutch government in 1945. Philips, a Dutch electronic company, bought up the majority of shares in 1956 from the Dutch government. Philips developed radar fire control systems, such as the Goalkeeper, and the company grew to 5,000 employees at most. In 1990, Philips decided defence was not a core activity anymore, and sold Signaal to a French electronics and defence contractor, called Thomson-CSF. They renamed in 2000 to Thales Group, from that time Signaal is called Thales Nederland. From building the whole system on their own, Thales outsourced most of the production in the past decennia, thereby dramatically reducing their employee level. Still Thales Nederland is the biggest defence company in the Netherlands.

Thales Group has about 68,000 employees in 50 countries all over the world, with a 14 billion turnover in 2013. 50% of the turnover comes from the defence industry. Thales Group is the 11th largest defence contractor in the world. The turnover of Thales Nederland was 400 million in 2012, with more than 85% in the defence industry.

Thales Nederland specializes in designing and producing professional electronics for defence and security applications, such as radar and communications systems. Defence is by far the most important market. Because Thales Nederland developed the worlds first digital fire control radar, the first digital multi-beam radar, the first non-rotating active phased array radar, Thales Nederland is seen as the most innovative naval radar developer in the world. After Raytheon (US) they are the second largest naval radar producer in the world.

Hengelo is the Dutch headquarter of Thales Nederland, which has also branches at Huizen, Houten, Delft, Enschede and Eindhoven. After several reorganisations, nowadays about 1,700 of the 2,000 employees in the Netherlands work in Hengelo.

Figure 1-1 I-Mast on a Dutch Patrol Ship

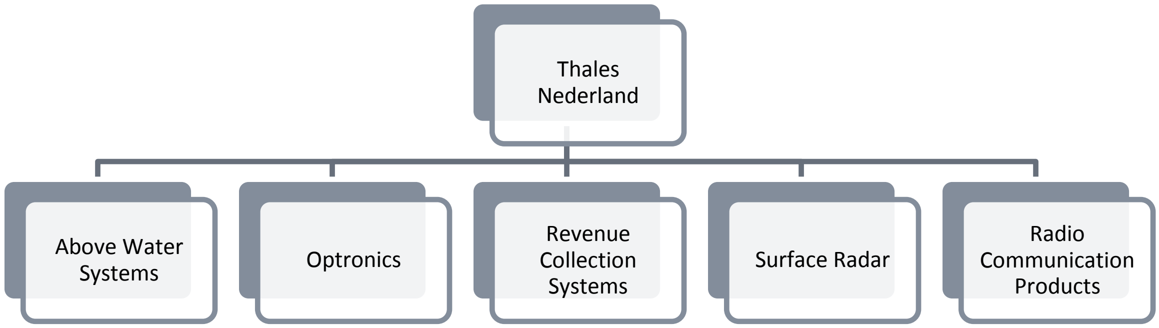

Figure 1-2 Business Lines Thales Nederland

The work of Thales Nederland is divided in five business lines, pictured in Figure 1-2. The radar systems we investigate are in the Surface Radar Business Line. This Business Line is situated in Hengelo. Within this Business Line, the department Radar Delivery takes care of the processes between product realisation until the test and integration of radar systems.

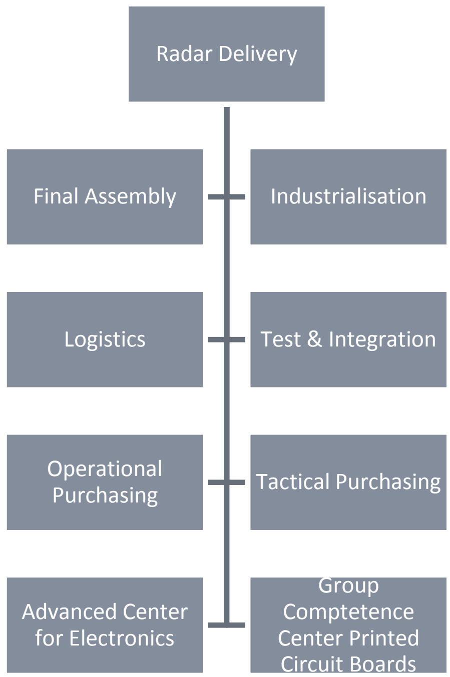

Figure 1-3 Radar Delivery Department

All the departments within Radar Delivery are given in Figure 1-3. This research is performed for the Industrialisation department. The Industrialisation managers are concerned with the interface between development of new systems and product realisation. They translate the design into a good manufacturable product. For the future they would like to have insight in lead time consequences of design choices, such that in this design phase, design decisions can be made also based on lead times.

Thales Hengelo is supplier and integrator of complete mission system solutions for surface ships. They have the broadest naval radar portfolio in the world, suited for all classes of vessels, from small high-speed intercept ships to destroyers and even aircraft carriers. This wide range of radars allows tailor-made weapon systems for each ship and any mission. Their latest development in the field of naval radar systems are the so-called Integrated Mast (I-Mast) and the SMART-L ELR long range surveillance radar.

The I-Mast, Figure 1-1, is currently installed on the four Patrol Ships, and the Joint Support Ship, the Karel Doorman, of the Royal Netherlands Navy. This system lets simultaneously work together every radar, sensor and antenna in this one housing, without interfering each other. Compared to rotating systems, this non-rotating system achieves four times the time on target, resulting in higher radar performance.

The SMART-L, Figure 1-4(on the front-page depicted on the air defence frigate Zr.Ms. De Ruyter), provides a very long-range coverage of 400 km radius. In a few years this is 2,000 km with an upgrade. SMART-L guarantees excellent performance, especially against stealthy targets in a coastal environment and in a few years for ballistic missiles. The high sensitivity allows for the early detection and tracking of very small aircraft and missiles. SMART-L is operational on the Netherlands' and German air defence frigates, the Korean Landing Platform Dock, and is under contract for the Danish Navy's Patrol Ships. SMART-L's derivative, S1850M, is currently being installed on the Royal UK Navy's Type 45 vessels and the French and Italian Horizon class destroyers and the new British Queen Elizabeth class aircraft carriers.

Figure 1-4 SMART-L

This gives some insight in the customers of Thales. The Royal Netherlands Navy is their launching customer. Their products are highly advanced and not rarely most innovative in the world, and therefore are sold to navies all over the world. The French parent holding broadens the customer range, and opens doors to customers America can not sell to because of political issues. Thales products are characterized as complex and sold in low series. Series range from 2 to 10 radar systems a year, other radars are only sold once in several years.

As one of the leading European players, Thales competes in surface naval systems with Selex, Saab, BAE Systems, and the American companies Lockheed Martin and Raytheon. Because the quality of Thales products is very good, and money is for navies not the largest issue, this competition puts pressure on Thales lead times.

1.2 THE RESEARCH PROBLEM

Problems arise where reality is away from the desired state. That state is given contrast by competitors, who give standards to which a product should meet. Besides that, Thales sets themselves high standards to be the most advanced radar system producer in the world.

As mentioned briefly in the previous section, from the market the pressure on lead time rises. The lead time of a radar system is seen as way too long because the marine ship the radar system is made for, has a way shorter lead time. Rough numbers are three years for large radar systems and one year for a marine ship. Also to stay competitive against other radar system producers, this lead time should be reduced.

We need a definition for the term *lead time*, such that we all know what is meant by the term.

Lead time is the time between a customer places an order, and the time the radar system is completed and can be shipped to the customer.

After this, the radar is transported and tested on the ship it is made for. Another time definition we will use, is the *cycle time*.

The cycle time is the time purchasing for a new system/ item starts, until the time the system/ item is completed.

So the lead time is at most as long as the cycle time. Reducing the cycle time will reduce the upper bound of the lead time. The lead time can be made significant shorter than the cycle time by measures like for example forecasts and inventories, at which we will come back later. Because Thales in general only starts buying and producing when an order is signed, we will use the term *lead time* throughout the report. Items most interesting for this research are *Long Lead Items*, which we will define as follows.

A Long Lead Item is an item with a relatively long lead time, in general more than 50% of the total lead time of the whole radar system.

These are the items that need reduction, if one wants to improve the lead time of the whole radar system. We know lead time depends on many factors. In general the processing time, where operations change and add value to the product, is just a small portion out of the total lead time. That other part is most interesting for improvement. It consist most out of waiting- and transportation time.

Several causes of the lead time, which is seen as way too long, are listed below.

- Due to the low series production, most of the items are not in inventory. Especially interesting is that Long Lead Items, usually also the most expensive items, are not in inventory. Therefore they are the main cause of a long lead time for the total radar system.
- In the design phase of a radar system, there is no focus on lead time.
- Currently Thales is using backward scheduling, so items come in just-in-time, with a certain safety time. Some delay, beyond the safety time, will therefore cause direct lead time extension for the system.
- It happens that products are not fully developed but production is started, which can result in design changes.
- Delivery dates from suppliers are often not achieved, Thales faces a bad on-time delivery of certain suppliers.
- There is almost no knowledge about what is happening behind the supplier of Thales, and where the lead time the supplier gives consists of. Information sharing with suppliers seems to be to few as we look to the degree of outsourcing. Due to more outsourcing this even becomes more important each year.

Throughout the whole supply chain of those radar systems, techniques can be used to improve the lead time. Inventory on Long Lead Items should be investigated. However, the items, modules and sub-systems a radar system consists of, cannot be changed anymore. Based on the specifications of a customer, the radar systems functionality, design engineers choose certain items from certain suppliers. This designing is done without taking lead time into account. But in this design phase actually the associated lead time for the system is determined, without being aware of it.

Strikingly this determination of items in the design phase can have considerable impact on the total lead time. Instead of improving the activities of an existing design, we should be able to change the design, for a good lead time of the system. To do this, consequences for the total lead time should be considered while designing the radar system. In this case certain items and production techniques would be reconsidered if the consequence of those, is a major increase in the total lead time.

For these issues, Thales requests a model for making improvements on the lead time in the design phase of a new radar system.

1.2.1 PROBLEM OWNER

For Thales as a company, reducing the lead time of radar systems is a necessity to stay competitive. So Thales as a company is the key problem owner.

Internal, several employees are confronted with this problem. First Industrial managers, working on the interface of product development and product realization, are currently facing the problems of not taking the lead time into account in the design phase. Those people are also doing production managerial work, and then have to deal with certain items with excessive long lead times, this can't be changed after the design is completed. With the latest radar system, cost was taken into account, but the industrial managers would have liked to also have insight in the consequences for the lead time. This would have had impact on decisions about items, resulting in probably a shorter lead time. At least this would result in reconsidering certain items, or investigating the lead time from suppliers.

In general, many employees face the consequences of choices in the design phase and are asked to minimize the lead time, while perhaps the biggest improvement in lead time can be made in the design phase where lead time is not taken into account.

1.2.2 PROBLEM RELATIONSHIPS

Many problems have a certain cause in the problem stated earlier. The question is, what are the cause-effect relations between these problems and what problems should be focused at. The core problem should be found and chosen such, that solving this problem should be possible, and have the most impact on the whole problem, namely a lead time reduction. To gain insight and make visible this relations, the following schedule is made (Figure 1-5 Problem Relationships). Waiting time can be defined as the time no value is added to the product within the total throughput time.

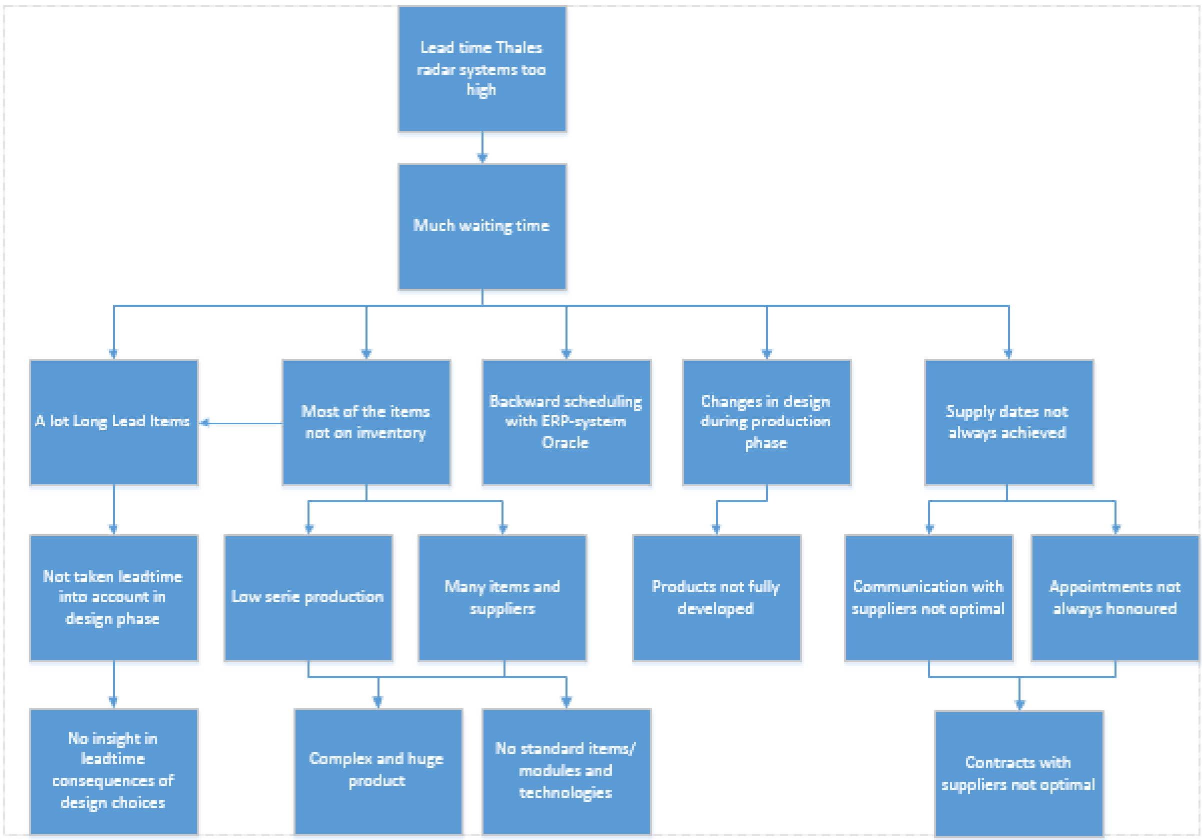

Figure 1-5 Problem Relationships

1.2.3 CORE PROBLEM

THE LEAD TIME IS NOT TAKEN INTO ACCOUNT IN THE DESIGN PHASE AND MOST OF THE LONG LEAD ITEMS ARE NOT IN INVENTORY

The impact of each item on the total lead time of the radar system should be made visible in the design phase. In this way, decisions for items can also be based on lead time consequences. This will result in reconsiderations of certain items. Having this visible and clear, this gives focus at which items should be focussed to improve the total lead time. Maybe this will result in less Long Lead Items or having them in inventory. The impact of having Long Lead Items in inventory, or certain sub items of those Long Lead Items, should be investigated, both for lead time and associated inventory cost. The focus should be at the items which are on critical path, the path that determines the total lead time, the longest path. Reducing the lead time of these items will have direct impact on the total lead time.

These are the problems chosen for research, because they can be improved and have the most potential for reducing the total lead time. This resulted in the following research question.

1.2.4 RESEARCH QUESTION

"How can the lead time for radar systems be reduced, in particular, what are lead time consequences of design choices?"

To answer the research question, we make several sub-questions, which all will contribute by answering a part of the research question. When we bundle together the information of all the sub-questions, we are able to answer the research question. The sub-questions are listed below.

1.2.5 SUB-QUESTIONS

1. Where does the lead time of a radar system consist of?
    a. How is a radar system designed?
    b. What does the demand and supply chain of a radar system look like?
    c. What are current inventory policies?

When this sub-question is answered, we know the current situation and procedures of building a radar system from start to finish. This information should be analysed in the next sub-question for problem finding.

2. What problems are causing the long lead time of the radar system?
    a. What current lead time reduction possibilities are used?
    b. What does the critical path look like?
    c. What can be found in the literature about coping with these problems?

The lead time of a radar system is seen as too long. By answering this sub-question we know the problems encountered in building a radar system. This gives us a direction for improvement. With this information in mind a literature research will be done.

3. How can we take lead time consequences into account in the design phase?
    a. Thales requests a model for this issue, what are their requirements?
    b. What should this model look like?

Now we know the areas for improvement and the critical path, we can start building the model. Thales requested a supply chain model for lead time improvement in the design phase of a new radar system. With this model, lead time consequences from design choices should be clarified. Then design decisions can be made also based on lead times.

4. What other possible alternatives for lead time reduction are promising?
    a. What are the pros and cons of each alternative?
    b. What is the best solution for the radar system used as example?

By answering this sub-question we can give an overview of the possibilities for lead time reduction for a radar system. On top of this we see the results of applying the most useful possibilities on the radar system used as example.

1.3 RESEARCH OUTLINE

This section describes the further outline of this research and what we can expect from this research. In the next chapter, the current situation of building a radar system is described, this answers sub-question 1. Also the problems encountered in the current situation are addressed in this chapter, answering sub-question 2a and 2b.

Chapter 3 contains a literature research for solutions applicable to the problems encountered in the first two chapters, answering sub-question 2c. In chapter 4 the supply chain model designed for Thales is described, answering sub-question 3. Chapter 5 answers sub-question 4. The conclusions and recommendations answering the research question are described in chapter 6.

1.3.1 NECESSARY INFORMATION

- Current information about inventory and performance of the supply chain
- Lead time information about items, modules, subsystems and the whole system
- Inventory cost per time unit per part
- Obsolescence cost of not using the part while having it on stock
- Reducing lead time techniques from scientific literature

This information will be gathered from Thales systems (documents and records of existing data), Thales employees, Thales suppliers, scientific literature and course material from the study Industrial Engineering and Management.

1.3.2 METHODOLOGY

To solve the problem methodological justified, the Management Problem Solving Method (MPSM) (Heerkens, 1998), will be used. With this methodology no important aspects of doing research will be overlooked. This method contains seven phases which will be done chronologically.

1. Problem identification	**First the core problem is searched out of all the problems found when looking for a shorter lead time for radar systems. We have seen this core problem is that lead time issues are not taken into account in the design phase, and that the Long Lead Items or sub items from them are not on inventory.**
2. Formulate plan of approach	**Based on the core problem, the research question is formulated. To split out the all the work for finding an answer to the research question, and for making the research structured and concrete, four sub-questions are formulated. These questions have fall together in the structure of current situation, problems encountered and improvements.**
3. Problem analysis	**After the current situation is described, and the problems encountered in here, we start analysing these problems. We zoom in on the most interesting parts for lead time reduction.**
4. Generate alternative solutions	**There are several alternatives for lead time reduction. We describe all of them. Eventually the pros and cons of the alternative will be made clear such that we can make trade-offs for determining which alternative can be used best.**
5. Choosing the solution	**At the radar system used as example, the most appropriate option(s) are applied.**
6. Propose implementation of the solution	**We describe how the findings of this research can be applied within the business their operations.**
7. Evaluate the solution	**The model and the whole research is tested on Radar A.**

Within this methodology a literature survey will be done. With the Universities access to scientific articles on Scopus and Web of Science applicable literature will be looked for. Also a lot of study material in Industrial Engineering and Management courses will be used.

1.3.3 RESULTS

This section sums up the deliverables of this research.

- A model determining the critical path, and highlighting interesting parts for improving the lead time of a radar system. This can be used in the design phase of a new system.
    - The option for inventory holding with associated costs is included
    - An overview of the value stream for certain items is included

  With this information visible, employees can make trade-offs based on lead time and cost. This model will be made in Microsoft Excel.

- The alternatives for lead time reduction of a radar system will be described.
- For Radar A, the lead time will be improved using the best applicable alternatives.
- A value stream analysis will be conducted for several items, showing the possible impact of this option.

1.3.4 LIMITATIONS

While looking for logistic optimisation, the model to be designed will highlight parts for possibilities of most impact in lead time reduction. Technical issues like using other applicable items and production techniques should be investigated by employees with technical knowhow for these issues. When lead time and costs are clear, these alternatives can be included.

Communication with suppliers will not be the primary research direction but will be useful for practicing the logistic optimisation.

2. CURRENT SITUATION

Before we can improve, our starting point has to be clear. The first two sub-questions are addressed in this chapter. For building a radar system, we have to know the current way of working at Thales, and every player involved. In section 2.1 the processes a radar system runs through are outlined. In this whole process not everything is going perfect, therefore the imperfections relevant to this research, are described in section 2.2. We end this chapter with a conclusion in section 2.3.

2.1 HOW A RADAR SYSTEM IS BUILT

A new radar system starts with a design phase, this is described in section 2.1.1. In section 2.1.2 the demand process of customers is described. The production steps of really building a radar system are outlined in section 2.1.3. The supply chain of Thales is described in section 2.1.4

2.1.1 DESIGNING A NEW RADAR SYSTEM

The design of a new radar system is not a matter for Thales alone. In collaboration with the so-called ambitious frontrunners, a few European navies, among others the German and Dutch navies, new needs and requirements for radar systems are determined. For the development of radar systems, Thales cooperates with their largest customer, the Royal Netherlands Navy, and various science and research institutes to be most innovative.

A design for a large radar system always is a project for several years. And only once in the two or three years a new system is designed. First the system architecture including the type of radar and hardware are chosen, then the system and subsystems are determined. The functional specifications are known, so design engineers can start developing a design which meets those requirements. They translate the question ‘what do we need’ into ‘what is possible’, the technical specifications. Thales makes partly built-to-print and built-to-design systems. So for suppliers Thales determines exactly the way the systems looks like and where it exists of, or just determines the functionality. This depends on the knowledge Thales has about the specific areas, and what they make themselves. ‘Make-or-buy’-decisions are made, suppliers are chosen based on skills, cost and preference. Together with suppliers responsible for subsystems, detailed product plans are made. Design engineers often do not just meet the requirements, but try to design a radar system even better, always working on the edge of what is possible. They want to design the most innovative and beautiful radar with the highest possible performance.

Designers bring up so-called release BOM’s (Bill Of Material). When this release BOM is made, this concept design is tested. Changes to the design can be made easily here by iterating release BOM’s, this is the prototype phase. A lot of testing still needs to be done in the development phase of the radar system, before the first system can be produced. In appendix A we show an overview of the activities from new ideas to production. When one design is made definitive for the first real system, the FOC (First Of Class), changes can only be made by change proposals. These changes are much harder, cost a lot of money and take significant more time.

One level higher than the designers, the work package managers and program manager look for the more practical issues, like cost. In multiple design reviews, employees like the program manager and industrial managers, have to take design decisions. In here Manufacturing and Technology Readiness Levels (MRL/ TRL) are considered. High scores on these levels are associated with high maturity and manufacturability of the design. Often several areas still need to be fully developed in the design phase, and not have the highest MRL/TRL levels. With this levels there are some lead time questions asked, but these have practical no influence on design decisions. The program manager also considers the lead time, but the lead time of the FOC, not the lead time for the system when it should be built later on again. Industrial managers should focus on the lead time for the system if it should be built later on again. In the design phase of the last systems, the cost impact of design choices is taken into account, but lead time consequences were not. Therefore negative consequences for the lead time of the system may arise.

Later on, when a system has to be built which is designed in the past, sometimes re-designs have to be done. The reason is most of the time obsolescence of certain materials. When materials cannot be bought anymore, they have to be replaced by others. This can have effect on more than just this material of the radar, for example that this new material has other characteristics in cooperation with other parts of the radar. Then the radar needs to be re-designed. For example it is seen that certain electronic components were standard 5-10 years, while a radar system can be sold 25-30 years. In our day-to-day life we see this for example with micro-SD, these cards get so fast smaller with better capabilities. For these issues an obsolescence engineer watches the market, but changes seem to be unavoidable.

2.1.2 DEMAND PATTERN

Thales can be seen as a build-to-order company. Once a customer places an order, the production starts. For some radar systems the demand is more high, two to ten systems a year. These radars are produced in series for cost reduction, and once this demand pattern is stable enough, they are produced on forecast. We further explain both type of demand patterns.

The customers of Thales are navies all around the world. The Dutch government has interest in Thales and determines to which countries the radars can be sold. For the newest systems, the Royal Netherlands Navy is the launching customer. This means they cooperate in the development of new systems and eventually purchase them. Holland and for example Germany want to be frontrunners, but not every navy wants to have the most new and technological advanced systems. Also that less ambitious navies are interesting to Thales with lower-budget radars.

As may be expected, Thales plays an active role in attracting customers. Product info is sent to potential customers, showing the possibilities with Thales systems. Each customer is different by its current technologies, ships, communication and information systems. Thanks to the broad portfolio a tailor-made solution is possible for all the navies. However, it can take several years of negotiating before an order is actually signed, or rejected.

For the systems produced in series and on forecast, historical demand patterns give an indication of the demand that can be expected the next years. For lead time reduction, production for these systems is started before the contracts are actually signed. The chance of really selling the system should be high enough. Based on two expectations, the chance that a customer places an order, and the chance that the order goes to Thales, actions before really signing the contract are taken. This actions are so-called pre-releases.

For these systems the Customer Order Decoupling Point (CODP) is relatively late. This is the point in the whole production chain of a radar system where the customer determines the further actions, how the product should look like. Because this CODP is relatively late, a few months before finishing production, producing on forecast is no problem for this radars. CODP issues are export licences, because for some parts the customer should be clear and approved selling to. New developments bypass this issue, first addressing Holland as customer and later when the final customer is known, that customer. Another point is the ultimate colour of the radar, just a few weeks before finishing production. This forecast and pre-release actions are at the time only used on a very low scale, because the consequences of eventually not getting signed the contract should always be avoided.

Next to the series production, some radar systems are only sold once in a few years. Also for these systems the chance of getting the order is used for beforehand actions. However, demand can come in all of a sudden. Even for relative old systems. For example the radar system we will use as example, Radar A, is ordered twice after not being sold in about seven years. The CODP of this system is also a few months before finishing production, around the start of the final assembly stage. This illustrates some of the issues faced when determining inventory management and early start of production.

2.1.3 PRODUCTION STEPS

The total lead time of a radar system is a process which consists of several stages. First we look at this process from a high level, later on we will focus on the most interesting stage for lead time improvements. When a radar system actually is going to be produced, the following stages have to be run through.

- Purchasing;
- Electronic Parts Manufacturing (EPM);
- Final Assembly;
- Test & Integration.

The times required for these stages depend on the type of radar system. There are radar systems where these stages in total last almost three years and others not even a year. In this research we use the Radar A as running example, this means it will be used throughout the whole report and when applicable extended and more detailed when the report is run through. To customers a lead time of 24 months is given for this system. This time stands for the moment the order is signed (EDC: Effective Date of Contract), until the time the system passed the Test and Integration stage, called the FAT (Factory Acceptance Test). This is represented in Figure 2-1.

For this large radar system the Final Assembly and Test & Integration stage both have a duration of two months. These both stages are done at Thales. Also at Thales a part of the total Electronic Parts Manufacturing is done in-house. In this stage Printed Circuit Boards (PCB) are produced and assembled. This is done at Thales, therefore it is outside the Purchasing stage. We see if we want to meet the 24 months goal, items to be bought for the EPM stage, should have a lead time of at most $(24 - 2 - 2 - 4) = 16$ months.

Non-electronic items need not to go through EPM, for example mechanical parts. But these parts can have even a longer lead time, for which a lead time of up to 22 months can be the case. We see that for this radar system more than two third of the total lead time can be found in the Purchasing stage.

Time (months)					
18			4	2	2
Purchasing			EPM	Final Assembly	Test & Integration
Total time (months):	**26**				

Figure 2-1 Processes

The stages Final Assembly and Test & Integration do not have a lot potential for lead time reduction because they are relative short and have a lot processing time. EPM is at the time partly outsourced, and conversations with other parties for more outsourcing are currently held. Therefore these stages are not considered, because of low influence possibilities for the total lead time.

The focus of this research therefore is on the Purchasing stage. Beside that it is the very largest stage in the total lead time, it is also the stage with the most potential for lead time reduction. Inventory, forecast, other suppliers and production techniques are arguments for this statement.

For total lead time calculations, assumptions are made for the lead time of the three stages besides the Purchasing stage. These are given in Figure 2-1. Every radar system looks like this example, with the same stages and per stage the same fraction of the total lead time. The total lead time depends on the size of the radar system.

THE RADAR SYSTEM USED AS EXAMPLE

We have chosen to investigate in depth Radar A. This is not the newest radar system, because from the newest radar not all the information is yet available. Although Radar A is an older system (built for the first time in 2003), it is a large radar system which will learn us a lot about the way radars are produced and how complex they can be. All the necessary information for this system is available and this system is currently under production. With this information we can make the research concrete and see the impact of the research. Above all it will give us insight in how to tackle the problems faced when striving for a shorter lead time.

Figure 2-2 example radar

Radar A consists as every radar system out of thousands of items. Like every other radar it has, among others subsystems, an Antenna system for sending and receiving a signal, a B-drive for circling around, a structure for the housing and an IFF for detecting friends or foes. These subsystems again consist of certain items. In Figure 2-2 we see a finalised radar. A simplified representation of the product-breakdown-structure (PBS) is given in Figure 2-3. We use anonymous data for confidentiality.

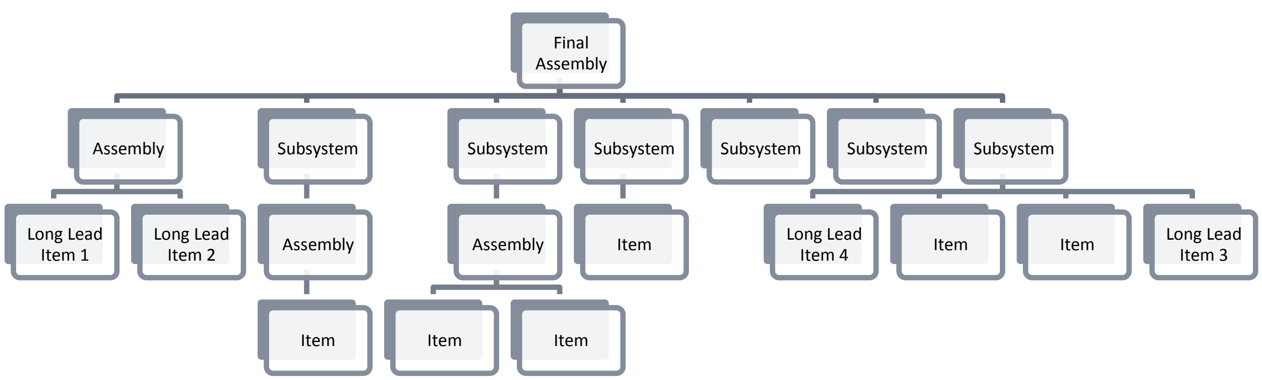

Figure 2-3 Product-breakdown-structure Radar A

In here we see items have dependencies on other items out of which they consist, and from which they are assembled. Dependencies can go seven layers deep, including multiple suppliers. The building process starts at the lowest level in the PBS. This continues until we reach the subsystems we summed up earlier are finished. After all those are finished, the final assembly can be started for finishing the radar system.

Some parts in the purchasing stage have a lead time more than 15 months, the Long Lead Items, at which we will come back in section 2.2.3. Next to the LLI, in this purchasing stage we have to look at all the dependencies of the subsystems and items of the radar.

If we follow the dependencies to the lowest level, we have a path. The lead time of this path is the sum of all the items in the path, one item on each level. In this above picture the top level, level 0, is the final assembly of the system. Before this can be run through, all the boxes in the level lower, level 1, should be finished. If we continue downwards for each possibility, we find the length of each path. For example one path is Long Lead Item 1 – Assembly – Final Assembly. One can imagine that each path has a different length, a different lead time.

One of those paths is the longest path, and this path determines the total lead time of the whole radar system. We further address this issue in section 2.2.2. The same as the PBS in Figure 2-3, can be represented in a Gantt chart, depicted in Figure 2-4. We see the same subsystems, items and assemblies as we have seen in the PBS, but now represented like a planning.

Figure 2-4 Gantt chart Radar A

At Thales several final assemblies of subsystems are done, and eventually the final assembly of the whole radar. In Figure 2-4 these activities processed at Thales are depicted grey. We see these activities are only a few months at most with one assembly line which is a few months longer. The items Thales purchases are shown in blue.

Therefore we call this the Purchasing stage, because almost everything out of this PBS is bought from suppliers. Thales gets lead times for the items they purchase from suppliers, but further information of that items like dependencies is unknown. If we also would define the dependencies of purchased items, the PBS will consist out of more levels. However, it would have the same length.

For more information about the items purchased at suppliers, we have to go to the suppliers. This will give us another representation for how a radar system is built, namely an overview of the supply chain.

2.1.4 THE SUPPLY CHAIN

Thales supply chain for radar systems drastically changed the past decades. From building almost everything of the radar system on their own, now Thales has outsourced almost the whole production, as we have seen in the past section. Thales finalises the radar with sub assemblies, final assembly and system integration.

Because a radar system is complex and consist of thousands of items, one can imagine there are for one radar system hundreds of suppliers. Out of all these suppliers, we find a supply chain when we look at one path in the PBS. Behind the supplier of one item, there are of course other suppliers. In some cases this means there is a supply chain of even seven suppliers, starting with the raw material supplier, and ending at Thales. The most used supply chains for Thales are in the mechatronic and electronic area. In Figure 2-5 we give an example supply chain.

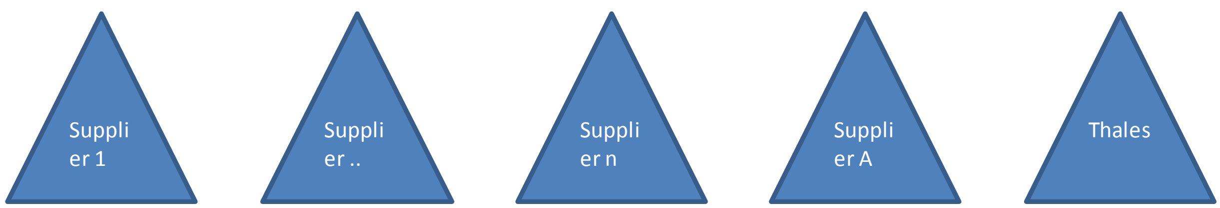

Figure 2-5 Supply Chain

Thales orders a lot mechanical parts at Supplier A, an important supplier. For all the items in Figure 2-4 Supplier A has to order again at other suppliers. Above we see the supply chain for one item. Thales orders this item at Supplier A, Supplier A orders at their suppliers. There can be multiple suppliers behind Supplier A, in Figure 2-5 displayed as $1, .., n$ suppliers.

At each supplier some kind of processing has to be done which takes certain time. Between the stages in the supply chain we have to take into account transport times and check-in and check-out times. If we sum up all the lead times given by each supplier in the supply chain, we find the total lead time of this supply chain.

But this is just the supply chain of one item of the radar system. For the whole radar system, there are dozens of supply chains. Later on we will make clear at which supply chain(s) we need to focus.

2.2 AREAS FOR IMPROVEMENT

Now we know how the current design and production of a radar system, we will focus in this section on the problem areas relevant for lead time reduction. We start with the possible design trade-offs in section 2.2.1. As we have seen in the previous section, purchasing is the most relevant stage. In section 2.2.2 the most interesting part of this stage is described. Another step deeper in problem finding is done in section 2.2.3, focussing on the Long Lead Items. The last section 2.2.4 describes current lead time reduction attempts at Thales.

2.2.1 DESIGN TRADE-OFFS

As we have seen in section 2.1.1, there is no clear overview of the total lead time in the design phase of a new radar system, and the items that are the cause for the total lead time. Therefore the impact from certain items and design decisions on the total lead time cannot be taken into account. Nowadays when lead time becomes more important to stay competitive, this is not a desired situation.

If the impact on the total lead time of certain items is huge, and when this is made visible, these items would be reconsidered. This means that other alternatives will be considered, for lead time improvement. Also the total lead time of the system which is designed would be helpful. In trying to reduce the lead time of a radar system to a certain time, exceeding this time goal would immediately be seen. The items responsible for this then also will be reconsidered.

Due to the complexity and innovativeness of a radar, a radar system cannot exist only out of standard components. Nowadays the design team aims for standard components, but these are not always selectable. Roughly can be said 90 to 95% of the components can be standard. The other 5 to 10% are so new, unique or customer specific, such that there is no standard component for.

For this problem, a model to keep track the lead time of the radar system should be made, such that design decisions can also be made on lead time consequences. This is further addressed in chapter 4.

2.2.2 CRITICAL PATH

As simple as can be said, the lead time of a radar system is seen as to long. What really determines this lead time of a radar system, is the path with the longest duration in the whole radar building process. When this path is delayed, the radar system has delay. Therefore it is called the critical path (Winston, 2004). The other way around, if we want to reduce the lead time of radar system, we should start by reducing this critical path.

From the PBS of Radar A, and adding the lead times for each item/ assembly, we can find the path with the longest duration. The critical path of this radar system is displayed red in Figure 2-6.

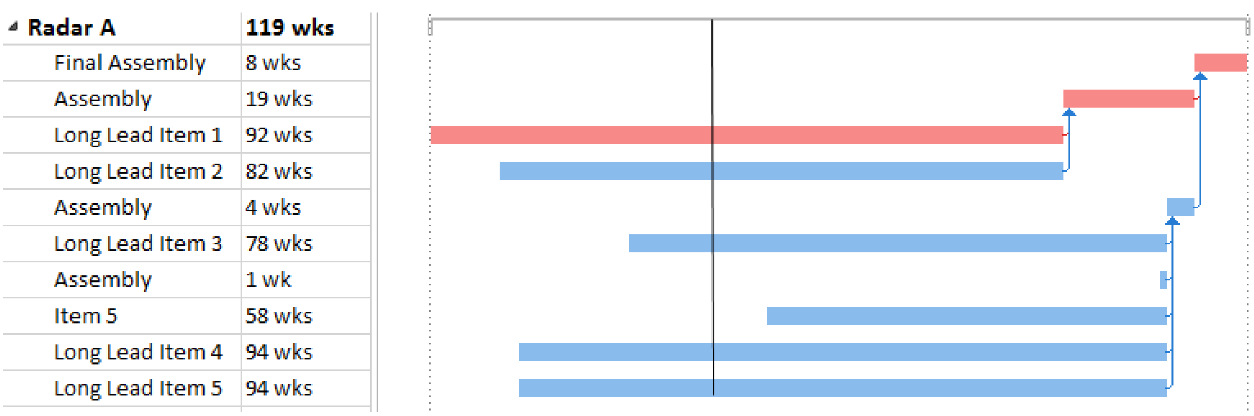

Figure 2-6 Critical path

The longest item in red is purchased and has a lead time of 92 weeks. After that, this item is assembled together with a lot other items (not all of them displayed in above figure) at Thales. This assembly has a duration of 19 weeks. This is followed by the final assembly, lasting 8 weeks. In total, this path lasts 119 weeks. Because this is the longest path for this radar system, we can say the radar system has a duration of 119 weeks.

This critical path is the path that should be reduced in order to reduce the total lead time of the radar system. By certain reduction another path becomes also critical. In Figure 2-6 we see when we reduce the item with the longest lead time in the critical path, after 10 weeks of reduction we also have to reduce the other path in order to still reduce the lead time of the total system. This we will investigate further in chapter 5.

As we already see in Figure 2-6, most of the long paths have an item with a very long lead time. Therefore we can say that Long Lead Items contribute to a large extent to the total lead time.

2.2.3 LONG LEAD ITEMS

We have seen that the Long Lead Items are a substantial part of the total lead time and also are a substantial problem for lead time reduction. Besides they have the longest lead times, these are also in general the most complex and expensive items. This is one reason for not having these items on inventory, but just ordering them when a contract is signed. Another reason is that most of these LLI are needed only once in a radar system, and radar systems are sold in very low quantities.

Another problem with LLI is that there is at almost no knowledge why such an item has this long lead time. The supplier from this item gives a lead time, but why it is this time and whether it could be improved, is not known. Maybe just some small relative cheap items are a main cause of the lead time. For the whole radar system there are more LLI, which we will analyse in chapter 5.

With all the information about such an item, the best cost- and lead time effective measure can be taken. It seems logical that in that case, a better measure can be taken instead of having the whole LLI on inventory. From this items, their supply chain and value stream should be investigated. The value stream is every step in the whole building process of an item which adds value to the product. This is also done in chapter 5. In here we will see the processing time and waiting time for this item, such that we know for what time the LLI can be reduced.

The more production is outsourced, the more information with suppliers should be shared for an effective and efficient supply chain. This lack of knowledge about the lead time of an LLI illustrates that a considerable improvement in supply chain management can be made.

2.2.4 LEAD TIME REDUCTION

At Thales there are at the moment a few indirect measures taken for achieving shorter lead times. They all have in common that they are done after the design phase. For the latest radar systems cost were taken into account, and considered in design choices. However, lead time consequences have not been taken into account.

The first attempt for lead time reduction we describe is rolling forecast. For six radar systems this kind of forecast is conducted. Every few months this forecast is updated. These radar systems have relatively stable demand therefore this rolling forecast is possible. Also they have relative late CODP’s, so al lot of the production can be done before the exact customer and his wishes are known. However sharing these forecasts with suppliers and having everyone committed to these forecasts, are still just future plans. Also for other radar systems forecasts are not shared with suppliers. This rolling forecast is not conducted for Radar A.

Chances of getting a certain order are taken into account. When this chance is large enough, pre-releases are done. These are already setting out orders before a contract is signed, with as a result a shorter lead time for the customer.

Due dates for delivery of radar systems are often not met. At the moment the focus is more on realising due dates than on lead time reduction. With Thales largest supplier, which has currently a bad on-time delivery, now attempts are done to meet the delivery times. This seems to be also a logical first step for lead time reduction attempts, such that Thales can be sure about made appointments.

Production capacity at Thales is not really an issue. If there is too much work for the current capacity, more people are deployed. This is only used when due dates seems not to be met, so no lead time reduction actually.

Inventory is being held, but of course not for all the items. Customer specific stock, items intended for a certain radar system, are not in inventory. Most of the customer specific items are very expensive, have a long lead time and are only once used for a radar system. Anonymous stock, for generic use instead of meant for a certain system, is in inventory. Anonymous stock are the more used and relative cheap items. For lead time reduction, current inventory policies seem to have no effect. We focus in this research on the customer specific items, the items not on inventory.

Overall can be said, no direct lead time reduction measures are taken. Some indirect measures can have a positive impact on the lead time, but on their own do not result in lead time reduction.

2.3 CONCLUSION

With the knowledge of this chapter about the current way of building a radar system, and the current relevant problems, we know our starting point for improvements. The stage in the lead time of a radar system where we will focus at is the purchasing stage. This stage is responsible for more than two third of the total lead time, except one in-house production line. In this stage we need to look for the critical path. This determines the duration of the radar system in the purchasing stage. Within this critical path the main cause of the long lead time are Long Lead Items. We need to investigate these items further, because improving these can immediately reduce the total lead time for a large amount. The supply chain and every operation in the lead time of a LLI has to become clear. This will give us the opportunity to make the most cost- and lead time effective improvement.

At the moment no lead time reduction possibilities are conducted. General items and cheap items are in inventory. We do not have to take into account the lead time of items which are in inventory. We will investigate the items which are not in inventory. These are radar system specific and more expensive items. These items need other measures than just inventory, because this will be too expensive.

We have seen that in the design phase of a radar system, lead time is not taken into account, and therefore design decisions are not made based on lead time consequences. Giving insight in lead time consequences of design decisions would make this possible, and perhaps result in lead time reduction. In chapter 4 a model for this idea is described.

First in chapter 3 we look in literature for proven ways of improving this kind of situations, and those kind of problems. After the design phase, also improvements in lead times can be made, these will have a logistic nature. In chapter 5 an analysis with the possible improvements is done. The applicable improvements are tested at the radar system under investigation, Radar A.

3. LITERATURE

In this chapter literature relevant to this research is given. The position of this research, within the scientific literature, is determined in section 3.1. Applicable literature about the critical path method, supply chain management, lead time reduction possibilities, and design issues, are given in the sections 3.2 through 3.5. Earlier research about this subject at Thales is given in section 3.6. We end the chapter with a conclusion in section 3.7.

3.1 THEORETICAL/ CONCEPTUAL FRAMEWORK

In the chase for lead time reduction, there are a lot of known concepts we have to consider. In general these concepts have a logistic nature, which are all improvements after the system is already designed. But in this research also trade-offs for lead time in the design phase are considered.

Nowadays when a larger amount of the product is outsourced, interaction with suppliers is way more important, highlighting the importance of right practicing of supply chain management. Inventory management is of course an interesting possibility for lead time reduction. However for the market Thales is facing, with low series and high complexity, inventory management is not applied most. Forecasting is also more difficult in markets like this. We should consider the Customer Order Decoupling Point (CODP), because if this point is very early in the supply chain, improvements are more difficult.

A series-production for Thales can mean two or four radar systems of one type in a year. But most of the systems are sold even less, like sometimes once a year, sometimes none in a year. Therefore we can look to the build-to-order concept. These radar systems consist out of thousands of items. The product structure can go down to even seven layers deep. This means there are a lot of dependencies for all the items. The great diversification of Thales product portfolio and the long lifetime of their products makes their situation even more interesting. Altogether, we face a very challenging environment.

In investigating the possibilities for lead time reduction for radar systems, we see a minor part of the total items is responsible for a large part of the total lead time. We look for bottlenecks and use the Pareto-rule, which states just a minor part may be responsible for a huge part of the total lead time. The so called Long Lead Items are the cause of long paths in the product structure. The longest path is called the critical path. This we determine with the Critical Path Method. When we reduce this path the total lead time will be reduced, but other paths can then become critical. The parts the critical path and other long paths consist of seems to be the most interesting for lead time reduction. To this LLI we will do supply chain analysis and value stream analysis for improvements.

Now the idea is to have influence on the system in the design phase. In here we can instead of treating symptoms, do root cause problem solving. In the design phase the new system is developed, and this process has its consequences for lead times and cost. In here the (production) technologies, materials and functionalities are determined. But what is overlooked, is that this phase also determines the lead time of the whole system, at least for the largest part. Logistic concepts can be practiced for improvements afterwards for the lead time but actually this is symptom treatment. When we also look at the lead time consequences of design choices, possibly there will be made other choices. This can have a large effect on the lead time of the radar system. Because lead time becomes more important to stay competitive, seeing lead time consequences in the design phase seems to be a necessity. A model for these issues is not yet available.

3.2 CRITICAL PATH METHOD

For determination of which items should be influenced, we use the Critical Path Method (CPM). In (Winston, 2004) this method is described. We can use this method to determine the length of a whole project. To apply CPM we need a list of the activities that make up the project. The project is considered to be completed when all the activities have been completed. For each activity, there is a set of activities, called predecessors, that must be completed before the activity begins. A project network is used to represent the precedence relationships between activities. In Figure 3-1 we see an example of such a project network.

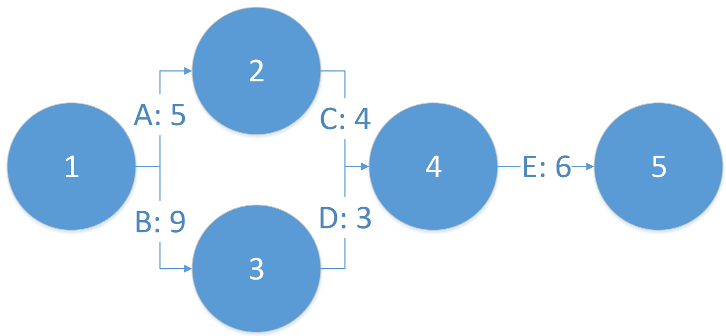

Figure 3-1 Project network

A circle is called a node. Nodes represent the completion of one or more activities. Node 1 is the starting node, representing the start of the project. Node 5 is the finish node, representing the end of the project. The activities to be done are the arcs, so we have activity A till E. The duration of each activity is also represented. For example the duration of activity A is 5.

We see the predecessors of activity E are activities C and D. So before activity E can start, activity C and D have to be completed. Activity C can start when activity A is completed and activity D can start when activity B is completed.

CPM uses Early Event Time (ET) and Late Event Time (LT) for each activity to calculate the critical items and eventually the critical path of the project. ET is the time the activity can start, and LT is the time the activity really has to start to not delay the whole project. The ET and LT values of the project in Figure 3-1 are represented in Table 3-1.

Table 3-1 Early and Late Event Time

Node	ET	LT
1	0	0
2	5	8
3	9	9
4	12	12
5	18	18

Second the method calculates the Total Float (TF) of each activity, e.g. the amount by which the starting time of activity n could be delayed beyond ET, without delaying completion of the project. Items with TF equal to zero are considered critical, because when these activities are delayed, the whole project is delayed. Each activity has a node before and after. The completion node of an activity we call i and the starting node $(i-1)$. The duration of an activity is represented by t_{ij}. TF is calculated by the formula $TF(n) = LT(i) - ET(i-1) - t_{ij}$.

Table 3-2 Total Float

Activity	Duration	Calculation TF	TF
A	5	8-0-5	3
B	9	9-0-9	0
C	4	12-5-4	3
D	3	12-9-3	0
E	6	18-12-6	0

We see in Table 3-2 that activities B, D and E are critical, because their Total Float is zero. Therefore the critical path of the project in Figure 3-1 consists of the activities B-D-E. This path has a duration of 18, which is the longest path in this example, therefore it is called the critical path.

Now the critical path is determined, CPM uses crashing to reduce the total project duration. For crashing the cost for reducing the lead time of each activity per time unit should be clear. With linear programming the best option for crashing or reducing the total lead time can be determined. This requires assigning a lot (estimated) cost factors which are hard to determine.

In this research we call this project network the product-breakdown-structure. In Chapter 4 this PBS is outlined. With the duration and predecessors of each activity we can determine the path that determines the total lead time of the system. If this path has delay, the radar system as a whole will be delayed. But reducing this path directly reduces the total lead time. In reducing this path, another path can become critical. This we address as the sensitivity of the critical path.

A Gantt chart is useful to represent this critical path. For large or complex projects, specialised project management software is much preferred.. the most popular example of such specialized software –is– Microsoft Project (Heizer & Render, 2011). The complete project schedule can be viewed as a Gantt chart. We can easily add or remove –or change– activities.. Microsoft Project automatically updates all start dates, finish dates, and the critical path(s). Perhaps the biggest advantage of using software to manage projects is that it can track progress of the project.

The Critical Path Method lets us focus on the most relevant part of the radar system for lead time reduction. However we will see in chapter 4 we will not need the whole method of CPM for this research. A Gantt chart already represents the necessary information when we determine from each item the name, successor and the lead time. Because a radar faces an assembly network structure, where each part has at most one successor and one or more predecessors, the critical path can easily be seen.

Several other well known concepts will also help us focussing on the most interesting parts of the radar system, which consists out of thousands of items.

- The Pareto-rule, which states that 80% of the results are caused by 20% of the causes. In this situation this would mean 80% of the lead time is caused by 20% of the items. We will see this is for a radar system even more extreme, way less than 20% of the items are causing 80% of the lead time.
- Most of the lead time is waiting time, and only 5% of the lead time is really value added time. This will be interesting to apply at the Long Lead Items.
- The Theory of Constraints (TOC) of Eliyahu Goldratt tells us to focus on the bottlenecks of the system because these determine the speed of the process. An improvement in here could be a huge improvement for the total process. For a radar system the bottlenecks seem to be the Long Lead Items.

3.3 SUPPLY CHAIN MANAGEMENT

We have seen Thales does not work with information through the whole supply chain. (Stadtler, 2005) defines supply chain management as follows

> *the task of integrating organizational units along a supply chain and coordinating material, information and financial flows in order to fulfill (ultimate) customer demand with the aim of improving competitiveness of a supply chain as a whole.*

The supply chain starts at the raw material supplier and ends when the final product is finished (Beamon, 1998). Throughout the whole supply chain these material, information and financial flows should be coordinated, then we can have a competitive supply chain, and thereby a competitive product. This is widely known and for a make-to-order company like Thales very useful, for example (Pannesi & Handfield, 1995) describe,

> *for 'make-to-order' customized markets, … In order to effectively manage time, optimization of the entire supply chain is necessary*

This study further concludes

> *The results lend support to the claim that improved supplier performance, combined with efforts to establish JIT purchasing activities with suppliers of critical inputs, can assist in reducing the leadtime.*

Cooperation with suppliers seems to be a necessity for lead time reduction, therefore we will investigate the possibilities for Thales with better supply chain management.

When we talk about information sharing in the supply chain, there is a well known issue we have to consider, namely the bullwhip effect. This is defined as *the increase in demand variability when moving upstream the supply chain* (Lee, Padmanabhan, & Whang, 1997). This can be decreased by only using centralized demand information, based on ultimate customer demand.

Within a supply chain there is a certain Customer Order Decoupling Point (CODP), this can be defined as the *separation between forecast-driven and order-driven activities.* From this point certain information about the customer requirements is necessary for continuing production. This point determines the work that can be done in advance. For improvements in lead time reduction, we have to take this point in a radar system into account.

Inventories in the supply chain will be considered. We know inventories more upstream are cheaper, because at that time less value is added to the product. Upstream means further to the beginning of the supply chain. For the Long Lead Items that are interesting this would mean inventory for some sub items of this LLI, instead of the whole LLI in inventory. When the inventory cost are known, we can determine the cheapest inventories for meeting a certain lead time goal.

Inventories are not always seen as useful but rather as waste. As Suzaki stated: Excessive inventory is the root of all evil. However, according to the Goldratt access, that the significance of inventory is „to protect the bottlenecks“ [Goldratt]. These two approaches show that the greater quantity of stocks in the bottleneck cannot be considered excessive, if it is necessary to maintain throughput. Therefore we will consider inventories as an option for lead time reduction.

3.4 DESIGN FOR LEAD TIME

We can say we are looking for the *design for lead time* concept, because in the design phase we will make decisions on lead time consequences. This concept is not found in literature so we come up with this terminology. In chapter 5 we explain the roadmap for *design for lead time*. Several known concepts touch this idea, which we now will describe.

By (Groover, 2007) *Design for Assembly* principles are described. We sum up the measures for this concept:

- Use the fewest number of parts possible to reduce the amount of assembly required;
- Reduce the number of threaded fasteners required;
- Standardize fasteners;
- Reduce parts orientation difficulties (symmetric design);
- Avoid parts that tangle;
- Use modularity in product design;
- Reduce the need for multiple components to be handled at once;
- Limit the required direction of access.

(Groover, 2007) also describes *Design for Manufacturability*, where manufacturing engineers serve as manufacturability advisors to product designers. The objective is to develop product designs that not only meet functional and performance requirements, but that also can be produced at reasonable cost with minimum technical problems at highest possible quality in the shortest possible time. This is interesting because one goal of this concept is short lead time, however it is not the main goal. But these principles are certainly helpful in our new approach, design for lead time.

In the design phase another concept is interesting. (Pannesi & Handfield, 1995) showed that Early Supplier Involvement is positively correlated with lead time.

> *In addition, the study found some measure of support that supplier involvement in design can have an indirect effect on leadtime performance, primarily through the introduction of more manufacturable designs which can improve JIT purchasing performance.*

We see again that cooperation with suppliers is very important, even in the design phase of the system. Another view than Design for Assembly and Manufacturing (DFM/A), is C*oncurrent Engineering*. (Sohlenius, 1992) describes Concurrent Engineering as follows.

> *It means a way work where the various engineering activities in the product and production development process are integrated and performed as much as possible in parallel rather than in sequence.*

The connection with our goal, lead time reduction, is found when considering the goal of this concept.

> *The main goal for the Concurrent Engineering is to shorten the lead time both for the development of new products and for individual orders. That is to say, on one hand the time from definition of product idea and functional requirements from the market to the first product that is produced, here called the development or design process, and on the other hand the time from order to delivery to the customer, here called the production process. Concurrent engineering embraces the Just in Time principles, which means that customer order control of the production proves is strived for.*

In this paper it is argued that development time, time from conception to production, is often seen as more important than delivery time, because rushing a product to market captures market share. However, reducing one of the two, increases the other. This is exactly what is seen at Thales, the program manager wants to produce the first new radar fast, while this perhaps has negative consequence for the delivery time.

(Pannesi & Handfield, 1995) describe several activities to reduce the number of engineering changes and material substitutions occurring during the MTO delivery chain, thus reducing lead time.

- In the MTO environment, the decisions made regarding the design of a product have a significant impact on manufacturing performance.
- Early involvement of manufacturing, purchasing, and suppliers in product design can play a critical role in improving a product's manufacturability.
- Improve designs by instituting programs aimed at using existence components, involving suppliers at the design stage, reducing the number of options and standards for the product, simplifying the assembly process, and developing an understanding of existing manufacturing capabilities.
- Value analysis, which seeks to reduce the cost and complexity of a product while retaining the original specifications as much as possible.

We see again in the design phase important decisions for the lead time later on are made. Also standardisation in the design phase is seen as important. Another researcher, (Walleigh, 1989), states that there can be little doubt that *standardization* has a powerful effect on lead time, through the reduction of parts, options, features, and connectors in products.

The latest point summed up is value analysis. This approach gives insight in what adds value to the product, but maybe more important, what does not adds value to the product. At this we will come back later.

The latest point in this section is about postponement. Postponement is considered by (Groover, 2007) as designing the product and production process in such a way that it allows late customization. This means putting the CODP at the latest possible point in the cycle time. By doing this, inventories and forecasts are made possible and less expensive, because a part of the value is added later in time.

3.5 LEAD TIME REDUCTION POSSIBILITIES

We have seen several options for lead time reduction. Also (Pannesi & Handfield, 1995) have shown that in order to compete on time in make-to-order markets, managers must consider all components within the supply chain. At Thales this seems very important because almost al the production is outsourced. Next to this, for reducing the lead time, we sum up the possibilities we have.

- Inventory holding;
- Pre-release;
- Forecasting: certain activities can already be taken when forecasts about future demand are reliable;
- Postponement;
- Standardization;
- Re-design;
- Eliminating waste.

Eliminating waste is not yet described, it is used in the *value stream mapping* (VSM) technique. A *value stream* is a collection of all actions (value added as well as non-value-added) that are required to bring a product (or a group of products that use the same resources) through the main flows, starting with raw material and ending with the customer (Rother & Shook, 1999). These actions consider the flow of both information and materials within the overall supply chain. The ultimate goal of VSM is to identify all types of waste in the value stream and to take steps to try and eliminate these (Rother & Shook, 1999). These *wastes* are: overproduction, waiting time, transport, inventory, motion, over-processing and defects. Eliminating these wastes reduces the lead time.

Applicable for this research, (Braglia, Carmignani, & Zammori, 2006) give a framework to make a *value stream map*, also for a complex Bill of Material, such as a radar systems.

1. Select product family;
2. Identify machine division;
3. Identify main value stream;
4. Identify critical path;
5. Identify and analyse wastes;
6. Map the future state of the critical path;
7. Identify new critical path and iterate.

So first we have to determine the critical path, or an critical item. Second the production process of this item should identified. All the processes and their times of the item, should be found and in total sum up to the lead time of the item. This identification enables us to make a value stream map of the current situation, like Figure 3-2.

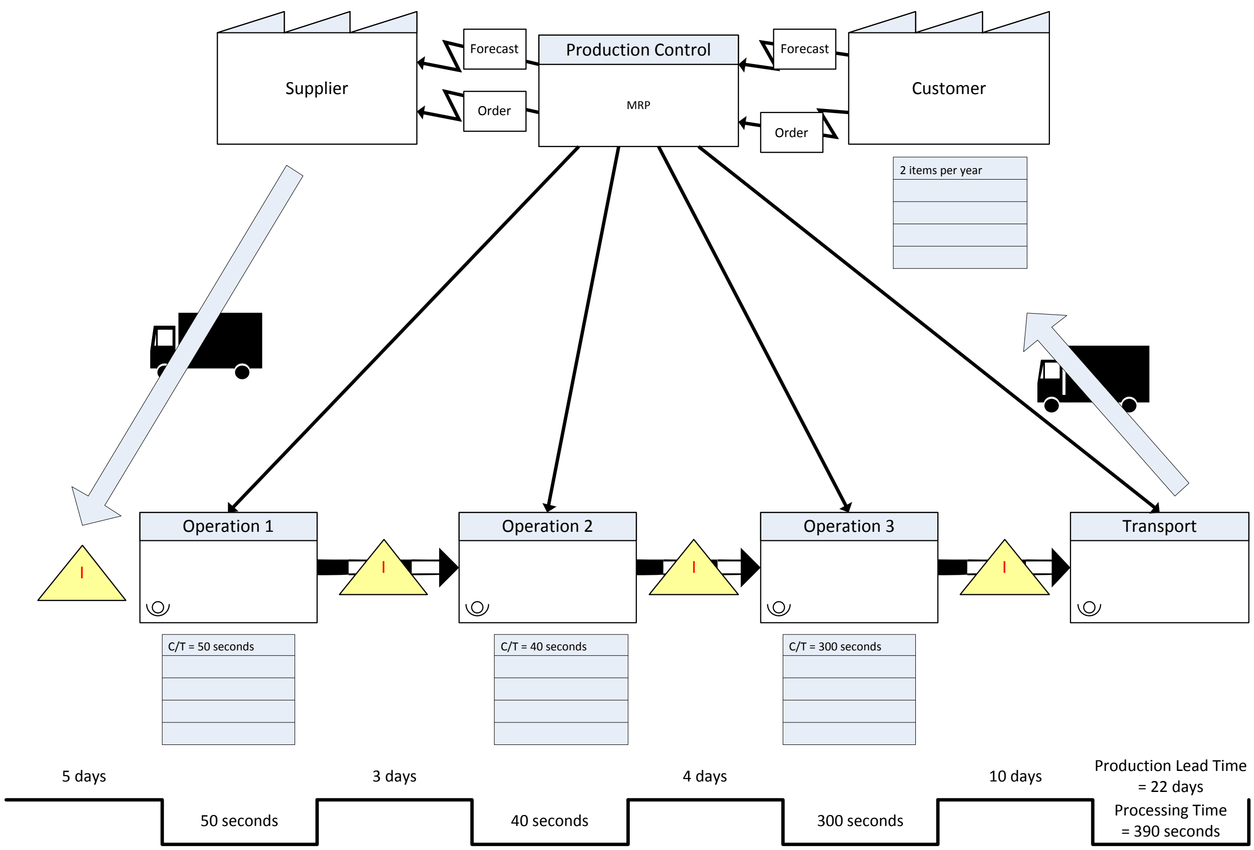

Figure 3-2 Value Stream Map example

This is an example value stream map. A customer (in the figure top right) orders at the company items with certain demand rate. The company decides when to order at the supplier, for producing the item the customer requested. In this example the production of the item contains three operations. Each operation has a certain processing time. We see in total the processing time for this item is 390 seconds. But the item has a production lead time of 22 days.

This time consists out of all the waiting time for each operation. In VSM all the time without the processing time is called waste. This processing time for the operations, is called the value added time. These operations add value to the product. Now we can calculate the value adding percentage of the lead time.

$$Value\ Adding\ \% = \frac{Value\ Added\ Time}{Lead\ Time} = \frac{390}{((22 * 8 * 3600) + 390)} * 100\% = 0{,}062\%$$

We suppose this is the VSM of the current state. Now we know this starting point, this percentage, we can start improving. This improving consist of analysing the waiting times which sum up to the total lead time. These times are responsible for the very largest part of the lead time, not the processing times. By reducing the waiting times the lead time of the item is reduced. Therefore the Value Adding % will rise.

This elimination of wastes should be done at items on the critical path. This directly reduces not only the lead time of the critical item, but also the total lead time of the radar. This procedure should be iterated until the lead time of the radar is on the desired level.

3.6 EARLIER RESEARCH AT THALES

Two recent other researches have been conducted at Thales for lead time reduction. This is outlined such that we do not reinvent the wheel, and use where possible the work of others to improve our starting point.

INTERNAL RESEARCH AT THALES, 2010. LLI REDUCTION. RADAR B AND RADAR C.

By this research there were five options mentioned for lead time reduction (Thales, 2010):

- Rolling forecast;
- Order on forecast;
- Stock at supplier (semi-finished/ raw material);
- Stock at supplier (finished products);
- Stock at Thales NL.

Semi- finished and raw material on stock at a supplier was seen as most interesting because the expected low cost and high effect for lead time reduction. The cost for holding inventory at suppliers in order to have a certain total lead time for the whole product were determined. With just analysing and updating chains of items with too high lead times, some were falling already within the necessary lead time. Also the option of rolling forecast with layered commitment was calculated. As example the supplier was very cooperative and enthusiastic about this opportunity for lead time reduction. The researchers saw the opportunities of this research but eventually nothing is done with this research. Bringing critical components to standard design was recommended. 52 items that needed 160 or 95 days lead time were determined.

Risk for uncertainty of the lead times are defined. Market changes, critical suppliers, technical critical products, changes in the product, export licenses, obsolescence.

FONTIJN, S. BACHELOR THESIS STUDENT, 2014. LEAD TIME REDUCTION AT SUPPLIERS.

In this research (Fontijn, 2014), the opportunity of both having inventory and having a rolling forecast for 1.5 year with a Commitment Model together is determined. Thales and suppliers can use the Commitment Model to improve each others reliability and on time delivery, because it determines when in the forecast Thales is committed to purchase the forecasted items and when suppliers are committed to supply the items. ASML is using this technique for not having alone all the risk, but to share the risk throughout the whole supply chain. Also lead time reduction is hereby established, because suppliers wants to have low risk and therefore add value as latest as possible in time.

This was for reducing the lead time of Radar B to 9 months. For the items that needed lead time reduction the necessary number of days lead time reduction was determined. For example having one item at one supplier on stock would already mean a reduction of three months for a subsystem of Radar B. No cost calculation and in-depth supply chain or value stream analysis is done. The recommendations in this report were not used until now at Thales.

3.7 CONCLUSION

In this chapter we have seen literature applicable to this research. The literature is used to improve the starting point of this research. What already is investigated, we do not have to do again. It also helps us conducting the research when we apply the literature applicable to this situation. When we combine several issues out of the literature, we find a roadmap for this research.

At first we will focus at the most interesting part of all the items a radar consists of. The Critical Path Method lets us focus on the most interesting path in the whole radar system, out of the thousands of items. The use of a visualisation tool like Microsoft Project makes understanding way easier. We do not need the whole CPM, the first phase of this method lets us already focus on the items to be improved. Second, which item to be improved within the Long Lead Item will be an easy trade-off, this we will see in section 5.3. For designing a radar with a shorter lead time we have seen in this chapter several concepts that can help us. Altogether these help us to come up with a roadmap for *design for lead time*. This roadmap is outlined in section 5.2, and can be used for reducing the lead time of a radar system in general.

Further analysis will be needed for Long Lead Items. This will be done at Supplier A. We want to know on what the lead time of several Long Lead Items depend, and we will do a value stream analysis. This will learn us where we can find the most appropriate improvement measure. We have seen from literature we can choose out of several alternative improvements for lead time reduction. By considering these alternatives in section 5.1, we can make trade-offs both for cost- and lead time effective measures for Radar A in section 5.3.

4. DESIGN OF THE MODEL

In the design phase of a new radar system, Thales would like to have insight in lead time consequences of design choices. For this idea they want to use a model. Requirements for the model from Thales are that it is easy to use, generic, and that it has clear and visual results. This chapter answers sub-question 3.

As we have seen in section 2.2.2, the critical path determines the lead time of the whole system. So we can say the items on the critical path should be included in the model. In section 5.3.1 we will see this are not the only items interesting when looking for lead time reduction of the whole radar. We will see we need the relevant subset out of all the items, existing of 39 items. This subset consists of the items needed to improve in order to reduce the total radar lead time. In this research we look for items on the paths that need reduction, in order to reduce the total lead time of the radar to 1.5 year. This means from 119 weeks to 78 weeks.

To make this possible, the total lead time of the radar system which is designed, should be tracked. Further, each design choice should be placed in the whole picture of the radar system. Then the effect of this choice on the total lead time can be seen. When this design choice is causing too much increase in the total lead time, this choice will be reconsidered. For these issues the model is build.

The model is made in Microsoft Excel. For visualization not Excel but Microsoft Project seems more appropriate (Heizer & Render, 2011). Importing the necessary information into Microsoft Project is described in the appendix. The model requires only a few input factors in the right input fields. Further all the calculations are done by the model, and it gives clear results. The model can be used for several applications, for example for a whole radar system, or a smaller subsystem.

In section 4.1 we describe how the model works with addressing the lead time tracking and critical path determination, and design change options. In section 4.2 the inputs the user need to enter and the outputs the user can expect are described, also addressing how the information from Excel can be easily imported in Microsoft Project. We end the chapter with a conclusion in section 4.3.

4.1 HOW THE MODEL WORKS

We have seen in section 2.1 how a radar system is designed and what determines the total lead time. In the begin of the design phase there is still a lot of uncertainty about the radar system. Therefore first estimates about lead times for several items in the product-breakdown-structure have to be made. This already gives direction at which items should be focused in the design phase. Namely at the subsystems and items responsible for the longest paths of the radar, measured by lead time. In general these estimations already will let the designers focus at the most important areas in the PBS for re-design, in order to achieve a shorter lead time.

When the design process develops, the design becomes more detailed, and with more certainty the lead times of each subsystem in the PBS can be given. This will let the user of the model focus at the more detailed part of the most important subsystems.

LEAD TIME TRACKING AND CRITICAL PATH DETERMINATION

In Figure 4-1 the parts of the radar system where we need a lead time estimation for are given. This figure represents the system and subsystems the radar consists of. The final assembly represents the only activity at level 0 of the system. One level deeper we see the subsystems for the radar.

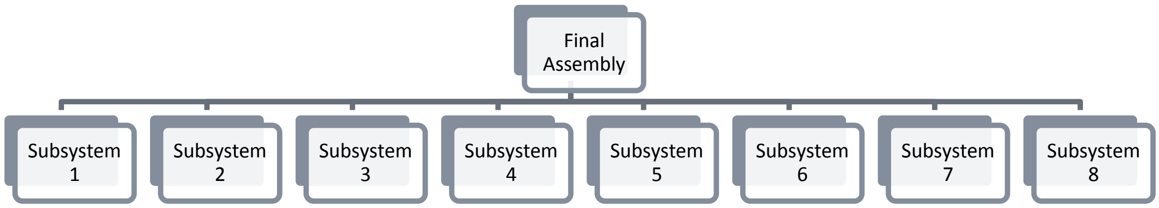

Figure 4-1 PBS level 0 and 1

Each subsystem has as successor the final assembly step. Therefore the cumulative lead time for a subsystem, is the lead time of the subsystem plus the duration of the final assembly. Also the assembly of each subsystem at level 1 has a certain duration. The next step is to define the items on the next level, level 2. Again for finding the cumulative lead time (LT), now for an item on level 2, we add the cumulative lead time of its successor. Then we have the duration of the total path of an item on level 2. So we can say

$$Cumulative\ LT\ item\ i\ at\ level\ x\ =\ LT\ item\ i + Cumulative\ LT\ successor\ of\ item\ i\ at\ level\ (x-1)$$

If we would do this for an item on level 2, we do not need to add the lead time of its successor at level 0, because this time is already in the cumulative lead time of the successor at level 1.

This process of going deeper into the product-breakdown-structure continues till the last level of what is known for Thales. In our example radar system, this is level five. This we represent in Figure 4-2. Again the cumulative lead time for each item represented in this figure, is calculated by adding the cumulative lead time of its successor to the lead time of that item itself. So for example for Item 6 this is

$$Cumulative\ LT\ Item\ 6 = LT\ Item\ 6\ + Cumulative\ LT\ Item\ 5$$

In Figure 4-2,Subsystem 1 and underlying items are also added, because the cumulative lead time of Item 1 and 2, is longer than the cumulative lead time of Item 6. So the number of levels do not show us the most interesting path, but the cumulative lead time of the item does.

When all the known lead times, and the estimated lead time are filled in, the model shows us the critical path of the radar system. The item with the highest cumulative lead time, is the end of this critical path. Because its successors are known, this critical path can easily be seen.

We do not need to fill in all the items of the radar system, this would be more than thousand items. We need to fill in the paths with a duration longer than the lead time to be defined by Thales.

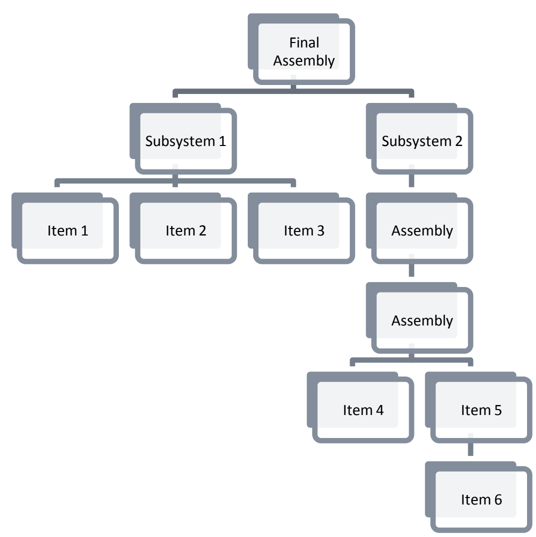

Figure 4-2 PBS up to level 5

We use the 78 weeks lead time goal for this example. For Radar A we will see later on, this means there are 39 items and assembly steps useful for consideration.

In Figure 4-3 we represent an example of the model we made. The names of the items we need are filled in, at the right level they have in the product-breakdown-structure. Also the duration and the successor of each item are filled in. The orange cells are the cells to be filled in by the user.

	Product-breakdown-structure: Name and level										
ID	0	1	2	3	4	5	6	Duration (weeks)	Cumulative DLT (path)	Successor	Total reduction needed (path)
1	Final Assembly							8	8		0
2		Assembly						4	12	1	0
3		Item 10						46	54	1	0
4		Assembly						19	27	1	0
5			Long Lead Item 1					92	119	4	41
6			Item 1					59	86	4	8
7			Item 2					59	86	4	8
8			Item 3					39	66	4	0
9			Item 4					39	66	4	0
10			Long Lead Item 2					82	109	4	31

Figure 4-3 Model example

With this information the model calculates the cumulative lead time of each path in the PBS. The user fills in the total lead time the radar should have. Then we see the paths exceeding this total lead time, displayed in red. The time these paths have to be reduced are displayed in the last column. In the first column we see the ID numbers of the critical path (longest path) displayed red.

Next to the above figure, the information in Figure 4-4 is determined. We see the sensitivity of the critical path, this are the weeks the critical path can be reduced for reducing the lead time of the whole radar. When the critical path is reduced by this amount, another path also becomes critical. For further reducing the lead time of the radar also this second path should be reduced. Below this information we see the items of the PBS where the critical path consists of.

Goal total lead time (weeks)	Started lead time (weeks)
78	119
119	Duration Critical Path
109	2nd Longest Path
10	Sensitivity Critical Path
ID's Critical Path	Items on Critical Path
5	Long Lead Item 1
4	Assembly
1	Final Assembly
0	
0	
0	
0	

Figure 4-4 Important summary

In determining which items to fill in in our model, if we can for example say, subsystem 2 will never be more than three months, it will not be interesting to fill in this subsystem. For the subsystems worth considering, not only the longest predecessor should be filled in, but also the second, third and maybe fourth longest predecessor. This tells us what the improvements can be when reducing the longest predecessors. Like we call it, the sensitivity of the critical path, which is also illustrated in Figure 4-5. This figure contains the same items as we have seen Figure 4-3, but now represented in a Gantt chart in Microsoft Project. We see immediately that in this example reducing Long Lead Item 1 is useful for $92 - 82 = 10$ weeks. If we further want to reduce the lead time of the radar, we also need to reduce the lead time of Long Lead Item 2.

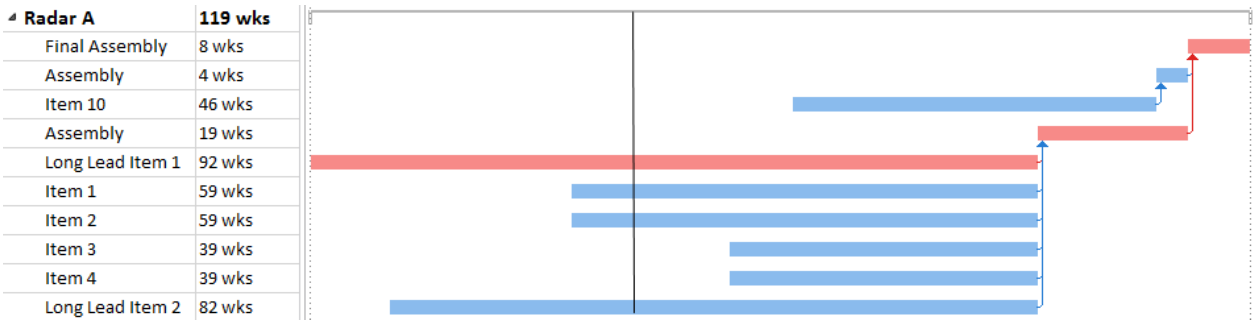

Figure 4-5 Sensitivity example

The critical path is displayed in red. For a certain lead time goal for the whole radar, we can add a line and immediately see which items need reduction for this goal. We will see in chapter five this almost always means that only the last item of the paths which are too long, should be reduced. This is the case because almost every path ends with a Long Lead Item, longer then 50% of the lead time of the whole radar. This LLI is almost always purchased at suppliers instead of produced by Thales itself.

This is a simple and intuitive way to find the critical path of a radar. We have seen we do not need the whole Critical Path Method for finding the critical path. The method we follow already gives us insight in which items to reduce in lead time, for improving the lead time of the whole system. Second it is hard to quantify the cost for crashing (reducing the lead time) of items. Designers can come up with a re-design which can have low cost, high cost or can say the item cannot be re-designed. Then other measures have to be taken. In general we cannot say which cost are needed for certain lead time reduction by re-design. This will be determined when a new radar is really designed.

For each item that needs lead time reduction, the several lead time reduction possibilities should be investigated with associated cost. Then the most cost effective lead time reduction measure can be taken.

DESIGN CHANGES

So if the lead time of a radar system should be at most a certain time, the model highlights all the paths that exceed that time, and gives the reduction in time needed for this path. Depending on the lead time goal, we can have multiple paths exceeding the total lead time goal. We should start with the critical (longest) path. Later on we will see we need to reduce the items the path ends with, the Long Lead Items. Now the items on this critical path should be reconsidered by designers. Maybe there are alternative design possibilities with shorter lead times.

These alternative design possibilities can be:

- Changing the product-breakdown-structure with as result a shorter lead time;
- Using other production techniques with a shorter lead time;
- Looking for other suppliers with a shorter lead time;
- Using standardized items instead of not standard;
- Involvement of suppliers in the design process about lead times.

The Long Lead Items again consist of other items. Possibly a sub item is causing most of the lead time. This should be investigated for finding the largest cause of the lead time. This information will only become available when suppliers are involved within the design phase.

To focus on the item with the most impact on the lead time of the total system, the next section is made. When the design cannot be changed anymore for a shorter total lead time, we need other measures to eventually establish a lead time reduction.

WHICH ITEM TO REDUCE THE LEAD TIME FROM?

The question is, which item(s) of these paths that are too long, should be reduced? We have already seen in section 2.2.3 that in many cases the most time (+67%) of a path is caused by one item, namely a Long Lead Item. Therefore we will focus on the Long Lead Items for improving the lead time of the whole radar. However, this LLI consist of other items. Perhaps just a few smaller items are responsible for a large part of the lead time. Than these items should be reconsidered. This will be analysed further in section 5.3.2. But these Long Lead Items have the most potential for lead time reduction with the lowest cost and the lowest effort.

FURTHER POSSIBILITIES FOR LEAD TIME REDUCTION

If all the LLI that need lead time reduction can be re-designed in such a way that they have acceptable lead times, we are finished improving. However, this is not very realistic. Because of the complex, unique and innovative items a radar consists of, there will always be items that need other measures. These items cannot be changed and have a lead time too long. Perhaps it is even a better choice to apply a logistic improvement instead of a re-design.

INVENTORY

For the items no easy re-design is possible, we will look for logistic improvements. We know which LLI need to be reduced for a certain amount. One option would be having an item in inventory. The model calculates the yearly inventory costs for the items that should be in inventory for a certain lead time reduction. For this inventory cost, the cost of an item is considered and we apply 15% inventory cost a year, because this percentage is used at Thales. Again, focussing on sub-items which can already reduce the whole lead time enough, is what should be done here.

Name	Duration (item)	Path Lead Time	New Path LT	Inventory needed?	Unit cost	Subparts in inventory?	New duration (item)	Cost Subpart(s)	Inventory cost a year	Reduction needed	Reduction accomplished?
Final Assembly	8	8	8						€ -	0	
Assembly	4	12	12						€ -	0	
Item 10	46	54	54						€ -	0	
Assembly	19	27	27						€ -	0	
Long Lead Item 1	92	119	27	X	€ 10.000,00	NO	0		€ 1.500,00	41	X
Item 1	59	86	77	X	€ 5.000,00	YES	50	€ 200,00	€ 30,00	8	X
Item 2	59	86	77	X	€ 5.000,00	YES	50	€ 200,00	€ 30,00	8	X
Item 3	39	66	66						€ -	0	
Item 4	39	66	66						€ -	0	
Long Lead Item 2	82	109	77	X	€ 10.000,00	YES	50	€ 2.000,00	€ 300,00	31	X

Figure 4-6 Inventory cost example

In Figure 4-6 we present an inventory cost example. The model calculated which items needed reduction in lead time and for how much, in the column with the red highlighted cells. The user fills in only the orange cells. This are the unit cost, if sub-item inventory is possible for the necessary reduction, the new duration of the item if it or sub-items are in inventory and the cost for the sub-items. Then we see the cost for the inventory when we have to meet the lead time goal. We made again a summary table, summing up the most important information for this inventory option, displayed in Figure 4-7. We

Total	119	Weeks
Goal	78	Weeks Goal
	41	Weeks reduction
	34,45%	Reduction DLT
Improved by Inventory	77	Weeks
	42	Weeks reduction
	35,29%	Reduction DLT
	€ 1.860,00	Cost a year

Figure 4-7 Inventory summary

work with fictive numbers. For this example we see we can manage the 41 weeks reduction for the radar with 1860 euro's inventory investment a year.

We only consider inventory for one radar, although an order normally exists out of multiple the same radars. This is done because radars have phased delivery times by those orders. So for the second radar there is more time, more than for the first one so we have additional time to order components. For large radar systems this are not just a few months but a lot, so we assume there is enough time for the next radar and we only need to have inventory for the first one. Thales can calculate the additional number of months they need when nothing is on inventory, and compare this with the phased delivery times such that they can be sure no additional inventory is needed.

VALUE STREAM

Possibly a less expensive option can be found by investigating the production process of the Long Lead Items that need reduction. When we make a value stream of this item and consider their supply chain, we can see if there is a less expensive option than having the whole or a sub-item of the LLI in inventory. Possibly several waiting times (wastes) can be reduced in the production process of the LLI. This investigation should again be done in cooperation with suppliers, because all the LLI come from suppliers. This addresses the importance of practicing supply chain management.

In the model there is a template made for both the inventory and the value stream possibility. We have seen the inventory possibility in the previous section. For the value stream possibility we do not use the whole value stream map like in section 3.5. This is chosen because all the items are build-to-order, so no forecasts are considered. Therefore we will only investigate the processing times and the waiting times of an item. So only the lowest part of Figure 3-2 is used. From this information we can calculate the value added time percentage and we see where the waiting times are in the production process which have to be eliminated or reduced.

In the next chapter we will see several lead time reduction possibilities applied to our radar system under investigation.

4.2 INPUTS AND OUTPUTS

We now summarize the input factors that are asked for working with the model, and the results the user gets from the inputs.

Table 4-1 Inputs and Outputs

Input	Output
The critical items (39), their lead times and their successor.	Length of each path The critical (longest) path is found
Total lead time goal of the radar	Paths exceeding this goal Reduction quantity needed per path
Cost for all the items to be purchased	Yearly inventory cost
Value stream of the LLI	Most cost-effective lead time improvement can be seen

4.3 CONCLUSION

The model we made in Microsoft Excel should be used in the design phase of a new radar. The model facilitates lead time tracking and critical path determination. When the names, lead times and precedence relations are known, immediately the paths and items that should be reduced and therefore reconsidered are known. This can be used if a radar should have at most a certain time, to ensure that Thales can give their customers the lead time they want.

Design engineers then are asked to improve the lead time of certain items. With their knowledge they can find other solutions by re-designing with shorter lead times. With this model these changes can be done in an early stage of the design, where changes still take the least effort and cost. This is an iterative process, when the critical path is reduced, other paths can become critical. Then these paths should be considered for re-design.

For visualisation we advise to import three columns from the model in Excel to Microsoft Project. This are the columns Name, Duration and Successor. This is an easy step and will improve understanding a lot because now the lead times are visualised in time bars. In the appendix the necessary steps to be taken in MS Project are described.

For the items that cannot be reduced by re-design, other measures have to be taken. The inventory possibility and an in-depth logistic analysis are also facilitated in the model. If these options will be less costly, these options can be chosen instead of re-design. These and other logistic possibilities are described and tested in the next chapter.

5. LEAD TIME REDUCTION POSSIBILITIES

In this chapter we start really improving the lead time of a radar system. This chapter answers sub-question 4, addressing the pros and cons for the alternative lead time reduction possibilities and applies these to Radar A. Section 5.1 is about the alternative ways of lead time reduction for radar systems. In section 5.2 we define the roadmap produced by this research for lead time reduction. Section 5.45.3 uses the lead time reduction alternatives useful for Radar A. We end the chapter with a conclusion in section 5.4.

5.1 ALTERNATIVE SOLUTIONS

This section is about the several options we have for lead time reduction. From our analysis in chapter 2 and literature in chapter 3 we know the following ways for lead time reduction. We address the pros and cons of each alternative.

5.1.1 FORECAST

At first we have seen rolling forecast is in the starting phase for certain radar systems. This option can reduce lead times but will not necessarily do this. Depending on the timing of an order, and the number of previous orders, the lead time for the customer can be a few to X months. Currently at Thales the chance of getting an order should be very high before already start producing on this forecast.

Commitments with suppliers should be made about compliance of the forecasts, e.g. what if the forecast was wrong, if Thales does not sell the system, for what part of what already is produced is Thales accountable? If there is agreement for these kind of issues, this option can be promising. The commitment model proposed by (Fontijn, 2014) and (Thales, 2010), and this should be used for this option. We explained this model in section 3.6.

Forecasts in general are hard because radars have irregular and low demand. Also they are very expensive. Therefore Thales only wants to start producing a radar when a customer has signed to purchase the radar, build-to-order. The current start-up at Thales for forecast on several systems which have items in common is an interesting direction, because this will reduce the chance that one of those items will not be sold.

After all forecast is not really an option for radar systems, although it would directly reduce the lead time because production can already start when the contract is not signed yet. The cost of eventually not selling the system are too high. For radars with a certain stable demand of more than two a year, the risks of eventually not selling the system are much lower. For this series production, forecast is definitely a way to reduce the lead time of these radars. This idea will develop at Thales the next years, but forecast will not be taken into account in this research. We assume the build-to-order policy, so the production starts when the customer signs the contract.

5.1.2 PRE-RELEASE OF LLI

The order of a system is officially signed by the customer, that moment is called the effective date of contract (EDC). Before this moment, some Long Lead Items that directly influence the total lead time can already start production. This is called a pre-release.

If the chance of getting an order is above a certain level, estimated by Thales, this option should be considered. This option can and is already used in the design phase of a system, for the first product, the first of class (FOC). But it can also be used for products that already have been produced before. For this the critical paths should be determined and the paths that are longer than the lead time given to the customer, should be started before EDC. It should be started the number of days before EDC, such that the system is fully produced as contracted with the customer. However, the time of EDC is in this point in time just an estimation. The sales people should, next to the chance of getting the order, also give the expected time before EDC.

This possibility of course has risks, because the customer has not signed yet. Therefore the cost of eventually not using the Long Lead Item for this radar should be used in the trade-off. Long Lead Items used in multiple systems will have less risk, because perhaps they can be used later on for another radar.

5.1.3 TOWARDS STANDARD DESIGN

Uncertainty in lead time for items is higher for non-standard items. Relative long lead times are also for a huge part the result of being out of the standard. Therefore items with more uncertain lead times should have more attention like more often updating lead times, and monitoring the progress of the item when ordered. Manufacturers like to produce massive standard products, because that is where they can earn money the most. Thales orders are in a very low quantity and most of the time way more complex than the standard. Is Thales interesting for suppliers? Given the fact that suppliers cannot earn a lot of money from them, Thales is not interesting for suppliers. The economical situation is important in here. If we live in a recession, suppliers do not work with full production capacity, then Thales is more interesting for them. If the economy is booming, suppliers in general have enough work, then Thales with its relative complex and low quantity orders, is not interesting.

If Thales could go with the flow of standard products, these above issues will not be the case. In the design phase of new systems, the standard of each critical item should be considered against the not standard option. An example is the use of 3mm aluminium, not standard. 1mm and 2mm are standard, gluing them together seemed no problem, dramatically reducing the lead time and cost. Therefore now the standard option is used, deleting all the uncertainty for this part.

Of course not every critical item can be standardized. Thales has to stay innovative and highly advanced. But for the parts where standardization is possible and is not making the system less valued, this option should be considered. Both for lead time and cost this can make a difference. Measures that have to be taken otherwise for lead time reduction, can be saved. The estimation is that in general for 5-10% of the items of a radar no standard option will be possible (Designer Thales, private communication).

GOOD ENOUGH VERSUS TOP LEVEL PERFORMANCE

Thales design engineers try to make the most technological sophisticated products, they want the best performance for their customers, most of the time better than the customer requested. This fact gives Thales a very good impression to their customers, on performance of their products at least, but there are other consequences. It results in a more complex design, which is often followed by a longer lead time and higher cost. The level of sophistication should be a trade-off with other important issues, like lead time for example. Cost is taken into account, but lead time is not. Because lead time is an important issue for management, we think it should have a larger weight in the trade-off with sophistication. This can result in less advanced systems, but if it is good enough for the customer, this is an arguable option. The customer also values the lead time criterion. Lead time should at least be considered in this trade-off, and the easiest improvement in lead time can be done in the design phase, otherwise we have to do symptoms treatment.

Applying this option on the whole radar will take a lot effort. However this option, like every other option, should be applied on the critical items of a radar. We will see in section 5.3 these are 39 items.

EARLY SUPPLIER INVOLVEMENT

In the design phase there is already cooperation between design engineers and suppliers, but this is more about manufacturability than the associated lead times. These conversations would be the right place for taking into account lead time issues. Lead times are not the only point these conversations should be about, but they would be a good addition to these conversations in the design phase, they can reduce critical long paths from the system. We already have seen the largest improvements can be made with purchased parts. Cooperation with the suppliers of those items in the design phase about lead times can prevent lead time issues to be solved later.

5.1.4 CUSTOMER ORDER DECOUPLING POINT

Products for which now a rolling forecast is started, all have in common a relative late CODP. Products fall into this category if they are fully developed, if they have a certain stable demand and the sales are at least two to four a year. The characteristic of the CODP is that before this point, there can be produced on forecast. After this point, the product is customer specific and only if the customer has given his specifications, the production can continue. These products have a make-to-order policy in the sense of rolling forecast, but due to the fact the order is not signed yet, it can be seen as make-to-stock. A late CODP seems to be a necessity for a shorter lead time by producing on forecast.

When designing a new systems however, having a late CODP should be taken into account as a goal. For lead time issues, this is recommendable. This can be achieved by designing the customisation of the system as late as possible in production. However, radars already have in general a CODP only a few months before finishing the system. And because radars are almost only build-to-order, the customer order decoupling point does not deserve that much attention.

5.1.5 INVENTORY

One way to reduce the lead time would be having every item, or a lot, in inventory. This would dramatically reduce the lead time, but is not very cost effective. The inventory cost should be used in the trade-off between lead time reduction and cost. This can be done with our model, like we explained in section 4.1. Earlier research at Thales (Thales, 2010) has been done on calculating the necessary inventory and accessory cost for certain lead time reduction of two systems. Eventually, nothing is done with this research, but the researchers saw for sure potential in inventory holding for improving lead times.

The anonymous stock which is kept standard in inventory is not relevant to this research, we assume these items are always available. The customer specific items are what we focus on in this research.

Customer specific items are items belonging to a certain system, or expensive items which are not standard in inventory. In the model we made, the necessary reduction of each item is determined, in order to achieve the goal set for the total lead time for the radar. With this information we can calculate the inventory cost per year for each item, resulting in total in the inventory cost for this lead time goal. We use 15% inventory cost per year.

It can be the case that just a small or cheap sub item of the item under investigation, is the cause for most of the lead time for that item. With this information that should be gathered about the item at suppliers, such affordable and lead time effective measures can be taken. Inventory for sub-items reducing the lead time from a Long Lead Item is what we should look for.

5.2 ROADMAP FOR LEAD TIME REDUCTION

We now outline the methodology we use for lead time reduction. This methodology is established by several concepts from literature we have seen in chapter 3, combined with Thales internal knowledge gathered by multiple meetings with several employees from design, industrialisation and logistic departments.

In this section the methodology is defined for reducing a radar system in general, in the next section this ‘roadmap’ for lead time reduction is applied for Radar A. We now define the roadmap for lead time reduction, which forms the concept *design for lead time*. It consists of five stages, after the initial design is made by the designers.

0. The initial design is made by the designers.
1. Determine the relevant minority of the items. This are the items where the paths, longer than the lead time goal set by Thales, consist of (for Radar A 39 items, 2.5% of all the items). Make this subset visual.
2. Select the critical path of the radar system, verify its lead times, determine its sensitivity for reduction.
3. Re-design for lead time reduction:
    - Changing the product-breakdown-structure with as result a shorter lead time;
    - Using other production techniques with a shorter lead time;
    - Look for other suppliers with a shorter lead time;
    - Use standardized items, perhaps with re-design;
    - Involvement of suppliers in the design process.
4. If re-design is not possible or too costly, investigate the supply chain and value stream of the Long Lead Item in the critical path.
5. Work out the following logistic options for lead time reduction for making the best trade-off on lead time reduction and cost:
    - Sub item inventory;
    - Deleting wastes (mostly waiting time);
    - Pre-release.

With this roadmap designers know where to focus at for lead time reduction. Re-design is a good option for lead time reduction when it does not increase cost. The change in itself it does not cost a lot, because in this design stage there is not yet a formal approved design. However changing to other components for example can be more expensive. Therefore re-design should be a trade-off against logistic options for lead time reduction. Assuming quality stays the same, cost will give the key punch for deciding between options.

5.3 LEAD TIME REDUCTION APPLIED

Now we are going to apply lead time reduction possibilities at the radar system under consideration, Radar A. We described this radar system in section 2.1.3. In that section we have seen a simplified product-breakdown-structure and we outlined where the lead time of that radar system consists of. The cycle time for this system is two-and-a-half year. In this section we describe chronologically how we can reduce the lead time of this radar.

The radar consists out of an enormous amount of separate items, which together are going to be the radar. In section 2.2.2 we have seen the critical path is responsible for the total lead time. If we reduce this path, the total lead time of the whole radar will be reduced. But the items this path consists of, are not the only items we should look at.

5.3.1 THE 20%: CRITICAL ITEMS

From literature, we have seen as a rule of thumb (Pareto) that in general 20% of the parts are responsible for 80 per cent of the total lead time. For a radar system we see also extreme percentages. In the PBS of Thales of Radar A, there are 1600 items, we will see later on we need to use from this total only 39 items. We look for a lead time for Radar A of 1.5 year, which are 78 weeks. This is a reduction of 35% in lead time. So for this research, from this radar system, only 2.5% of the total items are relevant for this lead time goal. We investigated also two subsystems, a mechanical subsystem from Radar A and an electronic subsystem from another radar, also here just a few items are responsible for a large part of the lead time.

For convenience we show a more extended version of the earlier shown product-breakdown-structure in Figure 5-1. The items displayed in this figure are all interesting because we will see these are the items responsible for the longest paths of the radar. Only items which are not standard in inventory are considered.

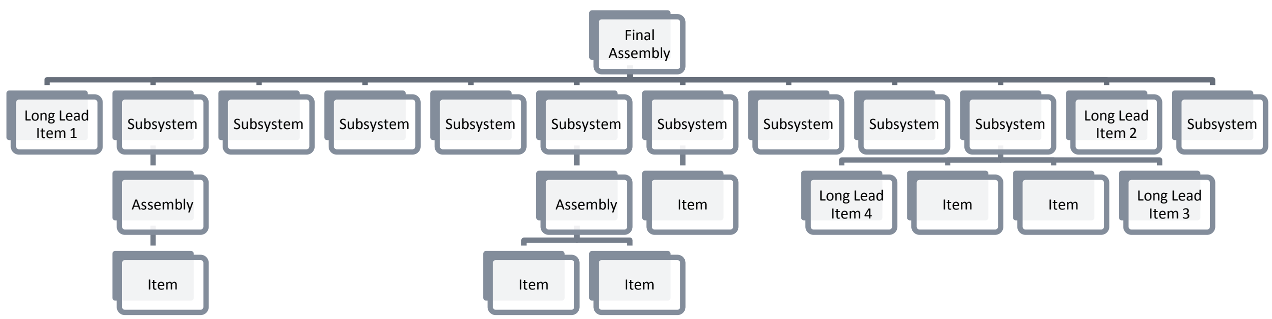

Figure 5-1 Product-Breakdown-Structure Radar A

Most of the 1600 items are not relevant for lead time reduction, namely 97.5%.This is the case because they don't have any influence on the total lead time, if we want to reduce the lead time to 78 weeks. We see this because on the one hand the items are in inventory, and on the other hand because they are in paths shorter than 78 weeks. If we filter out the relevant items out off all the parts, the 2.5%, we have a clear overview of the items responsible for the total lead time. Relevant is here characterized as influencing the total lead time, or necessary to improve for certain lead time reduction. These items we consider as critical for lead time reduction, we call them the critical items.

Of course the items on the critical path are critical items. But we have to look at more items than just the items on the critical path, because by reducing this path, another path with other items will become critical.

For finding all the critical items, we take the following steps.

- Find the items on the critical path: the path having the longest duration;
- Find other long paths, select all the paths longer than the lead time goal to be defined by Thales;

- Reduce the lead time of each of the items on the critical and long paths. This results in the sensitivity of the critical items, and other important items for lead time reduction are found, add these items;
- Fill Microsoft Project with this relevant subset, add the names, lead times and successors of each part.

These steps are done for Radar A. The pre-defined time we used is 1.5 year. This resulted in a subset of 39 items relevant for lead time reduction. An overview of these items is pictured in Figure 5-2. An item is purchased when depicted in blue, produced at Thales when depicted grey and on the critical path when depicted in red.

Form the figure we can see immediately which items that should be reduced, in order to reduce the total lead time. These are the items on the critical path, highlighted in red. This longest path has a duration of 119 weeks.

Figure 5-2 Critical Parts

IMPROVING

When we reduce an item on the critical path, we see it immediately reduces the total lead time. What we also see, is to which extent reducing this part has direct effect on the total lead time. Namely the path of Long Lead Item 2, this item should also be reduced if we want to reduce the total lead time even more.

What strikes is that some items have a very long lead time, the Long Lead Items (LLI). Some of those items have even a lead time of 80% of the total lead time, a lot have a longer duration than 50% of the total lead time. We assume the most cost-effective lead time reduction measure can be taken at the LLI. The orange line in the middle is on 66 weeks. So if we want to reduce the lead time of this product to 66 weeks, we can immediately see the paths that should be reduced to achieve this goal, and for how much.

Considering the knowledge only at first-tier level, the picture above is made. Now we know this picture, we are interested in what determines the lead time of such a Long Lead Item. This should be investigated to find possible improvements. In cooperation with suppliers the lead time of the LLI can be improved. We know examples where a cheap sub item caused huge delays, but almost would not cost much when having it in inventory. Also there is the assumption that most of the time will consist of waiting time instead of processing time. More in-depth information is required before we can take further lead time- and cost-effective appropriate measures.

VERIFYING THE INFORMATION

At first the lead times of the Long Lead Items were inquired by Thales employees and later on at the main supplier of the LLI's for Radar A, Supplier A. This first inquiry already gave interesting results. The first LLI under investigation was Long Lead Item 2. An Operational Buyer was surprised by the lead time the ERP system gave. Nowadays the lead time was not 101 weeks but 82. At once the path of this item was not critical anymore. Some more LLI had a shorter lead time than the ERP system gave. All the lead times of the LLI were inquired by the supplier responsible for almost all the LLI, Supplier A. Some items had a way shorter lead time than the ERP system told us, and some items had the same lead time we already knew.

In earlier years the mechanical parts manufacturer for Thales was a department of Thales itself. Seven years ago this department is outsourced to the firma Supplier A, this is now the supplier of almost all the mechanical parts Thales needs for its radar systems. Supplier A is one of the few companies in the world that can guarantee an accuracy of less than one-thousandth of a millimetre for its products. In general 50% of the LLI for radar systems come from Supplier A, for the Radar A this is even way higher. Therefore for this radar system, cooperation with Supplier A is the core of all the improvements.

One can imagine, this updating of lead times of LLI drastically changed the picture of our critical items. In Figure 5-2 the right lead times are depicted. By this updating some items were not relevant anymore because they already had a way shorter lead time. This emphasizes the importance of up-to-date information. For Thales it is not doable to keep the lead times of all the items, about 30,000, up-to-date. But we see before we are going to look for improvements, at least the lead times of the critical items of a radar system, should be updated. We have to work with the right information. Therefore the lead times of the items to be improved, the items in the longest paths, should be verified before starting improving.

With the right lead times of all the critical items, the total lead time seemed to be 119 weeks instead of the initial 131 weeks. The LLI are up to 80% of the total lead time, and therefore seems most interesting for lead time reduction. This is what we will focus on now.

5.3.2 LONG LEAD ITEM ANALYSIS

We will not investigate all the critical items. We will not even investigate all the Long Lead Items out of the critical items. From several LLI's with different characteristics we can learn how we should cope with them in general, in order to reduce the lead time. Eventually we will develop a roadmap for lead time improvement for Long Lead Items. Four of them will now be investigated.

As we have seen in Figure 5-2, on the critical path Long Lead Item 1 is responsible for $\frac{92}{119} = 77\%$ of the total lead time of this path. The sensitivity of this path is seen by comparing the length of the next critical path. The next critical path is the path that ends with Long Lead Item 2 and has a length of 109 weeks. So the sensitivity of the current critical path with LLI 1 is 10 weeks. This means we can win 10 weeks on the total system by reducing LLI 1 with 10 weeks.

LLI 1 is supplied by Supplier A. We need information about the operations, processes and further suppliers involved in the production of LLI 1, for making the most cost-effective lead time improvement. We have gathered the following data by multiple meetings with planners at Supplier A. Data like this could be discussed between Thales and suppliers to find together the best improvement solution. This data already gives a lot direction for lead time reduction. But Supplier A will be even more grateful to share data when not a graduate student from Thales doing research is their contact, but Thales employees who are really improving their cooperative business.

In Figure 5-3 we see where the lead time of this item consist of. We have seen Long Lead Item 1 has a 92 weeks lead time. The LLI contains more items, but this are the items where the longest paths consist of. With this items we can make a lead time reduction, there is no need the consider the other shorter paths.

Long Lead Item 1	**46,8 wks**
Safey time	3 wks
Final Assembly	7,2 wks
Item	12,2 wks
Item A	24,4 wks
Assembly	14,4 wks
Item	5,8 wks
Item B	13,6 wks
Item	2,6 wks
Item C	15,6 wks
Item	2,6 wks
Item D	15,6 wks
Item	6,4 wks
Item E	13,6 wks
Item	13 wks
Assembly	10,4 wks
Item	14 wks
Item	10,4 wks

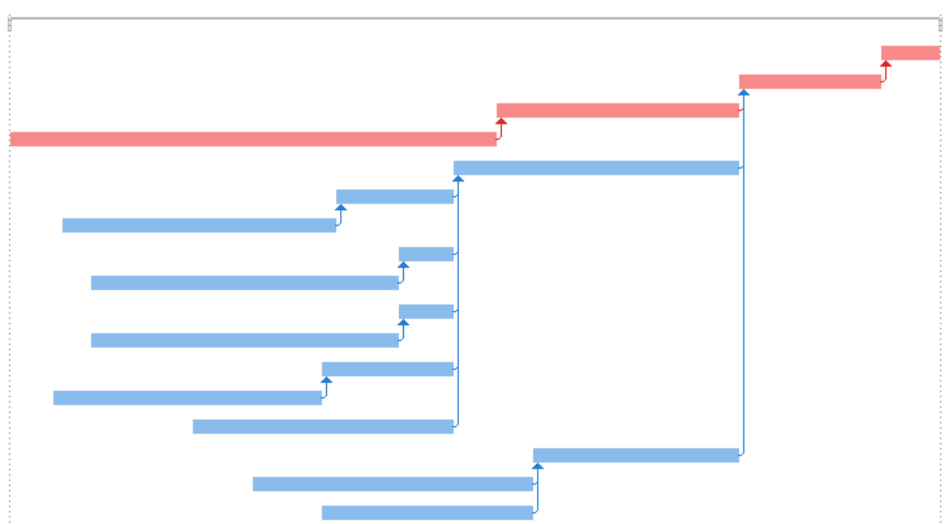

Figure 5-3 Long Lead Item 1

Now we see that the information of Supplier A tells us the duration for this item is way shorter than we expected by what is known at Thales. Instead of 92 weeks the lead time seems to be 46.8 weeks. Having these facts and figures aligned with the suppliers is very important for eventually improving the lead times. This lead time can even be shortened further by inventory measures with almost no cost. The items the five longest paths start with, items A through E in Figure 5-3, are relative cheap. Together they cost 2.27% of what Long Lead Item 1 costs. Having them in inventory will result in a lead time of 37.6 weeks. The real cost data is in appendix.

But with the knowledge of this shorter lead time, Long Lead Item 1 is already far from the critical path. Supplier A explained the process of building this item has been investigated, waiting times are shortened and now they can give a way shorter lead time than before. Because lead times also vary along the economical situation, suppliers give nowadays with the recession shorter lead times. This is possible because in general there are less orders. When larger lead times are given by Supplier A, sub-item inventory is an effective solution for lead time reduction. When the target lead time is 78 weeks for Radar A, Long Lead Item 1 should be less than 51 weeks. This is achieved by aligning the information we have seen above, because this resulted in a lead time of 46.8 weeks.

The second item we will investigate is Long Lead Item 2. Also this item is supplied by Supplier A, so also this data is acquired at Supplier A. With our initial data we expect this LLI to have a duration of 82 weeks. In Figure 5-4 we see the Gantt chart of this item. Again these are only the items the longest paths of this LLI consist of. We see the LLI has actually a duration of 74.4 weeks. The black line represents the 51 week target lead time for this LLI, such that this path is not exceeding the 78 weeks for Radar A.

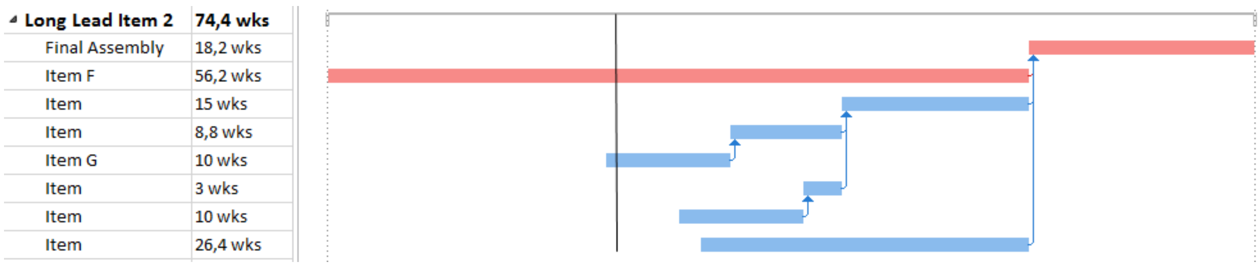

Figure 5-4 Long Lead Item 2

This figure clearly illustrates that if we want to improve the lead time of LLI 2, we should improve Item F. We see an improvement on Item F for 22.4 weeks results in a direct improvement on Long Lead Item 2 for 22.4 weeks. Then the second longest path becomes also critical. This means then we have approached the target lead time on one week. Then also the path with item G should be reduced with one week in order to meet the target with LLI 2. For further analysis we should investigate Item F. What is interesting, is that while LLI 2 is ordered at Supplier A, Item F is ordered by Supplier A at Thales.

We again analyze with a Gantt chart, in Figure 5-5 we see item F displayed. The target for this item is 32.8 weeks (51-18.2), because then the path reduces to a total of 51 weeks. Again the black line is that target of 32.8 weeks.

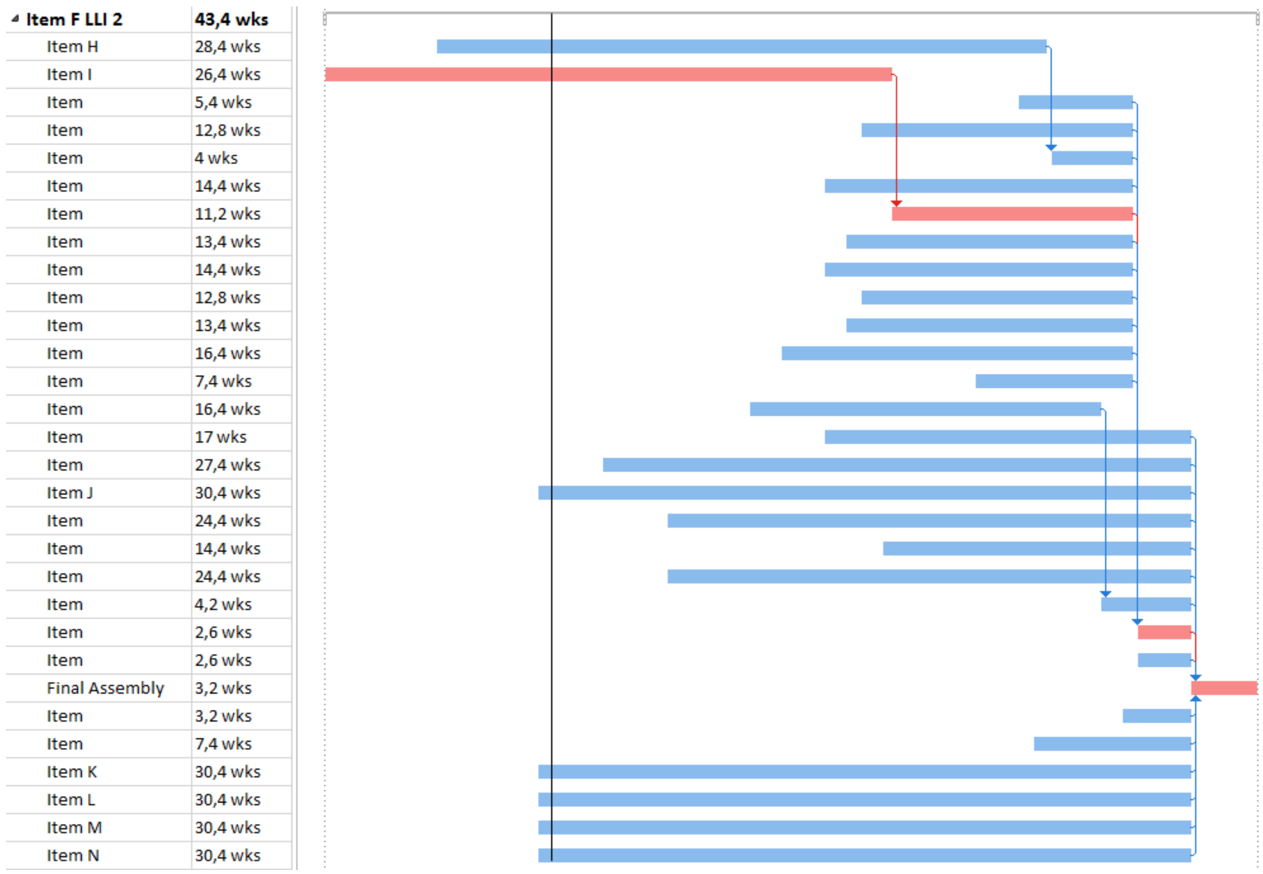

Figure 5-5 Item F

We expected a lead time of 56.2 weeks (Figure 5-4), but now we see a lead time of 43.4 weeks. So in this case Supplier A does not had updated information from Thales. We see already Item F has a lead time of 12.8 weeks shorter than expected. With improving the top two items, another 9.8 weeks reduction for Item F can be made. Then we are already very close to our target. However, these two top items are characterized as items that should be in inventory. Then we already have also these 49 days improvement.

Item J and the lowest four items (item K through N) are not standard in inventory. Other measures should be taken here to improve, if more improvement on Item B is needed. Interesting is that these lowest four items are ordered at Supplier A again. Ordering these items already when the whole radar building process is started seems a good solution to reduce the lead time of Item F even further.

Concluding for LLI 2 we can say a huge reduction in lead time can be made without any cost, by just having the right information corresponded with suppliers. This already approaches the target lead time to one week. More reduction in lead time can be accomplished when information about future needs is communicated with suppliers earlier. Again these items are relative cheap, so sub item inventory will even further reduce the lead time. Long Lead Item 2 has high cost, and item F costs 26.09% compared to LLI 2, so item F is not interesting for inventory. Item J through N are interesting for inventory, because they only cost 3.2% compared to item F. The real cost data is in appendix.

The third item we will investigate is Long Lead Item 3. In Figure 5-6 we see the Gantt chart of this item. The target for this LLI is on 66 weeks, depicted with a black line.

Long Lead Item 3	76,8 wks
Final Assembly	16,6 wks
Item O	32,2 wks
Item P	28 wks
Item Q	27,2 wks
Item R	28 wks
Item	12 wks
Item	24,4 wks
Item	20,4 wks

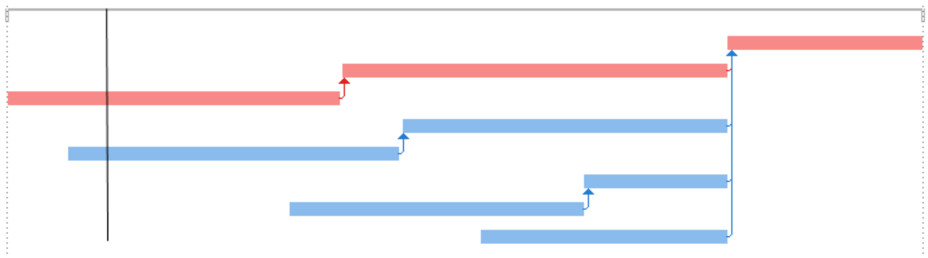

Figure 5-6 Long Lead Item 3

Again this LLI is ordered at Supplier A. Item O and Q are produced at Supplier A, where also the final assembly takes place, which has a duration of 16.6 weeks. Supplier A orders Item P and R at another supplier. These are huge and expensive items with a lead time of 28 weeks. Value streams of the four mentioned items should be made for finding improvements. Maybe this are the most difficult items to improve because they have a lot processing time. However, LLI 3 is not yet improved at the supplier like has been done with LLI 1. A waste analysis will be useful for these items. For this research this was not possible because we did not get the data from the suppliers. Thales however, should cooperate with the suppliers for waste reduction. Having item P and R in inventory will result in a new lead time for LLI 3 of 53 weeks. Those items cost 15.70% compared to LLI 3. LLI 3 is a very expensive item, so inventory for these two items P and R seems less interesting. Perhaps less costly sub item inventory or waste reduction is possible. The real cost data is in appendix.

The fourth and last item we will consider is Long Lead Item 4. The Gantt chart of this one is displayed in Figure 5-7. We expect a lead time of 94 weeks and the target for this item is 66 weeks.

Long Lead Item 4	39,6 wks
Final Assembly	7,4 wks
Item	8,8 wks
Item	19,4 wks
Item	4,6 wks
Item S	18,6 wks
Item	8,4 wks
Item	7 wks
Item	8,4 wks
Item	30,4 wks
Item	9,8 wks
Item	8,4 wks
Item	9,2 wks
Item	8,4 wks
Item	12,4 wks
Item	13,6 wks
Item	10 wks
Item	10,8 wks
Item	3,4 wks
Item	11,8 wks
Item T	20,4 wks
Item	13 wks
Item	14,4 wks

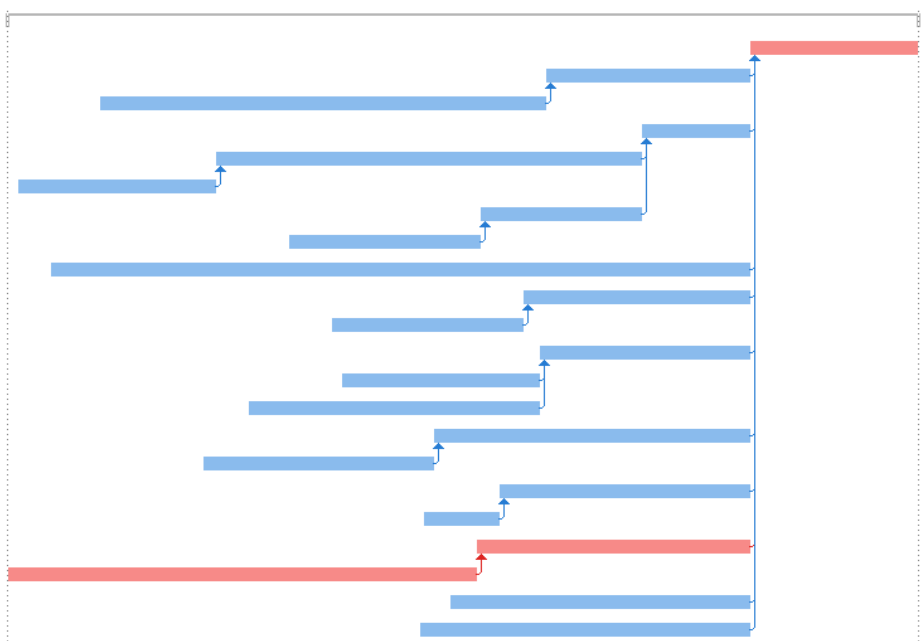

Figure 5-7 Long Lead Item 4

We expected a lead time of 94 weeks but now with data from Supplier A we see a lead time of 39.6 weeks. This is again a huge difference which immediately eliminates the LLI from the critical path. At once this item is not really interesting for lead time reduction of the whole system, because it is already below the target lead time. Although this is the case, we see interesting things for even further lead time reduction of this Long Lead Item. We can learn from this for other items. Item T we see on the critical path, with a lead time of 20.4 weeks, is an item which costs are very low. It costs 1.31% compared to Long Lead Item 4. This makes this item interesting for inventory. The real cost are in appendix.

Item S with a lead time of 18.6 weeks from the LLI 4 we investigated further. This item is produced at Supplier A.

Operation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Setup time	0	26	70	199	18	70	292	25	118	66	24	18	417	16	18	30	72	1479.00
Operation Time	0	4	0	246	0	0	198	0	78	106	15	0	625	2	0	0	2	1275.05
																		2754.05

Figure 5-8 Routing Item S

In Figure 5-8 we see the routing of item S. Supplier A has to complete 17 operations to complete this item. The operations 5, 12 and 15 are outsourced. The setup and operation time of each operation is given in minutes. We see processing time as the sum of the operation time. In total this item has 1275 minutes processing time. We divide this value by the 93 days in minutes. Then we see 2.86% of the total lead time of item S is processing time. This is less than what we would expect by literature, the 5% processing time in general.

For the outsourcing operations of course there is transportation time and check-in and check-out time. However, the rest of the time is waiting time. For some critical items influencing the total lead time of the radar, this value adding operations should be considered. Improving these waiting and transportation times which actually are called wastes, will give us shorter lead times which will result in a shorter lead time for Radar A.

With this information Thales can cooperate with Supplier A, and together they have to look for the most appropriate measure for lead time reduction, with the associated cost. For suppliers it is not necessary to reduce the wastes of every item, only the items that need lead time reduction in order to reduce the lead time of the whole radar. We have seen in this research this are only a few Long Lead Items.

5.4 CONCLUSION

In this chapter we have focused on the critical items of the whole radar system. This were 39 out of the 1600 items. Together these items form the paths which have a lead time longer than 78 weeks. We have seen that each of these paths has a Long Lead Item responsible for more than two third of the lead time of the whole path. Therefore we focused at those items. We analysed four Long Lead Items for lead time reduction possibilities.

In cooperation with the supplier of these items, we already have seen that two Long Lead Items had nowadays way shorter lead times than Thales expected. Therefore these were at once not interesting anymore for the critical path. However, the reason why they had way shorter lead times was interesting. At Supplier A lead time reduction has been applied. Waiting times were analysed and it seemed possible that a lot of these waiting times (waste) could be deleted when looking for lead time reduction. The lead time of Long Lead Item 1 was reduced by a half and Long Lead Item 4 even more. With sub-item inventory for low cost these lead times could even further reduce. From around 92 weeks these times were now around 40 weeks. The total lead time of Long Lead Items consists out of a lot buffers (waiting time). Of course in producing a radar with so many items, we need buffers to avoid not having items at the right time. However for the Long Lead Items on the longest paths in a radar system, these buffers should be reduced. By monitoring them more than less critical paths, the Long Lead Items can have less buffers.

Long Lead Item 2 had other characteristics. This LLI is ordered at Supplier A, while item F from this LLI is ordered by Supplier A at Thales. This item has the longest duration in LLI 2. Again other components Thales needs for item F are supplied by Supplier A. More cooperation for this LLI would already drastically reduce the lead time. Like already purchasing or producing items which the counterpart will need later in time, instead of waiting for an order. Again lead times were not up to date, for example the difference for Item F seemed to be 12.8 weeks. Of course we need to include some check-in and –out time, and transportation time, but that will not be 12 weeks. for the Long Lead Items that need lead time reduction, these times need also more attention, because direct lead time for the whole Radar can be made here.

The least lead time reduction has been accomplished for Long Lead Item 3. In here just a few items determine most of the lead time. Improving these will dramatically reduce the lead time for the LLI. However, this are expensive items. Waste analysis can probably improve these lead times. In contrast to the two LLI's with a way shorter lead time nowadays, this waste analysis has not yet been done at Supplier A for LLI 3. Another option, reducing this LLI by inventory, will need a serious cost investment.

We conducted a waste analysis for Item A of Long Lead Item 4. This item is chosen because data from this item was available, in contrast to other items. We analysed the routing of this item. Seventeen operations have to be done for this item by Supplier A, including three outsourcing operations. Only 2.86% of the lead time for this item is processing time. The rest are waiting and transportation times. This shows considerable improvements can be made for items like this, by reducing wastes in the lead time.

6. CONCLUSIONS AND RECOMMENDATIONS

In this chapter we answer the research question *"How can the lead time for radar systems be reduced, in particular, what are lead time consequences of design choices?"*. We start this chapter with the conclusions we can draw after this research, and end with the recommendations.

6.1 CONCLUSIONS

1. *The lead time of a radar system can significantly be reduced by improving a small part of the total items a radar system consist of.*

The lead time of a radar from Thales consists for the very largest part of items to be purchased at suppliers. Therefore we focussed on the external supply chain. The product-breakdown-structure of a radar represents the precedence relations for each item. With this information and the lead time of each item, we can find all the paths in the PBS of the radar. When Thales sets a target lead time for a radar, several paths exceed this target lead time. We used the 1.5 year target lead time. The items these too long paths consist of, are the items we need to consider for lead time reduction. When we reduce each of these items, we find the second longest items in these paths. This determines the improvement potential if we reduce the lead time of the items in the longest paths. For the radar we investigated, Radar A, this resulted in a relevant subset of 39 items, which is 2,5% of the total items the radar consist of.

One path is the longest path, the critical path. This is the first path we need to reduce in order to reduce the total lead time of the radar. All the paths end with an item which has a relative long lead time. We have seen these items have a lead time of more than 50% of the total lead time for the radar. These items we call the Long Lead Items. We focussed on the Long Lead Items which are purchased. These items have the most impact on the total lead time of the radar, and these items have potential for lead time reduction we have seen.

2. *Monitoring these 2.5% important items with our model in the design phase, reveals the lead time consequences of design choices.*

In the design phase Thales would like to be able to make design decision based on lead times, such that a radar has a certain lead time. For this need, we made a model. This model determines what paths of the radar are too long. We can immediately see which paths need reduction for reducing the lead time of the whole radar. These paths should be investigated further in the design phase. We need to find the sub items causing the most of the lead time. Design engineers then have to try to re-design for a shorter lead time. We call this concept *design for lead time*.

These 39 items can easily be imported in Microsoft Project for visualisation. This visualisation will create understanding about what impact certain items have, on the total lead time of the radar.

For some items re-design for shorter lead time will be possible. If this results in a path duration of an acceptable level, this path is finished. For other paths re-design for shorter lead time will not, or not enough, be possible. For these cases we analysed logistic measures.

3. *Logistic measures have potential for significant lead time reduction with low cost.*

We investigated four Long Lead Items for lead time reduction. The lead times of all these four LLI's can largely be reduced. All these items are ordered at Supplier A. The first improvements were already made by comparing lead time data with that supplier. Several improvements in lead time have been conducted at the supplier. Aligning this information is crucial in planning, production, and finally for improving lead times. Out of the lead time of the Long Lead Items, waiting times were reduced. This identification of what really determines the total lead time, then analysing these times, can result in extensive lead time reduction without large cost. We identified the processing times of one item, this was only 2.86% of the total lead time for this item. The other part should be analysed for reduction.

Next to the waiting time analysis, lead time reduction for low cost can be achieved by having inventory for sub-items. We have seen for several Long Lead Items, cheap sub-items can be responsible for a significant part of the lead time.

Finally all the four Long Lead Items could be reduced sufficient such that their paths were shorter then 1.5 year. For one LLI this would mean larger inventory cost for sub-items. The lead times of the LLI's were reduced by 30 to 60%.

6.2 RECOMMENDATIONS

1. *By this research we developed a roadmap that should be used for lead time reduction.*

The roadmap developed by this research can be applied for lead time reduction. We start with an initial design made by the design engineers. Then the longest paths with a lead time too long, are identified and considered for re-design by the designers. For the paths that cannot be re-designed to an acceptable lead time without increasing cost, logistic measures have to be taken when the radar is really built. The roadmap consists of 5 steps and it outlined in section 5.2.

This roadmap includes two approaches for lead time reduction. The re-design option and the logistic option. In both approaches a trade-off has to be made, because certain lead time reduction can be achieved for certain cost. This reduction in lead time should be conducted with still satisfying the quality requirements. Trade-offs for both approaches have to be compared for finding the most cost-and lead time effective improvement measure.

2. *Thales should largely extent cooperation with key suppliers.*

When more then 50% of the production is outsourced, extensive cooperation with the most important suppliers is extremely important. Already in the design phase of a new radar, this cooperation has to start. With *Early Supplier Involvement* lead times can be estimated better and alternative designs can be discussed for shorter lead times. We recommend to include the *design for lead time* concept in conversations that already take place in the design phase of a radar with suppliers, but currently without the lead time consequences.

Thales should align lead times with suppliers. We have seen large differences about lead times at the supplier and Thales. This can already result in shorter lead times, making other measure easier or even unnecessary. Not the lead times for all the thousands of items should be aligned, but the lead times for the critical items. For our radar investigated, this meant 39 items. These items determined the total lead time for the radar. When these times are aligned, and all parties can realise these planned times, further improvements can start. But this alignment is a necessary prerequisite. Earlier giving orders to suppliers, earlier than the lead time would suggest, such that the supplier already can plan this order, reduces the chance of receiving the order later, e.g. because of capacity problems at the supplier. When already is know that the supplier will later on need items from Thales, these items can already be produced. For the longest paths these options should be applied.

We recommend to make a value stream analysis for the Long Lead Items that need lead time reduction. This highlights the wastes in the production process of the item. Most of those items are purchased at suppliers. Eventually both for the supplier and Thales waste reduction is interesting. Because we do not need to do waste analysis for a lot items, only those that cause the length of the lead time, we think this is an option suppliers also might find interesting.

In this value stream analysis or an analysis of the product-breakdown-structure of a Long Lead Item, certain sub-items might be found that cause a significant part of the total lead time. Then sub item inventory is an interesting option for lead time reduction. We have seen in our research that this is not rarely the case, that sub items with very low cost are responsible for a considerable part of the total lead time.

In general improvements should be made in practicing *supply chain management*. When all the information of producing from start to finish an item that needs lead time reduction is identified, the most cost- and lead time effective measure can be taken. For making this possible, information sharing and cooperation with suppliers is the key.

3. *Monitoring the critical paths when really building the radar is essential.*

Even like the design phase, the relevant subset determining the lead time of the radar, should be monitored closely when the radar is actually build. At first all the lead times of these items have to be aligned with suppliers, because it can be the case that the radar is not build in a number of years and lead times have been changed.

When production is started, keeping track of the progress of these items is essential for achieving all the due dates. The importance for this recommendation cannot be underestimated because a day lost at the critical path, is immediately causing a day lead time extension for the whole radar.

When backwards scheduling is used, one can say every item is critical and every item deserves the same attention. But for reducing the lead time of the whole radar, giving the longest paths more attention by monitoring and reducing waiting times, this can immediately reduce the lead time. Shorter paths can have more waiting or safety time, because this will not influence the lead time of the whole radar, therefore they can have less attention.

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8 APPENDIX

IMPORTING IN MICROSOFT PROJECT

We now outline how the information entered in the model in Excel, can be imported in Microsoft Project.

You can easily select the columns you want to import. We need three columns. The names of the items, their lead times and the successor of each item. This are the columns in the tab ‘MS Project’. Further we can apply the following improvements in MS Project to have the entire project visible.

- Project tab; Project Information; Schedule from: Project Finish Date.
- Select the whole column Task mode; right-mouse click; click auto schedule.
- Select the whole column Task mode; right-mouse click; click information; click tab advanced; constraint type: As Late As Possible.
- Format; check ‘critical tasks’.
- Format; check ‘Project Summary Tasks & Summary Tasks’. Now the total project time is visible.
- View; ‘zoom entire project’. Now the whole project is visible.

This is the way a clear and visible overview of the critical items can be made, like Figure 4-5.