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MASTER THESIS: REDUCTION OF ORDER HANDLING THROUGH OUTSOURCED KITTING

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THALES

Management Summary

This research was initiated by the purchasing department of Thales Nederland. The goal was to reduce the costs of this department using outsourced kitting. A kit can be defined as a container with the needed parts for one or more assembly operations for a sub-assembly or a whole end product and kitting can be defined as the collection of these parts. Outsourcing the kitting to a supplier means that the supplier delivers the kit with its parts already kitted. The research investigated how outsourced kitting should be organized at Thales Nederland. The research question was as follows:

How should Thales Nederland organize outsourced kitting of parts of a single supplier for the same radar?

We approached this research by studying literature on in-house kitting due to lack of literature on outsourced kitting. The literature formed the basis for the model we used during this research. This model was used to find the relevant parameters and locate possible obstacles which could increase the costs. We formulated solutions to these obstacles when possible and calculated the savings based on a case study on with the SYSTEM-X as system and Supplier-X as supplier.

Using the model, the current situation was analysed. The following factors can cause extra costs when outsourcing the kitting:

- Incomplete kits, because the assembly cannot start when not all parts are present and the part needs to be reordered.
- Inspections, since it would create a lot of movement and waiting of the parts.
- Late deliveries, since their number can increase due to outsourced kitting.
- Design changes of parts, since the changed part must be traceable.
- Special handlings, since a part with a special handling must be traceable.
- The bill of material, since implementing a kit in the BOM is currently difficult
- Delay due to missing/broken parts that are currently kept on stock, since there is no internal buffer for these parts anymore.

The major benefits of outsourced kitting are a reduction in the number of order lines, picks at the warehouse and a reduction in warehouse capacity needed.

Outsourced kitting requires some changes in the current process. The following changes must be implemented when outsourcing the kitting:

- There must be a manufacturing-BOM (M-BOM) in which kits can be defined. The M-BOM is just a regular BOM, but is more independent than a regular BOM from engineering influences.
- Outsource visual (V) and functional (F) inspections to supplier to prevent movements of kits.
- Supplier keeps a stock policy which is equal to or better regarding the fill rate than Thales' stock policy to prevent production/delivery delay. This policy counters the possible benefit of a reduction on holding costs, since the stock is moved to the supplier. The value of the stock is small compared to the possible delay costs.

Besides these changes, the kit must meet some requirements. Its design must facilitate the pick and assembly operations such that it can improve these processes. Subsequently this design must be kept up to date. The kits must have some distinctive features, such that it and its parts are recognized. The kit should have its own number and the parts must be kept in their original packaging. Kits must not incorporate parts that are difficult to kit due to their size or the special handling they require. As last, the kit should have space for other parts of suppliers such that it can move as one kit to the final assembly.

We analysed the costs and the gains of outsourced kitting using the theoretic model. Taking the costs and gains of both Thales and Supplier-X into account, the savings of outsourced kitting are around the €XXX per System-X. These savings create enough margin regarding errors and exceptions. When taking only Thales into account, the gains are €XXX per System-X. Comparing these gains with the costs of a System-X, which is several XXX, the gains are very marginal. Implementing outsourced kitting is not very interesting when only taking the gains into account. However, the side effects of easier communication and control and enforced coordination could create additional gains. Yet these effects are only present when a supplier has performance issues. Alternatives which solve these issues are probably more effective. Outsourced kitting could be used to share the information on the assembly process. Since outsourced kitting leads to a small saving, it is a suitable alternative to accomplish this sharing. Outsourced kitting could also be a useful tool to support the outsourcing of assembly activities. It is questionable if outsourced kitting should be implemented for its direct savings or savings due to easier communication and enforced coordination, but it can be implemented for sharing information of the assembly process or as tool to support the outsourcing of assembly activities. If one of those two benefits is wanted, we advise to implement outsourced kitting.

The parts that are currently ordered in a quantity bear the risks of outsourced kitting. If the quantity used is a small fraction of the quantity ordered, these parts do not contribute much to the overall gains of a kit. This results in that these parts are sensitive for errors. Excluding these parts could therefore be an option to reduce the risks.

It is questionable if outsourced kitting is profitable for other suppliers. The location of Supplier-X causes a very short delivery time. This reduces the costs if a part that currently is kept on stock, is broken/missing. Other suppliers that are not located nearby cannot provide these small delivery times and resulting in higher costs for missing/broken parts. Removing the parts with a low ratio on quantity used compared to quantity ordered can make outsourced kitting at other suppliers more interesting.

As stated earlier the gains of Thales are €XXX per System-X. These gains are realised for a large part by the reduction of the handling at the logistic inbound and the picking and storing activities at the warehouse. The gains for the purchasing department are €XXX per System-X, which is almost nothing. So outsourced kitting does not contribute to the goal of reducing the costs of the purchasing department.

There are already projects started that facilitate the changes needed for outsourced kitting. When implementing outsourced kitting, we advise to create awareness on outsourced kitting such that outsourced kitting can be taken in account in these projects. We advise to start with a project to outsource the V and F inspections. When all projects are finished, we advise to start outsourced kitting with the kits that are the most robust regarding costs against missing/broken parts. These kits can help in detecting and solving the start-up problems without much cost.

Preface

Studying is like an adventure and that is how I would describe my time during my study Industrial Engineering and Management. Just like all the adventures, the last part is always the most interesting one. The last part of my adventure started at Thales Nederland and this thesis is the end of this part. Having done a minor "Krijgswetenschappen", being able to my thesis in the defence industry, was a very interesting opportunity. I would like to thank Thales Nederland for this opportunity. Particularly I would like to thank Jan Wennink and Krista Keijzer for supervising me at Thales. Furthermore I would like to thank all the colleagues for the nice time at Thales. Besides Thales, I would like to thank Matthieu van der Heijden and Fons Wijnhoven for being my supervisors from the Universiteit Twente.

Yet this master thesis is only a small part of my adventure. I would like to thank my family for their support during my study. I also would like to thank my friends for making my time as a student, a time I will never forget. I want to end this preface with a quote of Gandhi:

> "Live as if you were to die tomorrow. Learn as if you were to live forever."

Siebren Elgersma

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Abbreviations

BOM: bill of materials
WIP: work-in-progress
MTO: make-to-order
ETO: engineer-to-order
CODP: customer order decoupling point
MRP: master requirements planning
AOC: advanced order commitment
ERP: enterprise resource planning
PI/PC: Partial information sharing and partial coordination
FI/FC: Full information sharing and full coordination

1. Introduction

This chapter introduces the research outline. Section 1.1 introduces Thales Nederland, the company where this research takes place. Section 1.2 addresses the problem of this research, formulate the research questions and define the scope. Section 1.3 discusses the further outline of this research.

1.1. Background of Thales

In 1922, the predecessor of Thales Nederland, NV Hazemeyer's Fabriek van Signaalapparaten was founded in Hengelo. Hazemeyer founded this company to produce fire control system for the Koninklijke Marine (Royal Netherlands Navy). After the Second World War, the company was bought by the Dutch government. The Dutch government, aware of the importance of a good defence industry, renamed it to N.V. Hollandsche Signaalapparaten (or better known as Signaal) and invested in new buildings and facilities. In 1956, the government sold the majority of its shares to Philips. Philips continued the growth of the company and Signaal had around 5000 employees at its peak. At the end of the Cold War, defence budgets were reduced dramatically, leading to a staff reduction. Furthermore, Philips had decided that “Defence and Control Systems” was not a part of its core business. Signaal was sold to Thomson-CSF and became known as Thomson-CSF Signaal. Thomson-CSF renamed itself in 2000 to Thales Group and Signaal became known as Thales Nederland.

The Thales Group is currently very active in the defence market. Around 50% of its income is generated by its defence branch. Thales Group is the eleventh largest defence contractor of the world and the fourth in Europe by its earnings from this industry. Like the group, the turnover of Thales Nederland is for a large part generated by selling military equipment. It is producing military systems for naval, air defence and communication purposes. Although Thales Nederland does produce for the civil market, the defence market is by far the most important market. The defence systems produced by Thales Nederland belong to the best of the world.

Figure 1 A view of a part of the Thales terrain with some of their products on the roof

Thales Nederland currently is facing a market in which the competition is increasing. To cope with the increased competition, Thales needs to increase its competiveness. One way to achieve the increased competiveness is to decrease their costs. In the past years, Thales started to buy parts instead of making them themselves. In the era of Signaal, most parts used in radars could not be bought on the market due to their complexity. Currently those markets have caught up and made it possible for Thales to outsource parts of its production. Nowadays Thales considers her core competence regarding the radars as being able to design, configure, assemble and test its radars.

1.2. The research problem

As stated in Section 1.1, Thales needs to reduce its costs. This section links the goal of cost reduction with the goal of the research. This research takes place at the purchasing department of the business unit Sensors. This business unit is responsible for the production of radars. The business unit is changed from a business unit which produced its parts internal to a business unit that is buying most of its parts at suppliers and doing only the assembly. This change created a more complex supply chain, resulting in higher dependency on its suppliers. Although outsourcing has many benefits on production costs, a more complex supply chain increases costs for the purchasing department. As stated earlier, Thales needs to reduce its costs, so the purchasing department also needs to reduce its costs. The main goal of this research is to reduce the costs of the purchasing department.

There are different ways to reach this goal. One way would be to examine the activities of the purchasers and try to optimize this. Another way could be to reduce the workload of the purchasers. Thales states that it can reduce the order costs by ordering parts together for a single radar. If those parts are kept together, parts can be ordered and handled together, resulting in a cost reduction. The difference between the current situation and desired situation is shown in Figure 2 and Figure 3. Currently all goods are handled individually at the procurement, shipping, inbound logistics and warehouse. They are combined when they are needed at the final assembly in a kit. A kit can be seen as a container with the needed parts for one or more assembly operations for a sub-assembly or a whole end product (Christmansson, et al., 2002). In the desired situation, the supplier puts all these parts together and the parts are shipped and received as a kit. A few years ago, Thales conducted a preliminary research on this topic and concluded that the savings could be €XXX per radar system. Although savings come from multiple departments, one of these departments is the purchasing department. The purchasing department is convinced that outsourced kitting could have a major impact on their costs. Ordering the parts together instead of individually, results in a reduction of the workload of the operational purchasers. Combining this argument with the total expected savings, we choose to focus on outsourced kitting.

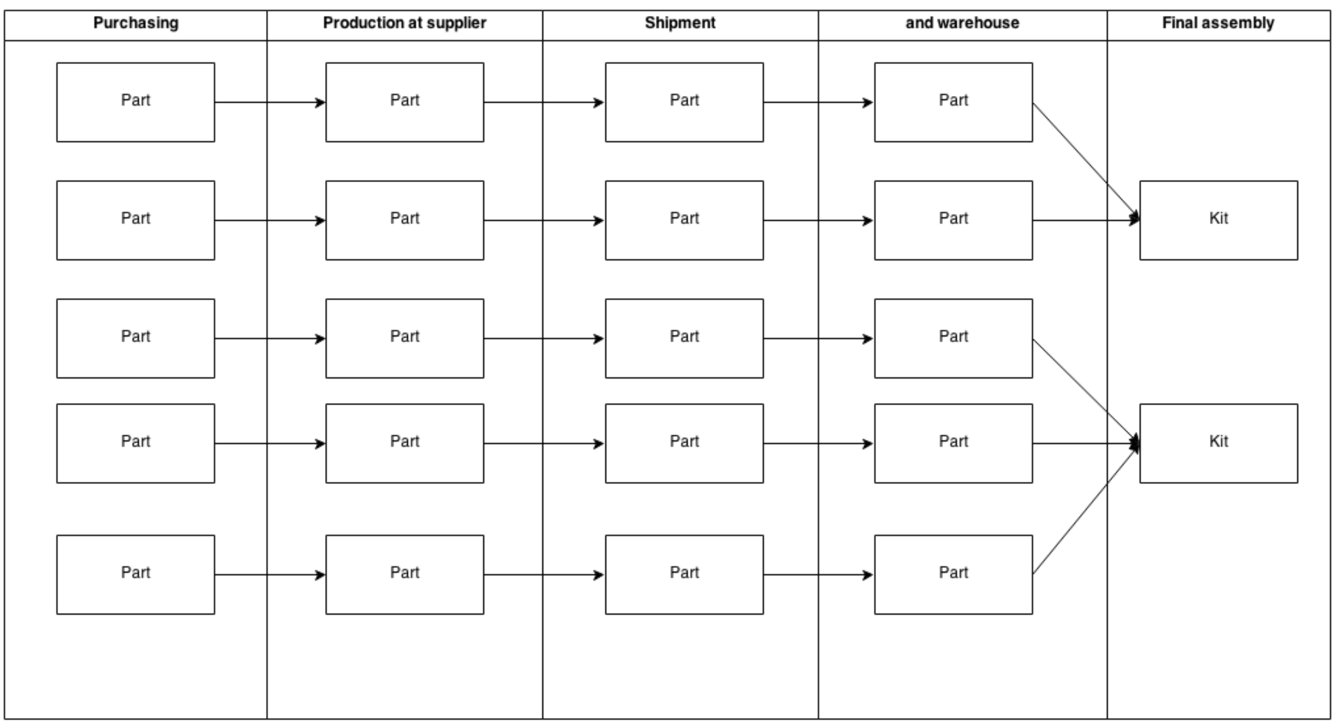

Figure 2 A simplified flowchart of ordered goods in the current situation

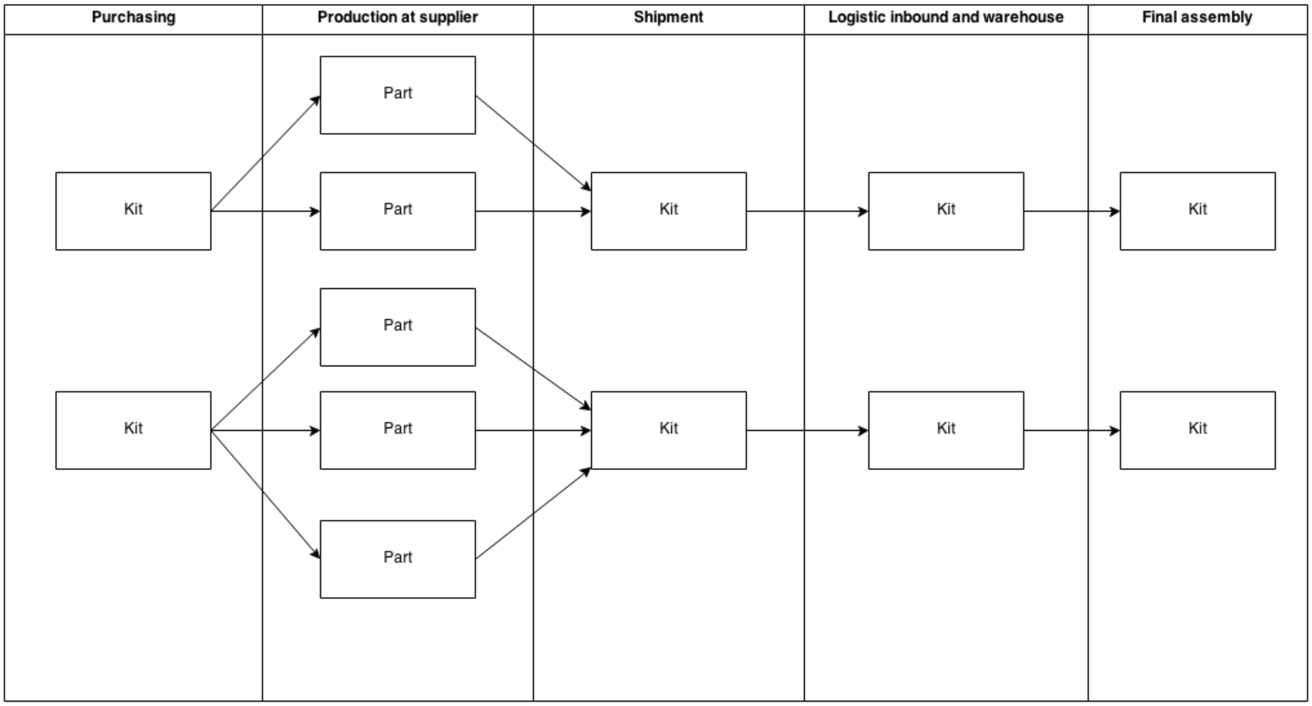

Figure 3 A simplified flowchart of ordered goods in the desired situation

Tracking parts becomes also easier when they are in an outsourced kit. Instead of tracking parts individually, a kit can be tracked. So communication and maintaining the overview becomes easier, which also could lead to a cost reduction for the purchasing department. Although these benefits are difficult to quantify, they are a major benefit and should be taken in account when making the decision to outsource the kitting.

Literature on kitting primarily focusses on in-house kitting. The cost reduction in these researches focusses on the order picking. Although outsourcing kitting is done by Toyota (Ramirez, Hausman-Cohen, & Venkataraman), when searching on the terms “kitting” or “outsourced kitting” on Scopus, we do not find useable articles on outsourced kitting. Another approach to this problem is the coordinated replenishment problem resulting from inventory management. The book Inventory Management and Production Planning and Scheduling (Silver, Pyke, & Peterson, 1998) for example does address coordinated replenishment, yet does not include a topic that can be related to outsourced kitting. Therefore, this topic is interesting from a scientific point of view.

When constructing the outsourced kits, we only consider parts that are from the same supplier. It would be possible to combine parts from multiple suppliers. Yet in our opinion creating kits consisting of parts from multiple suppliers from the start is more difficult than a kit from a single supplier for an organization that has no experience in outsourced kitting. The same holds for a supplier, because it needs to take over the control of the suppliers of the outsourcing party. We focus only on systems that fully developed and have a stable product configuration. These systems are labelled at Thales as chain 2 systems. We do not include new systems (called the chain 1 systems at Thales) or spare parts (called chain 3 at Thales). Chain 1 is not suitable, since many changes are made in the product design and therefore kit configurations are not stable. Chain 3 on the other hand is not linked to an assembly step and so kitting is not very useful.

We formulate the central research question as follows:

How should Thales Nederland organize outsourced kitting of parts of a single supplier for the same radar?

The goal is to asses if outsourced kitting leads to a cost reduction and how large this reduction is. To determine the profitability, we need to find possible obstacles in the current processes regarding outsourced kitting, develop if possible solutions for these problems and create a financial overview in which we can compare the benefits with the costs of the found obstacles to asses if outsourced kitting leads to a cost reduction.

To answer the central research question, we have to formulate sub-research questions. The first research question concerns the current situation by analysing the current process from the decision making that a part must be ordered until that part is installed in the final assembly we can assess the problems that will arise when outsourcing the kitting. We formulate our first sub-research question as follows:

1. *What are the problems in the current situation regarding outsourcing the kitting of parts from the same supplier?*
    a. *How do the processes currently operate?*
    b. *What are the problems for these processes when changing to outsourced kitting?*

By answering the question on current processes, the difficulties of using outsourced kitting are revealed. By redesigning some processes, some of these difficulties can be solved. We formulate our second research question as follows:

2. *What are good alternatives for the problems caused by outsourcing the kitting of parts from the same supplier?*

Combining the knowledge found by answering question 2, we can make a financial overview to assess the profitability of outsourced kitting. We formulate our third research question as followed:

3. *What are the savings resulting from outsourcing the kitting of parts from the same supplier?*
    a. *How can the savings of outsourced kitting be calculated?*
    b. *What are these savings?*

1.3. Research outline

This section describes the further outline of the research. Chapter 2 contains a literature research. Chapter 3 answers sub-question 1, which concerns the current situation. Chapter 4 contains the affected processes, answering sub-question 2. Chapter 5 concerns the cost analysis, answering sub-question 3. Chapter 6 contains the conclusion, recommendations and further research.

2. Literature

In Section 1.2, we mentioned that a kit can be described as a container with the needed parts for one or more assembly operations for a sub-assembly or a whole end product (Christmansson, et al., 2002). Although others ((Brynzér & Johansson, 1995), (Bozer & McGinnis, 1992), (Limère V. , 2011)) mention that a kit is for a complete end product or just for starting the assembly ((Som, Wilhelm, & Disney, 1994), there are others besides Christmansson et al. that mention that a kit can also be for a sub-assembly ((Wilhelm & Wang, 1986), (Hanson & Medbo, 2012), (Ramachandran & Delen, 2005)). The definition that a kit is only used for a complete end product has as disadvantage that such kit cannot be made for products consisting of large array of assembly steps. We define a kit as a container with the needed parts for one or more assembly operations for a sub-assembly or a whole end product. Kitting is defined as collecting the parts in a kit and the delivery of the kit ((Bozer & McGinnis, 1992), (Christmansson, et al., 2002), (Brynzér & Johansson, 1995), (Ramachandran & Delen, 2005), (Limère V. , 2011), (Hanson & Medbo, 2012)).

Bozer and McGinnis (Bozer & McGinnis, 1992) compared kitting with line-stocking. Line-stocking provides the assembler a stock of the parts he needs at his assembly station. In this comparison, they made a list of advantages and disadvantages of kitting compared to line-stocking (Figure 4). These advantages and disadvantages are based on in-house kitting and will not necessarily hold when kitting is outsourced. Yet analysing the advantages, it seems that these are related to the production, which is not affected by outsourcing the kitting process. Outsourced kitting also can lead to a reduction in order handling. If parts are currently bought in small batches or per piece, then it reduces the order handling, since the order handling of these parts is combined. The disadvantages regarding the production process also holds. Yet compared to in-house kitting, the impact of these disadvantages is higher. If parts are currently kept on stock, then these stocks disappear, because the parts are bought in a kit. If these parts are not kept on stock anymore, it takes longer to get these goods if something goes wrong, which worsens the negative effects. This leads to problems when a part is delayed, missing or broken. A kit is ready when all its parts are ready. Thus, a delay in a part causes a delay of the kit. With more parts that can cause a delay, the chance of late delivery also increases. If a kit arrives incomplete, it requires some more exception management. A part arrives or it does not arrive, but a kit can arrive partially. When a part is broken, it leads to an incomplete kit, resulting in the same problem for the assembly. The disadvantages storage increase when preparing the kits in advance and not adding direct value to the product disappear. Because the supplier prepares the kits, there is only room needed for the kits and therefore reduces the space requirements. Furthermore the kitting is done by the supplier and therefore reducing the non-adding value processes in the own production processes. Although it could be said that the supplier ends up with this activity and therefore creating more non-adding value activities in his processes, the opposite could also be true. Since the supplier has to collect and send his own parts anyway, combining them in a kit will not cause them much extra work. Therefore, it reduces the non-value adding activity. Figure 5 contains an overview of the advantages and disadvantages of outsourced kitting compared to in-house kitting we described.

Advantages of kitting

- Saves manufacturing space and reduces work-in-process at the workstations
- Product changeover is accomplished with relative ease
- Offers better control and higher flexibility
- Facilitates material delivery to workstations
- Provides better control and visibility for high cost and/or perishable components and subassemblies.
- Offers potential increase in product quality and workstation productivity
- Supports small batch size operations with a large variety of products
- Facilitates robotic handling at the workstations

Disadvantages of kitting

- Kit preparation consumes time and effort with little or no direct value added to the product
- Is likely to increase storage space requirements
- Demands additional planning to assign on-hand parts to kits
- Temporary shortage of parts may force the user to use incomplete kits; doing so will reduce the overall efficiency of the operation
- Defective parts that are inadvertently used in certain kits will lead to parts shortages at the workstations.
- Components that may fail during the assembly process, will require special consideration or exceptions
- If parts shortages develop some kits may get “cannibalized”

Figure 4 Advantages and disadvantages based on Bozer and McGinnis (Bozer & McGinnis, 1992, pp. 5-6)

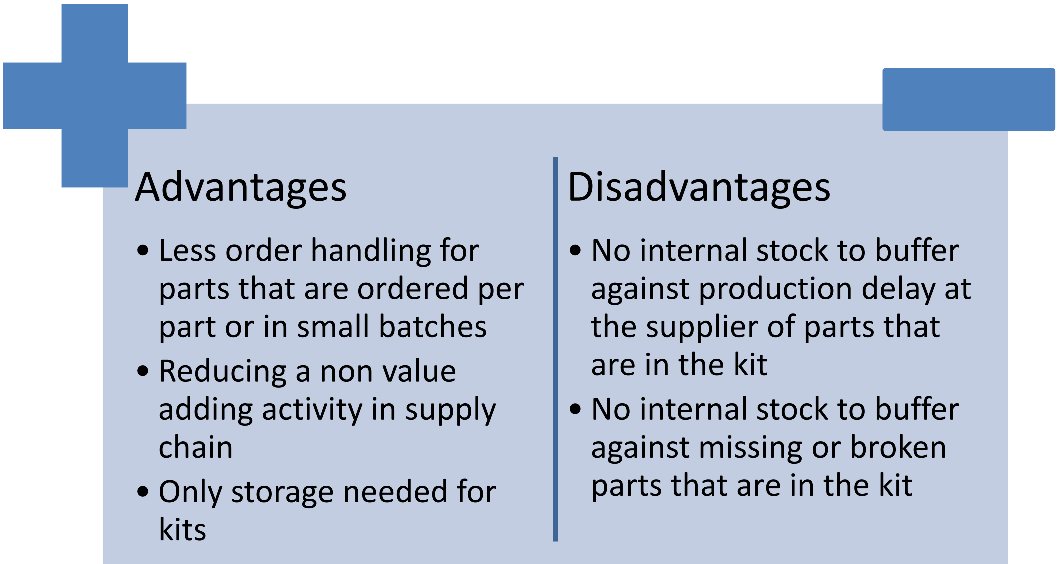

Figure 5 Advantages and disadvantages of outsourced kitting compared to in-house kitting

The goal of this research is to determine the profitability of outsourced kitting. To measure the impact of outsourced kitting, the advantages and disadvantages of Figure 5 need to be translated into measurable variables. The advantages consist of cost reductions. To measure these reductions, the current situation of the three variables needs to be compared with the outsourced kitting situation. The disadvantages lead to an increase in costs. These costs can be measured by delay costs. A missing or broken part cannot be used for assembly and so the assembly operation cannot take place. If the assembly operation cannot take place, delay occurs and so the corresponding costs are created. If the production of a part is delayed at the supplier, the kit is delayed and so results in delay at the assembly process of Thales. There could be other costs regarding outsourced kitting than the discussed costs. These costs could be created due to some activities that currently are in place at Thales.

The study of Sahin and Robinson Jr. (Sahin & Robinson Jr., 2005) investigates information sharing and coordination policies. Since outsourced kitting does a bit both, it is interesting to take their findings into account. They investigate five different situations, namely:

- No information sharing and no coordination (NI/NC)
- Partial information sharing and no coordination (PI/NC)
- No information sharing and partial coordination (NI/PC)
- Partial information sharing and partial coordination (PI/PC)
- Full information sharing and full coordination (FI/FC)

Partial coordination means that the manufacturer coordinates replenishment and transportation of individual items to reduce its cost. Full coordination means that there is a central coordinator who coordinates the replenishment and transportation of items to achieve a supply chain optimum. Partial information sharing means releasing all planned orders in the MRP as advanced order commitments (AOC) such that the supplier can minimize its order fulfilment costs and full information sharing means besides sharing the MRP information on planned orders, also sharing the projected inventory balance and gross requirements per time period. In these settings they take in account the inventory costs, procurement costs and receiving costs for the manufacturer and equipment change costs, inventory costs, invoice costs for the supplier and the transportation costs. They concluded that the total costs were the lowest at FI/FC considering both firms. Yet the gains for the manufacturer are only a few per cent compared to the NI/NC situation and the major gains were for the supplier. PI/PC on the other hand delivered a gain around the 30 per cent for both the manufacturer and the supplier compared to the NI/NC situation. Yet the sum of the total costs of both firms was higher compared to the FI/FC situation. Gain sharing in this situation is likely. When sharing the gains, both parties can improve their performance. Not sharing the gains would make the manufacturer reluctant to cooperate, since the PI/PC has more benefits for the manufacturer. An outsourced kit has the properties of partial coordination, since it combines the parts that from the perspective of the manufacturer when ordered together would reduce internal handling, minimizing the costs of the manufacturer. An outsourced kit also shares some information, since the longest lead item determines the lead time of the kit. This makes the order date of the kit dependent on that item. This results in that other parts are released earlier. This information sharing would be between partial and no information sharing according to the definition of Sahin and Robinson Jr. The benefits of the coordination and information sharing cannot always be contributed to outsourced kitting. If there is coordination and information sharing which is comparable or better than those of outsourced kitting, outsourced kitting does not generate these benefits. On the other hand, outsourced kitting could be tool to achieve a kind of coordination and information sharing.

As stated, outsourced kitting can provide some information sharing. Prajogo and Olhager (Prajogo & Olhager, 2012) state that besides the sharing of information, the information technology must be able communicate this information to maximize the benefits. To be able to gain the possible benefits of the information sharing, the IT-systems must be able to communicate a kit. If comparable or better information sharing methods are present, outsourced kitting does not generate the benefits of information sharing. Although the benefits of information sharing are not necessarily present, the supplier still needs the information of which parts must be included in the kit. This information must be communicated regardless of the benefits of information sharing. This means that the IT-systems must be able to communicate the outsourced kits.

Combining the factors following from Figure 5, the possible advantage of information sharing and coordination and the need of an IT-system that can support outsourced kitting, results in the factors described in Figure 6.

Figure 6 Overview to determine the financial result of outsourced kitting

Examining the advantages and disadvantages of outsourced kitting compared to in-house kitting, it seems that outsourced kitting is very suitable for companies with low volume products, which are between the engineer-to-order (ETO) and make-to-order (MTO) perspective, so companies which order their parts when they get an order. In cases of high volumes or companies with a customer order decoupling point (CODP) more down streams, buying parts in large quantities becomes an option. This also reduces the need for order handling, yet it does not have the weaknesses of outsourced kitting. The advantage of reduced order handling due to outsourced kitting is in the cases of low volume producing MTO and ETO companies stronger. The disadvantage of a more vulnerable assembly line is less compared to mass production companies, since most of the parts are procured at the moment an order arrives at the supplier and these parts are not kept on stock. In the case of in-house kitting, the assembly also had to wait on these parts.

Thales produces in low quantities and its assembly department requires a high flexibility in product changeovers. Therefore kitting is very useful for Thales according to Figure 4. As stated earlier it seems that outsourced kitting is the most suitable for companies that produces in low volume and order their parts when they receive an order. The benefits of outsourced kitting can be maximized in companies such as Thales.

Research on kitting primarily focusses on the relation between the warehouses and the assembly line. Bozer and McGinnis (Bozer & McGinnis, 1992) compare in their research the differences between line-stocking and kitting based on average WIP, shop floor space requirements, replenishments of the line per day and container flow. Carlsson and Hensvold (Carlsson & Hensvold, 2008) extended the model of Bozer and McGinnis with the number of replenishments of the warehouse per day, the walking time of the assembly operator, kitting time per day, physical part handling per day and space needed for kitting. Limère (Limère V. , 2011) and Limère et al. (Limère, Van Landeghem, Goetschalckx, El-Houssaine, & McGinnis, 2012) also focus on the differences between line-stocking and kitting. These studies focus on which part should be in a kit and which parts should be line-stocked to minimize costs. Other studies analysed the kitting process. Wilhelm and Wang (Wilhelm & Wang, 1986) made a model of the kitting process and used it to calculate kit earliness or tardiness, and the time that parts are in-process inventory. Some other studies used queuing theory ((Som, Wilhelm, & Disney, 1994), (Ramachandran & Delen, 2005), (De Cuypere & Fiems, 2011)) for analysing the process. These studies showed that the kitting operation can be decoupled from the assembly operations down-stream. Although these studies on the process used two inputs, Ramakrishnan and Krishnamurthy (Ramakrishnan & Krishnamurthy, 2007) used more than two. Their model can be used for the impact of inventory levels and supply rates on the delay in the kitting process. Hanson and Medbo (Hanson & Medbo, 2012) studied the fetching of the parts in a kitting situation compared to line-stocking. They concluded that fetching the parts was shortest when kitting. Carlson, Yao and Girouard (Carlson, Yao, & Girouard, 1994) studied kitting in printed circuit boards. They concluded that kitting made work process more flexible and accurate. Günther et al. (Günther, Gronalt, & Piller, 1996) also investigated kitting at printed circuit board assembly. They used a model where kitting was used to minimize the number of operating stations. Bryznér and Johansson (Brynzér & Johansson, 1995) examined different companies where they use kitting. They concluded that storage policies could be improved; batch and zone picking could be efficient if there is no extensive sorting and administration, traveling time was less compared to line-stocking, kits can support picking information and warehouses where assemblers are responsible for the picking show more efficient picking. Christmansson et al. (Christmansson, et al., 2002) did research on the ergonomics of kitting. They concluded that item-to-picker reduced the stress on the human body. Medbo (Medbo, 2003) researched kitting at a company that was doing kitting for some years. This study pointed out that the kit configuration must be adapted on changes in the production process. Hua and Johnson (Hua & Johnson, 2010) researched the gaps in the literature concerning the choice between kitting and line stocking. They conclude that there is more research needed on problems that triggers the re-examination of the choice, the cause of these problems, the process of converting between these systems, the problems with these conversions, the performance improvement or degradation after a conversion and the reason of improvement or degradation. Choobineh and Mohebbi (Choobineh & Mohebbi, 2004) did a simulation study on the impact of shared components in different kits on inventory, kit availability and backorders. When more components are shared, there are less backorders and higher kit availability. Hanson and Brolin (Hanson & Brolin, 2013) compared line-stocking and kitting based on two case studies. They conclude that kitting provides fewer men-hours needed on the production line, yet these savings in hours are fewer than the extra hours of work needed in preparing the kits. They also pointed out that kitting can provide support for the assembly processes. This only is true when kits are structured and are correctly prepared. Furthermore according to this study kitting increases flexibility, but increases inventory level. Chen and Wilhelm (Chen & Wilhelm, 1993) studied a multi-echelon kitting process where kits consisted of parts from suppliers and in-house sub-assemblies. They developed a model and some heuristics to analyse the allocation of parts to a kit. In a more recent study (Chen & Wilhelm, 1997), the authors extend their model with more layers, an option for substitutes and a new heuristic. Funk (Funk, 1989)researched kitting versus line-stocking in combination with offshore production facilities in printed circuit board assembly. This study compared three options, kitting to order, kitting to stock and line-stocking and concludes that line-stocking is the most cost-effective except when there is a combination of a high average component cost, large number of components stored at each station and a low number of parts per board.

Since the focus of this research is on outsourced kits, the main trade-off is buying in kits or in quantities, which can be kitted later. Since previous research regarding kits was focussed on trade-off between kitting and line-stocking, this research provides some new insights. Figure 6 contains an overview to analyse the profitability of outsourced kitting. These parameters in this overview can be used in the following chapters to analyse the impact of outsourced kitting.

3. The current situation

This Chapter discusses the current situation to answer the sub-research question "*What are the problems in the current situation regarding outsourcing the kitting of parts from the same supplier?*" We start by discussing the processes of the involved actors regarding outsourced kitting. The actors are chosen because they are involved in the production of a radar system. We will use actors to describe the situation and subsequently analyse their problems using Figure 6.

3.1. The processes

This section addresses the processes of the actors involved in outsourced kitting involved. The actors we define are the logistics department in general, its subsidiaries warehouse and inbound logistics, the supplier, the purchasing department and the final assembly. We also analyse the control of the radar production. Although this process is not directly involved in outsourced kitting, this process defines the input for the ordering process. Discussing this process creates a better overview. After discussing this process, we continue with the processes of the actors. We start with the production planning, which is done by the logistic department. Next, we discuss procurement. Thereafter we discuss our case supplier, Supplier-X. Although this process is outside of Thales, the supplier also is involved in outsourced kitting, since the supplier is responsible to place the parts in the outsourced kit. After we have discussed the supplier, we continue with the remaining processes, inbound logistics, the warehouse and the final assembly. To finish this section we give an overview of the processes.

3.1.1. Control of the radar production

The production of radars at Thales is based on two input factors. The first factor is receiving an order from a customer. The second factor is based on a forecast. Thales has a system where they keep track of the possible orders. In this system two important parameters are present. The first parameter is the likelihood of an order to be placed in the market. The second parameter is the likelihood that Thales gets that order. Using this information the orders are divided in three classes, high, medium or low probability of getting the order. The high and medium probability order forecasts are used in the budget and production control of the core part of radars. The core part is defined as the part of the radar that is not customer specific. A downside is that Thales takes the risk of not selling these core parts. The advantage of producing in advance on the other hand are volume discounts on parts and if the customer decides to place the order, Thales can promise a shorter lead time. Subsequently customer specific parts are only purchased for radars ordered by a customer.

3.1.2. Logistics department

The production planning is based on customer orders and done by the logistics department. A customer order is translated into a project. For these projects a project plan is made. This project plan is translated into a procurement plan and a production plan. These plans contain which parts must be procured and produced. These plans are constructed by the enterprise resource planning (ERP) system. Thales simulates these plans to find the most critical parts for reaching the due date. These parts are communicated with the production department and purchasers, so they can try to speed up production or delivery.

The coordination effects as described in Chapter 2 are currently equal to the coordination a kit provides. The procurement plan contains dates on which the parts are needed at the final assembly and these dates determine the delivery date of the parts. If parts are needed for the same assembly step, these dates match. A kit is based on the same principles and so cannot add more coordination.

When using outsourced kitting, the procurement plan must be made based on the kits and the simulation must detect critical kits. The ERP gets the bill of materials (BOM) from a system called KIS. Defining a kit in this system is currently not possible. It gets its input directly from the engineering environments. Changes in the BOM must be done in the engineering environments. Currently many logistic changes in the BOM are not done, since the costs of implementing it are high. Examining Figure 6, these costs can be placed under the IT costs.

In Figure 7, an overview is shown of the important steps of the production planning. The left part column represents administrative processes and the right logistic processes. This figure is part of a larger figure, Figure 13.

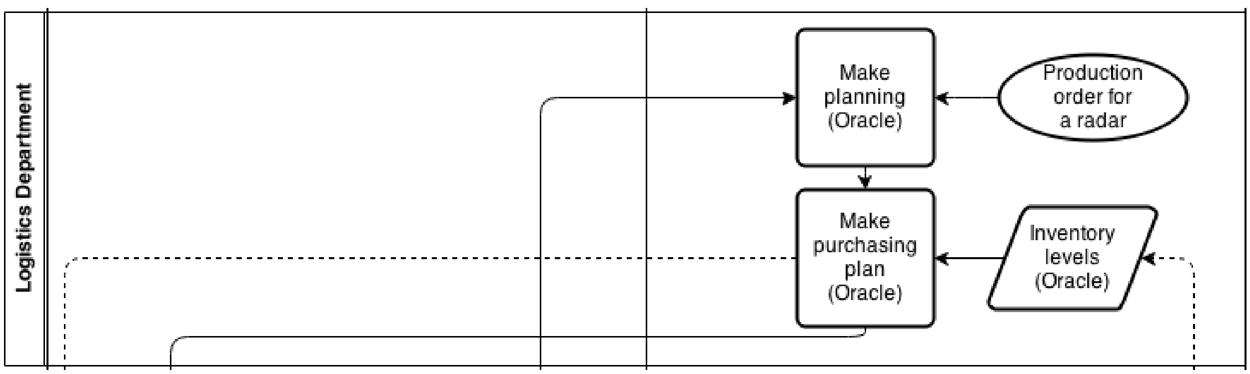

Figure 7 Overview of the important steps regarding outsourced kitting of the production planning

3.1.3. Procurement

There are two major processes in the procurement of parts. The first is the tactical procurement. If Thales starts to produce a new radar type, it has to find suppliers that can make the parts it needs. This process is done by the tactical purchasers. Another responsibility of the tactical purchasers is the procurement of the complex and expensive parts. Besides finding suppliers and handling the expensive parts, they make contracts with the suppliers and maintain the relations with important suppliers. When outsourcing kitting to a supplier, the contracts have to accommodate outsourced kitting.

The second part is the operational procurement, which does the ordering of the parts. As discussed in Section 3.1.2, the purchasers get a procurement plan. This plan consists of needs. A need is defined as a part, sub-assembly or module that must be ordered to build a radar. The operational purchaser takes these needs out of the procurement plan and put them in something they call the production environment. This transfer is done need by need. In the production environment the operational purchaser combines the needs into an order using the price list and sends the order to the supplier. From this point, a need is an order line of order. The supplier sends back a confirmation. The operational purchaser registers the confirmation in the ERP. In case of outsourced kitting, the number of transfers from the needs from the procurement plan to the production environment and number of lines that need to be confirmed can be reduced. The ERP could automate the transfer of needs, but this currently not done, since control on the needs is currently needed.

It is not uncommon that parts are changed. This happens due to customer requests, supplier requests or improvements on the design. The operational purchaser has to communicate these changes with the supplier. When a part, sub-assembly or module is changed, the operational purchaser receives a form of modification. This form contains information about the change, but also a revision number. This number is used to communicate the changes to the supplier. The supplier can find the changes using the number in the system that Thales uses to communicate product designs. These changes nowadays cause many problems because they are released when the engineer finishes his design, resulting in an unpredictable release of changes. This creates delay in the production process. In case of outsourced kitting, these changes still must be communicated and this problem will still be present. Yet if changes are communicated on kit base, it is unclear which component is changed and this could create a mess with the revision numbers. The current information systems do not create much flexibility on ordering a kit and communicating changes on part level, since these systems define a kit in the same manner as a part.

The number of transfers of needs into an order line and the number of confirmations of these order lines changes when outsourcing the kitting. This reduction in transfers and confirmations can be categorized ad a reduction in order handling costs according to Figure 6. The design changes create two problems. The first is traceability of which part is changed. The effort the supplier has to do to find this change results in extra costs. Comparing this cost with Figure 6, it can be categorized as extra costs caused by the IT. The other cost factor is the delay caused by the design changes. The costs for these delays could be placed under the delay caused due to the disappearance of the internal stock. Yet it is arguable that if a part is redesigned, the current stock cannot be used anymore. So design changes do not influence this parameter. It could be that the delay caused by the design changes lead to additional delay and so extra costs. This delay has the same impact as delay in production/delivery of parts that are not kept on stock, which is discussed in the analysis of the final assembly, Section 3.1.7.

In Figure 8, an overview is shown of the important steps of the product changes and operational procurement. The left part column represents administrative processes and the right logistic processes. This figure is part of a larger figure, Figure 13.

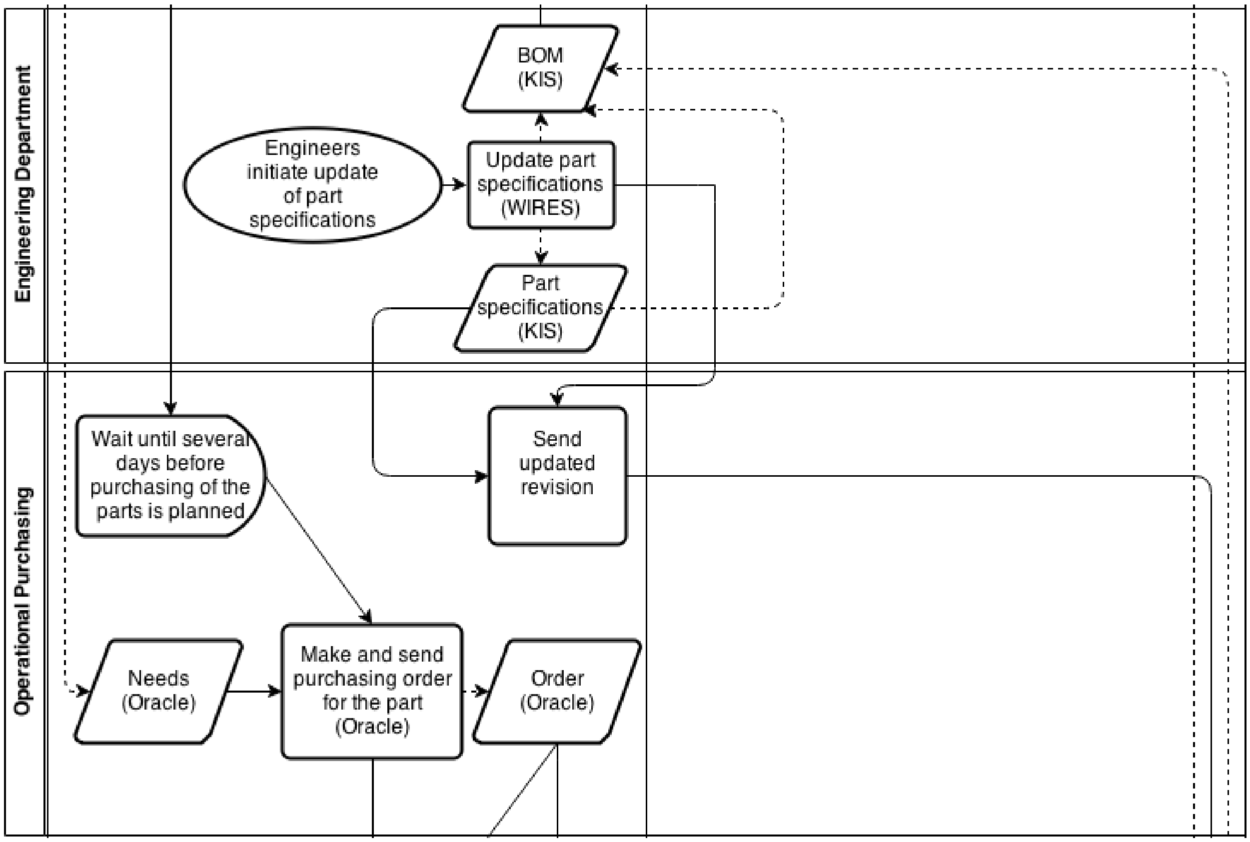

Figure 8 Overview of the important steps regarding outsourced kitting of the product changes and operational procurement

3.1.4. Order handling at the case supplier

This section discusses the order handling at our case supplier, Supplier-X. As stated in the previous section, Thales sends an order to produce a certain part. On this moment, Supplier-X books the order in, plans it, starts the production and delivers the order on the agreed delivery date. When outsourcing the kitting, the supplier also gets a cost reduction since it has to register less order lines and so reducing its handling costs for booking an order. On the other hand extra costs can occur to assemble the kits.

The most important change according to Supplier-X is that they receive orders for parts earlier. Receiving these orders earlier is due to the information sharing discussed in Chapter 2. Another option to get this information sharing is to order parts earlier in the process. Currently Thales investigates rolling forecast to facilitate the information sharing, see Fontijn (Fontijn, 2014). This is a tool that can facilitate advanced order commitments (AOC). Goedhart and Dijkhuis (Goedhart & Dijkhuis, 2004) describes how rolling forecast is used at ASML. Due to this initiative, outsourced kitting cannot create additional information sharing as defined by Sahin and Robinson Jr. (Sahin & Robinson Jr., 2005).

Comparing the changes with Figure 6, the reduction on costs by less order handling is caused by less order lines and so can be linked to that part of the figure. The costs regarding the kitting activity the supplier gets can be linked to the reduction of a non-value adding activity.

In Figure 9, an overview is shown of the important steps of the supplier. The left part column represents administrative processes and the right logistic processes. This figure is part of a larger figure, Figure 13.

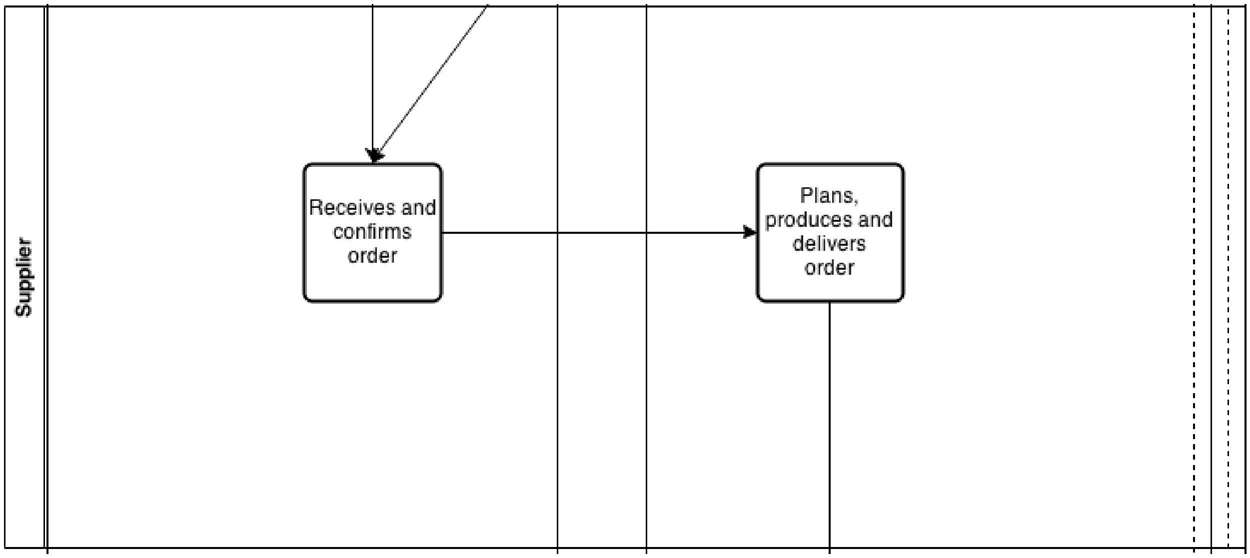

Figure 9 Overview of the important steps regarding outsourced kitting of the supplier

3.1.5. Inbound logistic

At inbound logistic the parts enter Thales. Inbound logistics receives, checks and registers the incoming goods. There are different kinds of checks. The first is called the XX control. This control is done on goods that are received for the first time. The second kind is called the ZG control. This control inspects if the goods that are delivered, are the same as the goods that should be delivered. Beside these two inspections, there are two classes of inspections that include a ZG control, but with some additional checks. The first class are the controls that belong to the visual (V) class. Inspections in this class are visual based, for example if the product is painted well. The second class is the functional (F) class. This class checks if the product on its functionality, for example if the transistor works. Most of the V and F controls must be done by specialists. Yet these specialists currently are located at another location at Thales, so the parts that need a V or F control must be moved.

Outsourced kitting reduces the number of goods that need to received, checked and registered, since it can be handled as one product. To be handled as one product, the kits must be recognizable as kits, otherwise inbound logistics will not know they are dealing with a kit and can cause a disassembly of a kit. The V and F controls can become problematic. If an outsourced kit has different kind of V and F controls, the kit has to be moved to all different inspections or the parts have to be taken out of the kit and move individually to the inspections. The first option creates a longer lead-time because the inspections must be done sequential, where the current situation makes parallel possible. These longer lead times mean more items waiting, resulting in higher holding costs. The second option causes a temporarily disassembly of the kit. Disassembling a kit is needs to be prevented because if these parts are spread individually across the plant someone has to keep track of where these parts are, leading to extra handling costs.

The extra costs occurring due to the V and F inspections can be classified in Figure 6 as Thales specific problems. The reduction in receiving, checks and registering can be regarded as a reduction in order handling, since less order lines need to be handled.

In Figure 10, an overview is shown of the important steps of the inbound logistics. The left part column represents administrative processes and the right logistic processes. This figure is part of a larger figure, Figure 13.

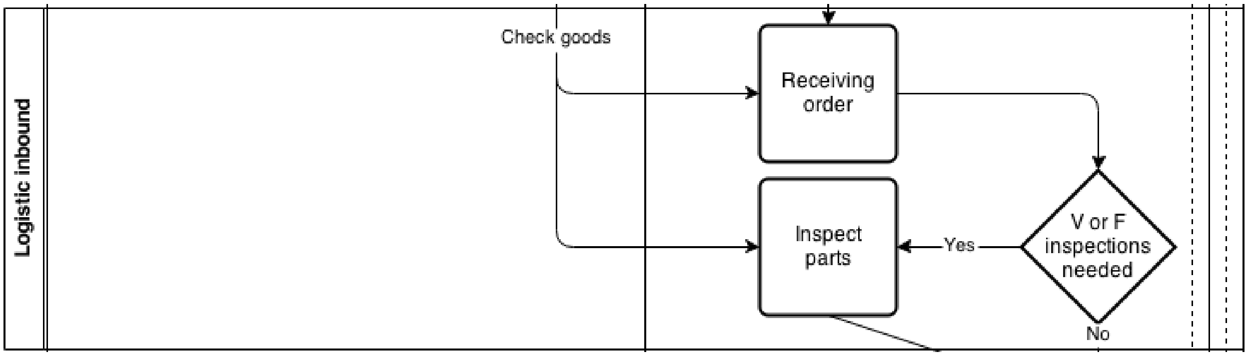

Figure 10 Overview of the important steps regarding outsourced kitting of the inbound logistics

3.1.6. Warehouse

When the parts are checked and registered, they are stored in the warehouse. The parts stay at the warehouse until the pickers receive an order from the final assembly to collect them. A pick order consists of multiple items and is used to form a kit. This picking is done based on picker to item. When outsourcing the kitting process, less picking and storing operations are needed since parts are already in a kit. Yet a kit does need more space than an individual part. If it can fit on a pallet, then size is not a problem. There is even room for items of XXX cm by XXX cm. Yet it is questionable if a kit should have dimensions larger than a pallet. The benefit of taking a pallet size as maximum size of a kit is that the pallet size is a European standard. Therefore, it is easy to move for a forklift and many locations are made fit for movement and storage of pallets. The warehouse has currently a capacity of XXX pallets.

Some parts have SH-codes (Special Handling code). These codes indicate that a part needs to be handled different due to certain properties. For outsourced kitting, some of these SH-codes have to be taken into account. They can roughly be divided in four categories. The first considers administrative SH-codes. These codes for example state that a part is export licensed or that a leaflet should be included. Therefore documents must be able to accompany a kit and there must be a system that is able to keep track of export licenced parts. The second considers products that need extra attention when storing, for example that products cannot be exposed to water or electro static discharges. Kits with these items need extra attention in handling or storing them. The products that can be kept in storage for a limited time due to for example degradation are the third category. If such a product is present in a kit, then the kit gets a restriction in how far it can be ordered in advance. The last category involves lasers and products with beryllium. On these rest some special legislation and requires special attention.

The capacity of the warehouse is according to Figure 6 less needed. The outsourced kits are replacing the parts, leading to a reduction in the required capacity. Since the supplier does a part of the kitting, the pickers in the warehouse need to perform less picks. The difference in pick activities can be used to calculate the reduction of non-value adding activity. There is also a reduction in the order handling. Since parts are received in kits, they do not have to be stored individually, leading to a reduction in order handling. The special handlings on the other hand can create extra costs. The special handlings can lead to extra costs for tracing the special handling back to a part or the exception management if there is a problem with a part that has a certain SH-code. The costs created by the special handlings are regarding Figure 6 IT costs.

In Figure 11, an overview is shown of the important steps of the warehouse. The left part column represents administrative processes and the right logistic processes. This figure is part of a larger figure, Figure 13.

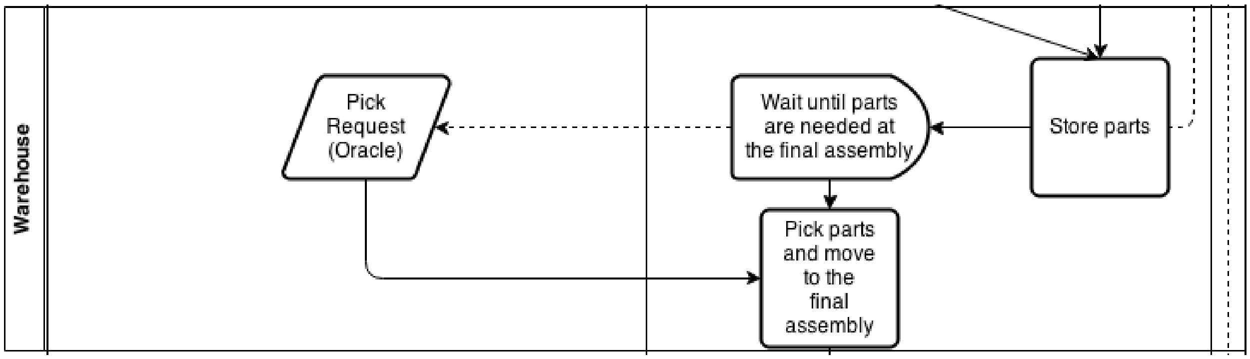

Figure 11 Overview of the important steps regarding outsourced kitting of the warehouse

3.1.7. Final assembly

The final assembly is responsible for assembling all components. Since final assembly already works with kits, there are not many changes for the final assembly. Yet an increase for the requirement of shop floor space can occur. A kit currently contains one assembly step. Including more assembly steps results in an increase in the usage of shop floor space. The only restriction the final assembly has concerning the floor requirements is that there are only parts on the floor that are needed are on the floor. This restriction does not allow more parts on the floor than that there currently are. So a kit, outsourced or not, can only be used for one assembly step.

The greatest concerns of final assembly regarding outsourced kitting are late deliveries of kits, an incomplete kit at the assembly or a kit with a defect part. When a part is too late or is missing/broken, they cannot continue their work. Currently they solve this problem by looking in the warehouse for the parts if these parts are kept on stock. If these problems happen with parts that are currently not kept on stock, it cannot be solved by using the stock in the warehouse. Regarding outsourced kitting, not much change for these parts. Yet if a kit supplies parts for multiple assembly steps, the chance on delay increases. Outsourced kits with only parts for one assembly step always have to wait until all parts are ready, otherwise the assembly cannot start. When including multiple assembly steps into a kit, parts for one assembly step could be ready, while parts of other assembly steps are delayed, resulting in extra delay. As stated earlier, the final assembly only wants to have parts on the floor that are needed on that moment. Therefore, a kit cannot consist of multiple assembly steps. If delay in parts that are currently not kept on stock occur, then these parts do not create more delay than they currently cause.

The delays described in this section are delays caused by missing/broken parts and late deliveries of parts. These delays only causes extra delay if they are currently kept on stock, since the stock currently used as buffer against these phenomena's. These delays are comparable with the delays described in Figure 6.

In Figure 12, an overview is shown of the important steps of the final assembly. The left part column represents administrative processes and the right logistic processes. This figure is part of a larger figure, Figure 13.

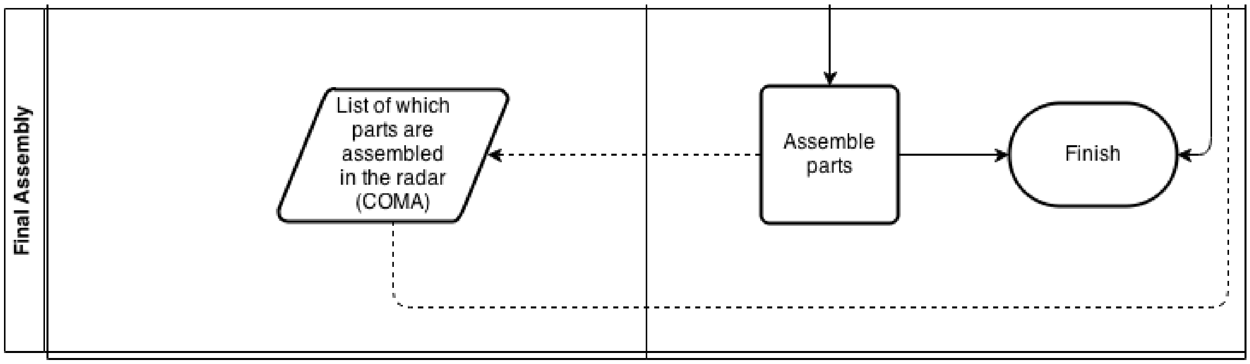

Figure 12 Overview of the important steps regarding outsourced kitting of the final assembly

3.1.8. Overview

This section constructs an overview of the processes discussed in the Sections 3.1.1 to 3.1.7. Figure 13 contains the overview of the regular flow and describes the relation between the processes and the input they need. It also contains the systems that are used. These systems are between the brackets. A larger version of Figure 13 can be found in Appendix B. Figure 14 gives an overview of the important documents regarding an order.

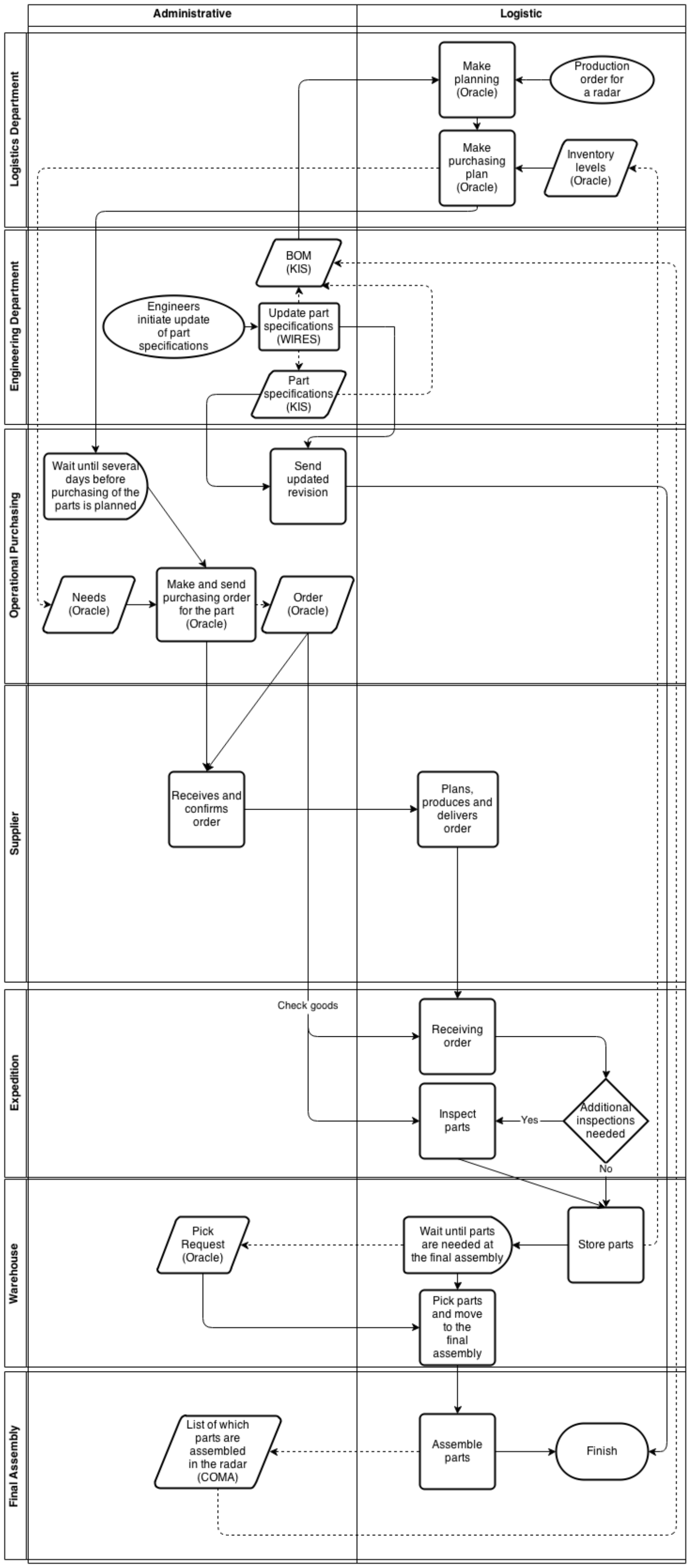

Figure 13 Overview of the regular radar production with responsible information systems

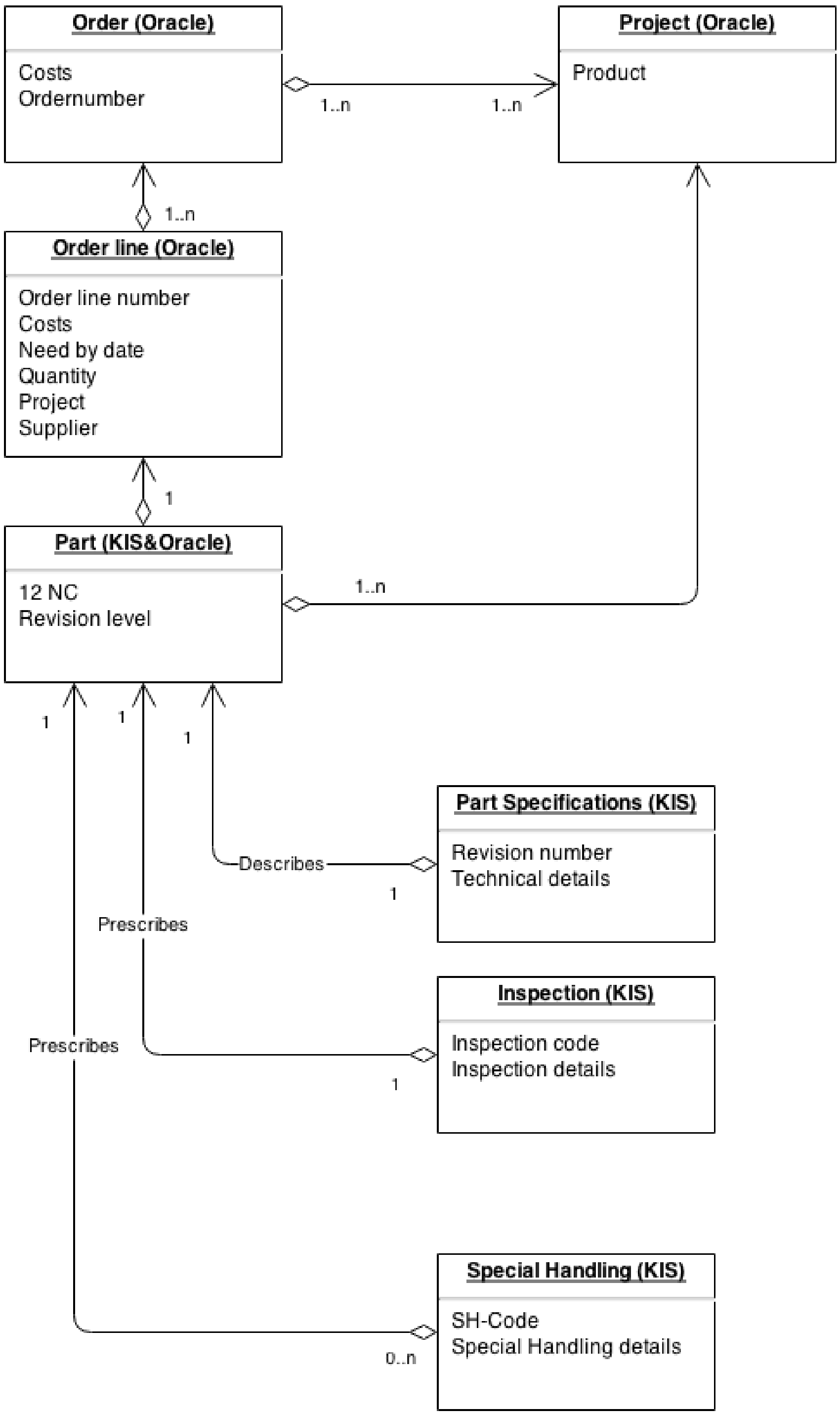

Figure 14 An overview of the relation between the different documents

3.2. Problems and parameters

Section 3.1 analysed the current situation of the important processes and searched for the parameters and problems regarding outsourced kitting using Figure 6. This section creates an overview of these parameters and problems by using the structure of Figure 6.

3.2.1. Reduction in order handling costs

The reduction in order handling is created by the reduction in the number of order lines and less physical handling of the parts. The reduction in the number of physical handling is the same amount as the order lines, because parts of an order line are kept together until it reaches the warehouse. To asses the difference between the current and the future situation, we need the difference in order lines. The reduction in order lines has impact on the purchasing department, the supplier, the logistic inbound and the warehouse. The purchasing department has fewer transfers of needs into order lines and receives fewer confirmations. The supplier receives less order lines and therefore has to confirm and plan less order lines. Subsequently inbound logistics receives less order lines and the warehouse has to store less order lines.

3.2.2. Cost reduction in a non-value adding activity

The cost reduction in a non-value adding activity is realised if the kitting activity of the supplier is cheaper than the activity at Thales. To measure the difference we need to know the extra costs the supplier gets due to kitting and the reduction in kitting costs at Thales. The reduction of kitting costs at Thales can be calculated using the reduction in picking activities. The extra costs of the supplier are based on if the supplier gets extra work. The supplier already has to pick these items, so does not receive extra costs due to the picking.

3.2.3. Reduction in storage costs

The reduction in storage costs is dependent on how much stock is affected by outsourced kitting. The stock that is affected is the stock of the parts that are currently kept on stock. This stock disappears and so results in a reduction in holding costs.

3.2.4. Costs due to assembly delay

The extra delay at the assembly can occur due to missing/broken parts that are currently kept on stock. If not kept currently on stock, the delay is the same, since there is currently no internal warehouse which can act as a buffer against these phenomena. The same holds for the delay caused by production/delivery delay of the parts. The delay caused by design changes do not create additional delay due to outsourced kitting, since it follows the same logic as production delay.

3.2.5. Costs due to problems specific to Thales' current processes

The V and F inspections create additional costs when outsourcing the kitting. Currently if a part needs such inspection, it can move there independently. If such part is present in a kit, the whole kit has to move to the inspection location and wait until the part is inspected. This leads to additional waiting time of the waiting parts and so creating extra holding costs.

3.2.6. Costs to make the IT suitable for outsourced kitting

Due to the current way of working of Thales, some extra costs can occur due to outsourced kitting. To order a kit, the kit must be defined in the BOM. With the current information systems, this is an expensive operation, since it has to be defined in the engineering environments. Extra costs are also created due to the design changes. Currently these design changes are communicated on part level and due to the current information systems communicating them on part level when outsourcing the kitting becomes difficult. If the changes are communicated on kit level, the supplier has to find out which part is changed and so resulting in extra work and corresponding costs. Special handlings have partially the same problems as the design changes, since these special handlings must be traceable to the product. Furthermore if something happens to a part with a special handling, additional exception management can be needed.

3.2.7. Excluded parameters

The coordination and information sharing gains are not relevant. The current delivery dates of the parts create the same coordination effects as the kit provides. The current initiatives regarding rolling forecast provide more information sharing than outsourced kitting. The presence of coordination equal to a kit and information sharing processes which provide more information than a kit, the coordination and information sharing effect of a kit does not result in a reduction of the costs.

3.2.8. Overview of the problems and parameters

With problems and parameters discussed, they can be linked to Figure 6. In Figure 15 we modified Figure 6 with the findings of this chapter. These findings can be used in the coming chapters to create the financial overview and find a solution for some of the cost factors.

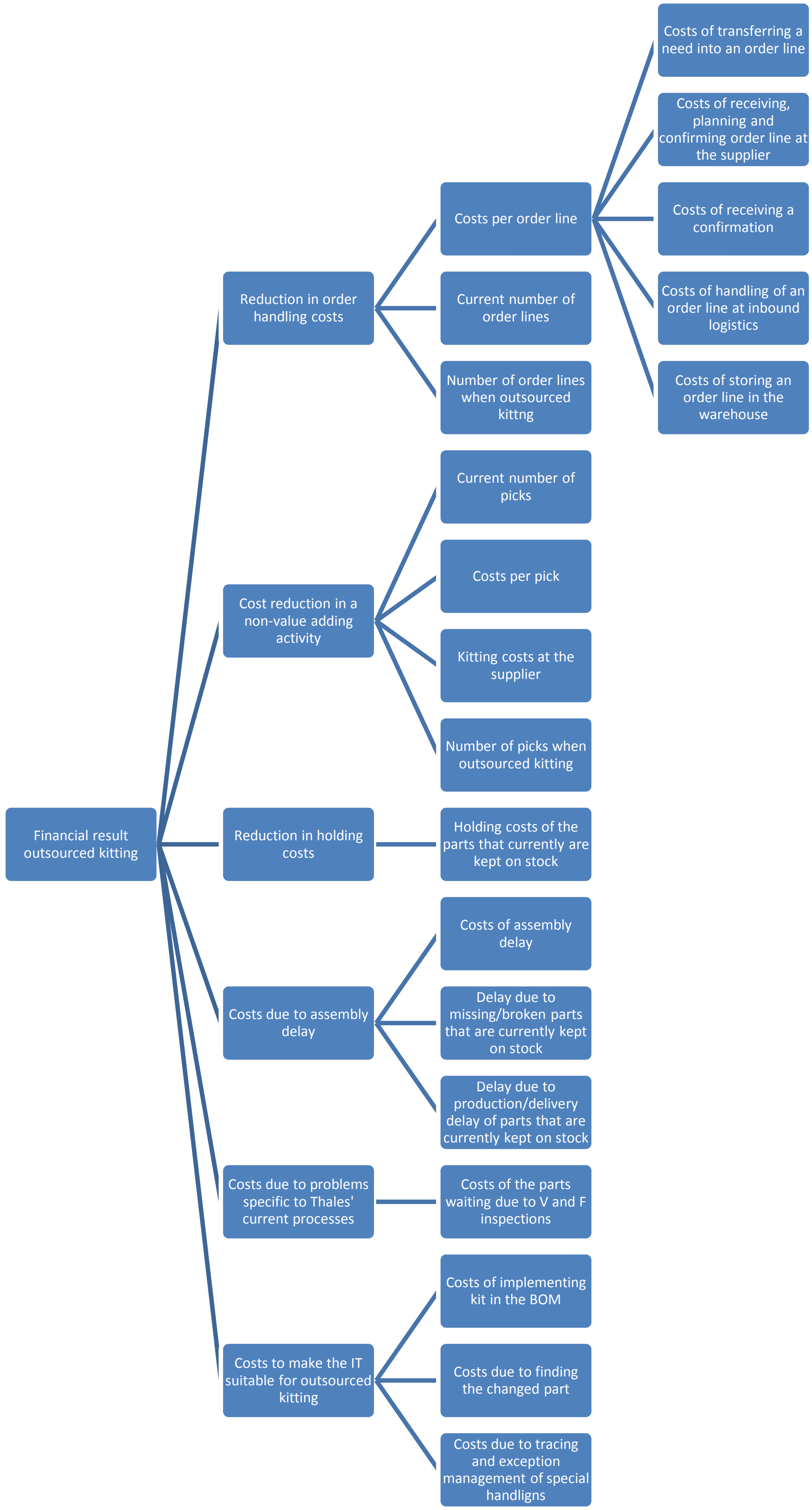

Figure 15 Overview to examine the link the found problems and parameters to the goal

3.3. Conclusion

This chapter discussed the current situation and the problems that these processes will face when Thales starts with outsourced kitting, answering the research question "*What are the problems in the current situation regarding outsourcing the kitting of parts from the same supplier?*" The following problems are defined as problems that can cause extra costs when outsourcing the kitting:

- Incomplete kits, because the assembly cannot start when not all parts are present and the part needs to be reordered.
- Inspections, since it would create a lot of movement and waiting of the parts.
- Late deliveries, since they can increase due to outsourced kitting.
- Design changes of parts, since the changed part must be traceable.
- Special handlings, since a part with a special handling must be traceable.
- The bill of material, since implementing a kit in the BOM is currently difficult
- Delay due to missing/broken parts that are currently kept on stock, since there is no internal buffer for these parts anymore.

These findings can be used in the next chapter to analyse if these effects can be minimized.

4. Design of the outsourced kitting process

This chapter investigates how the processes should be organized when Thales decides to start with outsourced kitting, answering the research question “*What are good alternatives for the problems caused by outsourcing the kitting of parts from the same supplier?”* This chapter starts with a redesign of some processes to minimize some negative effects of outsourced kitting. Thereafter, we analyse the new design using Figure 15.

4.1. Process design

Figure 15 describes some issues in the current situation which will lead to an increase in costs when outsourcing the kitting. This section formulates alternatives to prevent these costs, if possible. This section also addresses some minor issues that could improve the overall efficiency of outsourced kitting. Validation of these ideas is done by discussing the ideas with the responsible actors.

4.1.1. Logistics department

Currently it is difficult to support outsourced kitting. The current BOM is based on the structure as the engineers designed it. Yet changes that could be beneficial for the assembly are not implemented in this BOM. These changes need an official change request and these logistic requests are not honoured due to the costs. Since the BOM is input for ERP for the ordering process, the kit has to be introduced in the BOM. Therefore, outsourced kitting can become problematic. Yet Thales currently is implementing a system that can facilitate these changes, called Windchill. It is able to create a so-called engineering BOM (E-BOM), which is the same as the current BOM, and a manufacturing BOM (M-BOM). The M-BOM is a BOM linked to the E-BOM, but the structure can be changed for logistic issues. This system can be used to facilitate outsourced kitting. This system is also built as a communication system with the supplier on technical details. Information about the kit can easily be communicated through this system.

The logistic department, which does the planning, should together with the final assembly design the outsourced kits. The final assembly is needed for insight on how a kit can support the assembly. The logistic department is needed, since they manage the internal logistics and are responsible for the usage of kits in these processes. If the ERP can work with the kits, then there are no problems with these processes. The ERP needs input from the M-BOM to perform this task. The M-BOM is under control of the logistics department. Therefore, the logistics department is needed to facilitate implementation of kits in the M-BOM. Besides as stated in Section 2, it could be that ordering parts in an order quantity instead of a kit could be cheaper. This analysis must also be done by the logistic department.

Defining the kit in the BOM was one of cost increases in Figure 15. Although the kit still needs to be defined in the M-BOM, it requires less work than currently and so reducing the costs for implementing outsourced kitting.

4.1.2. Procurement

In Section 3.1.3 we stated that tactical procurement is responsible for the contracts. An outsourced kit can have some other complications than a part, sub-assembly or module, such as a missing part. Besides extra complications, the supplier can bill extra costs for kitting the items. If the decision is made that a supplier does the kitting, then the contract with that supplier needs to be changed. Although we are not going to discuss the details of contracts, these points should be covered in the contract:

- Incomplete kit

- Defect part in the kit
- Extra costs due to outsourced kitting
- Production delay of a part in the outsourced kit at the supplier

To reduce movement of goods, in the situation of an incomplete kit and a defect part we advise to create a clause that only the missing/defect goods are moved. In case of the delay the kit should stay at the supplier, since the assembly only can start when all parts are present. Moving the kit earlier only creates extra movement and exception management. Including a penalty clause on incompleteness, a defect part of delay will cover three of the four points.

The change for operational purchasers concerning outsourced kitting is that they order kits instead of individual parts. Concerning ordering, it does not make a difference if a kit or a part is ordered if the systems are able to provide the right information. Yet ordering a kit requires fewer man-hours. Windchill is able to provide the information on the kits and parts. Therefore, there is no extra work needed to communicate information regarding kits.

Changes in product configuration are still occurring and communicating these changes will remain an important activity of the operational purchaser. These changes can be communicated on part level, since the kit is only defined in the M-BOM. By defining the kit in the M-BOM, the kit does not need to have specifications and so the part becomes the highest hierarchy on which changes occur.

In Figure 15 one of the cost increases is caused by the increased difficulty of communication of the design changes in parts. By defining the kit in the M-BOM, the communication of these changes does not change. Thus by defining the kit in the M-BOM, no extra costs have to be made to communicate the design changes.

4.1.3. Order handling at supplier

If Thales starts outsourced kitting with a supplier, it is important that a supplier knows which parts must be present in a kit. As stated earlier, Windchill would be able to provide this information by sending it in a BOM structure to the ERP system.

As discussed in Sections 3.1.5 and 3.2, inspecting parts that need a visual (V) or functional (F) inspection can become troublesome when present in a kit. It would be beneficial to do these inspections at the supplier if possible. If the supplier is able to do the inspections, the kit has not to move to every inspection. Another advantage is that when a part does not pass the inspection, the supplier can solve it quicker. If the error was detected at Thales, fixing the problem requires more handling since the supplier needs to be notified and the part must be sent back or shredded. If these inspections can be done at the supplier, it would reduce costs and makes outsourced kitting easier. The only concern is that the quality of these inspections does not meet the quality standards Thales demands. If a supplier does not meet the quality standard, Thales should focus on improving the inspections together with the supplier. The supplier gets extra costs by doing these inspections, yet Thales reduces its costs by outsourcing them. Thales could use these savings to pay the supplier for the inspections.

Bryznér and Johansson (Brynzér & Johansson, 1995) stated in their research that a kit could support the picking operation by providing extra information. If a kit is well designed, the kit itself provides information on which parts should be included. Therefore, the kit makes it clearer if a part is missing and so reducing the chance that parts are missing or kits are incomplete. However, a supplier can have extra handling due to the kitting and so bill extra costs.

If the V and F inspections are outsourced to the supplier, the costs that are created when parts are waiting on other parts that need these inspections disappear. By outsourcing the V and F inspections, the costs in Figure 15 regarding the waiting time are not present anymore. Eliminating the extra costs regarding the kitting activities the supplier gets, is not possible, since they are inherent to outsourced kitting. It could be that the supplier does not have extra costs, but that only occurs when supplier does not to perform additional work compared to the current situation.

4.1.4. Inbound logistics

When kits arrive at inbound logistics, the employees of this department must be able to identify a kit. An easy solution for the correct identification is by giving kits a distinctive code. Parts currently are identified with a code consisting of 12 digits, the so-called 12 NC. Thales sometimes uses the first few digits of this code to identify the type of goods. A kit could also have its own distinctive digits such that it is recognizable as a kit.

In Section 4.1.3 we stated that the supplier should do the V and F inspections. Even without outsourced kitting, this reduces movement of goods and therefore costs. The supplier does not have extra costs by doing, since the work that must be done is the same. Outsourcing these inspections will lead to a cost reduction. When outsourcing the kitting, these inspections can become bothersome, as described in Sections 3.1.5 and 3.2. When outsourcing the kitting, these inspections must be outsourced.

4.1.5. Warehouse

If the supplier does a part of the kitting, it leads to a reduction in pick activities at the warehouse. Yet as long as the supplier does not deliver all the parts needed for an assembly step, parts still must be picked from the warehouse. From an assembly perspective, it would be beneficial if all parts for an assembly step are in one kit. Therefore, the parts of other suppliers should be added to the kit. These parts are picked in the same way as they currently are. Outsourced kitting also leads to a reduction in the number of items that needs to be stored. Since parts are combined in an outsourced kit, only the kit needs to be stored, which requires less handling.

Another change is the reduction in warehouse capacity needed. Since some parts are ordered in quantities larger than there is needed for an assembly step, ordering them in kits could lead to a reduction in holding costs. Since the kit is not kept on stock, the parts in the kit either are not kept on stock. This could lead to reduction in holding costs. However, it is likely that the supplier has to keep the items on stock to minimize production costs or to ensure on-time deliveries.

As discussed in Sections 3.1.6 and 3.2, special handlings can become a problem. Fortunately, the information systems are able to link special handlings to a higher hierarchy. It can show in the case of export-licenced products that it contains an item that has an export-license. Making a kit recognizable as a kit, should make it clear to employees dealing with a kit that the special handling concerns a certain part in the kit and not the kit itself. Using the original packaging and numbering makes it able for the employee to trace the special handling back to the part. This numbering could for example be shown on the kit packaging. Although special handlings do not seem to cause any trouble regarding outsourced kitting, we advise to exclude parts with an export license special handling. It is questionable if the required tracking for parts with an export licence can be delivered by the information systems when these parts are in an outsourced kit. To prevent possible problems and corresponding costs, we advise to exclude these items.

In the research of Limère et al. (Limère, Van Landeghem, Goetschalckx, El-Houssaine, & McGinnis, 2012), research is done on the question if items should be line-stocked or kitted. Due to the low volume and product relatedness of parts, many parts are not suitable for line-stocking. Besides, there is not much floor space for parts at the final assembly. So if a part is used in multiple products, is used in a relatively high volume and does not take much floor space, the option of line-stocking this item should be compared to kitting that part in a kit, outsourced or not. When line-stocking, options as vendor managed inventory are possible.

The M-BOM provides, combined with usage of the original packaging and coding, enough information to trace the special handlings to the products. Regarding Figure 15, the costs created by the special handlings are not relevant anymore. It is also questionable if there is a cost reduction on the holding costs. Although Thales holdings costs will reduce, these costs could increase for the supplier. This increase can be caused by for example optimal production quantities.

4.1.6. Final assembly

At the final assembly the kit is used. The final assembly does not have much storage space on the work floor, so they do not want any parts on the floor that are not needed for that assembly step. Therefore a kit can only contain items for the same assembly step. Some items are larger than a euro pallet, such as a hull. Due to their size, which makes them recognizable, including or excluding them in a kit does not make any difference for the assembly operators. The kit on the other hand becomes difficult to move, which causes more difficulties in preceding departments. These large parts are probably most of the time the base on which the other parts of the kit are mounted. This creates a large kit on the floor, which is most of the time for a large part empty. Since the space on the shop floor is scarce, this is a waste of space. Therefore, parts larger than a pallet must not be included in an outsourced kit.

Chapter 2 discussed the kitting literature. The research of Hanson and Brolin (Hanson & Brolin, 2013) stated that kits must have a structured design to be effective. This structure depends on the handlings that need to be done at the assembly. The current kit design would be applicable. However, Thales does not have a structure in its kits. Designing this structure could be done by the final assembly department. They should also be responsible to check if the kit design is still up-to-date. If a kit is not up-to-date it must be updated to be effective as stated by Medbo (Medbo, 2003). A part of the design knowledge will be present in the M-BOM. Since the M-BOM is designed to facilitate the assembly process, it contains the items that are needed for an assembly step. The other part of the knowledge is the assembly experience. This experience can be used for a more detailed level of the kit design. The structure of the kit must always be designed, regardless of in-house or outsourced kitting. Therefore, designing the structure for the kit does not result in extra costs regarding outsourced kitting.

According to Figure 15, delay costs at the final assembly increase due to outsourced kitting. Parts that are kept on stock can be taken from the warehouse in the current situation and so preventing delay. If those parts are in an outsourced kit, they are not kept on stock at Thales anymore and this buffer against production delay disappears. It is likely that the supplier will produce in higher quantities than there are needed in a kit to minimize production costs, which results in a stock. This stock can buffer against the production/delivery delays. Thales could demand from its supplier that it uses a stock policy that is comparable with the current stock policy. This would not create extra costs from supply chain perspective, since the stock is kept in another place. In the worst case the costs are moved from Thales to the supplier. Since the supplier keeps a stock, the gains on the stock reduction are none. The costs of delay are probably higher, since it includes lost work hours at the final assembly and contractual penalties on a late delivery of a radar system. Trading the benefit of reduced stock against the extra delay costs will maximize the benefits of outsourced kitting.

The other factor causing delay costs, incomplete kits, is not tackled by placing a stock at the supplier. The process of getting the missing part cannot be used anymore, since kits are ordered. On the other hand, it is likely that the occurrence of missing parts is reduced. If a kit is designed well, it supports the picking activity (Brynzér & Johansson, 1995). If it supports the picking activity, a mistake is less likely. Therefore, the chance that the supplier forgets a part is less. If a part is really missing, the chance is that due to the support the kit provides the problem is detected earlier. Kits are sent when they are complete. An incomplete kit only arrives at Thales when a part is broken, resulting in an incomplete kit, or the kit somehow manages to bypass all the controls to prevent missing parts. A solution could be to keep a small stock at Thales, yet this creates also extra costs. Since the supplier keeps these items on stock, accepting the delay could be cheaper. The delay caused is in these cases only the delivery time, which can be very low if the supplier is located nearby. Another reason not to keep a small stock is that the stock is moved to the supplier. Keeping stock as buffer at two locations is counter intuitive, which could make implementing it bothersome. Cannibalization is also an option. In principle, cannibalization is unwanted, since the problem is only moved from one kit to another. Therefore the warehouse should guard the kits against cannibalization. The costs regarding the delay are not the only costs for missing and broken parts. They also have to be reordered, which creates additional costs.

If a kit is incomplete and the part is not on stock, the kit needs a place can wait until the missing part arrives. This could be done in the warehouse if detected before it arrives at the final assembly. Yet putting them somewhere in warehouse makes it not clear if there is something wrong with the kit. They need to be stored at a place such that it is recognizable that there is something wrong with the kit. A suitable location could be between defect parts or dedicated shelf. Such dedicated shelf would cost some money, but since the parts in the kit normally also had to wait on that part in the warehouse, the costs stay the same. If discovered on the final assembly it can stay on the floor, since it is in an area that is allocated for the system it belongs to. If the production of a system is on hold and there is a kit present, it is clear that there is something wrong with that kit.

Comparing the findings of this section with Figure 15, the production/delivery delay and the reduction on holding costs cancel each other. The only factor left to influence the delay is the delay caused by the missing parts. Yet we have to include reordering costs, the corresponding delay costs and the alternative to accept the delay, the costs of keeping a small stock of these parts.

4.1.7. Overview

This section constructs an overview of the ideas discussed in the Sections 4.1.1 to 4.1.6. Figure 16 contains the restrictions on the process and kit design for outsourced kitting. In Figure 17 an overview is created on how the outsourced kit is defined in the information systems.

Kit design

- Kit design must support assembly process
- Kit design should be kept up to date
- A kit must not be larger than a pallet
- Kit must be recognizable as a kit (own kit code in the ERP and on the kit itself)
- Kit design should provide information for the picking operation
- Kit must incorporate space for parts from other suppliers
- Do not include parts with special with export licence
- Use original packaging of the parts

Process design

- M-BOM in which kits can be defined
- Outsource inspections to supplier
- Supplier keeps a stock policy which is equal to or better than Thales stock policy

Figure 16 Overview of the restrictions of the kit and process design for outsourced kitting

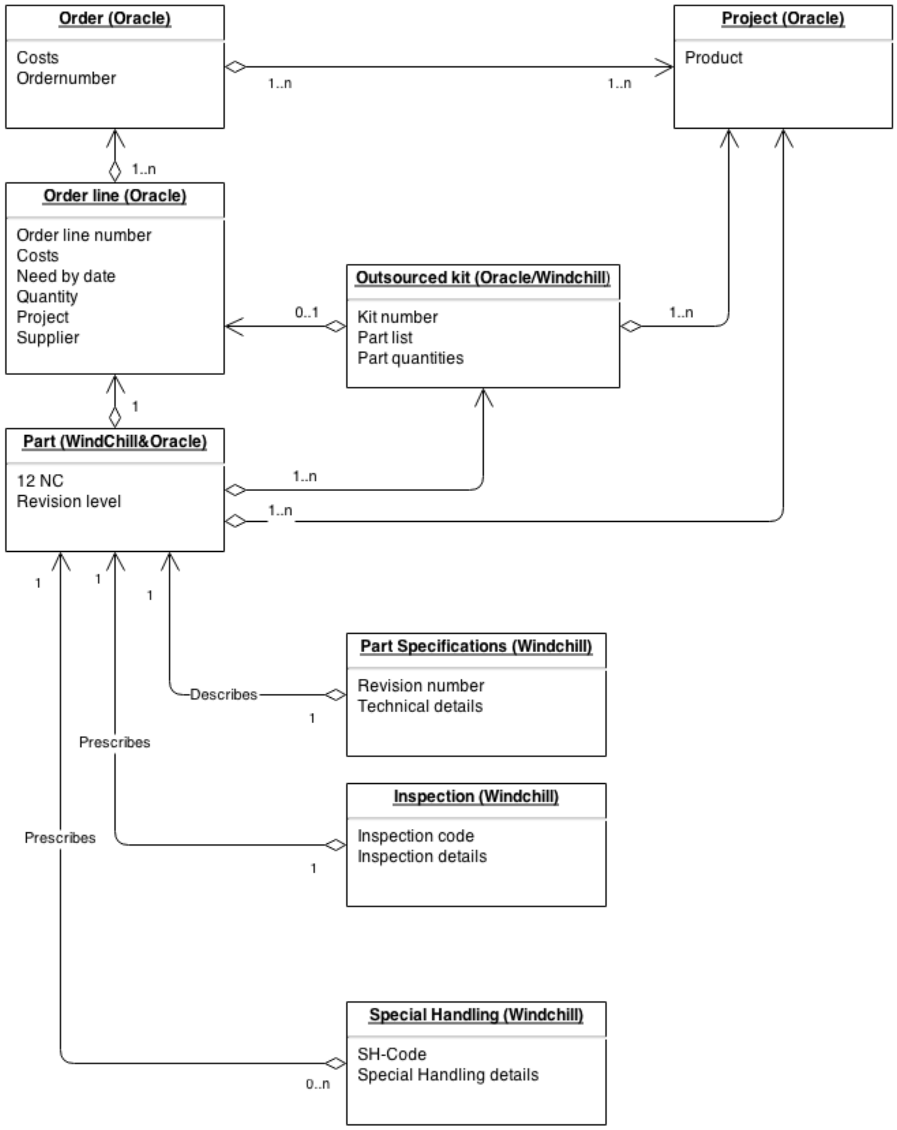

Figure 17 An overview of the relation between the different documents in the new situation

4.2. Cost parameters after solutions

The discussed solutions have impact on the cost parameters described in Figure 15. Regarding the Thales specific costs, the costs regarding the inspections are not increasing compared to the current situation, which makes them irrelevant. The tracing of the special handlings and design changes do not become more difficult compared to the current situation, which also makes them irrelevant. The implementation of the kit in the BOM becomes a lot easier due to Windchill, yet the kit still needs to be defined in the BOM. Another change regarding Figure 15 is the disappearance of the costs regarding production/delivery delay and benefits of reduced holding costs. If the supplier keeps a similar stock policy, the production/ delivery delay will not increase compared to the current situation. However, extra holding costs can occur when using a small stock to buffer against delay caused by missing/broken parts. Applying these changes on Figure 15, results in Figure 18.

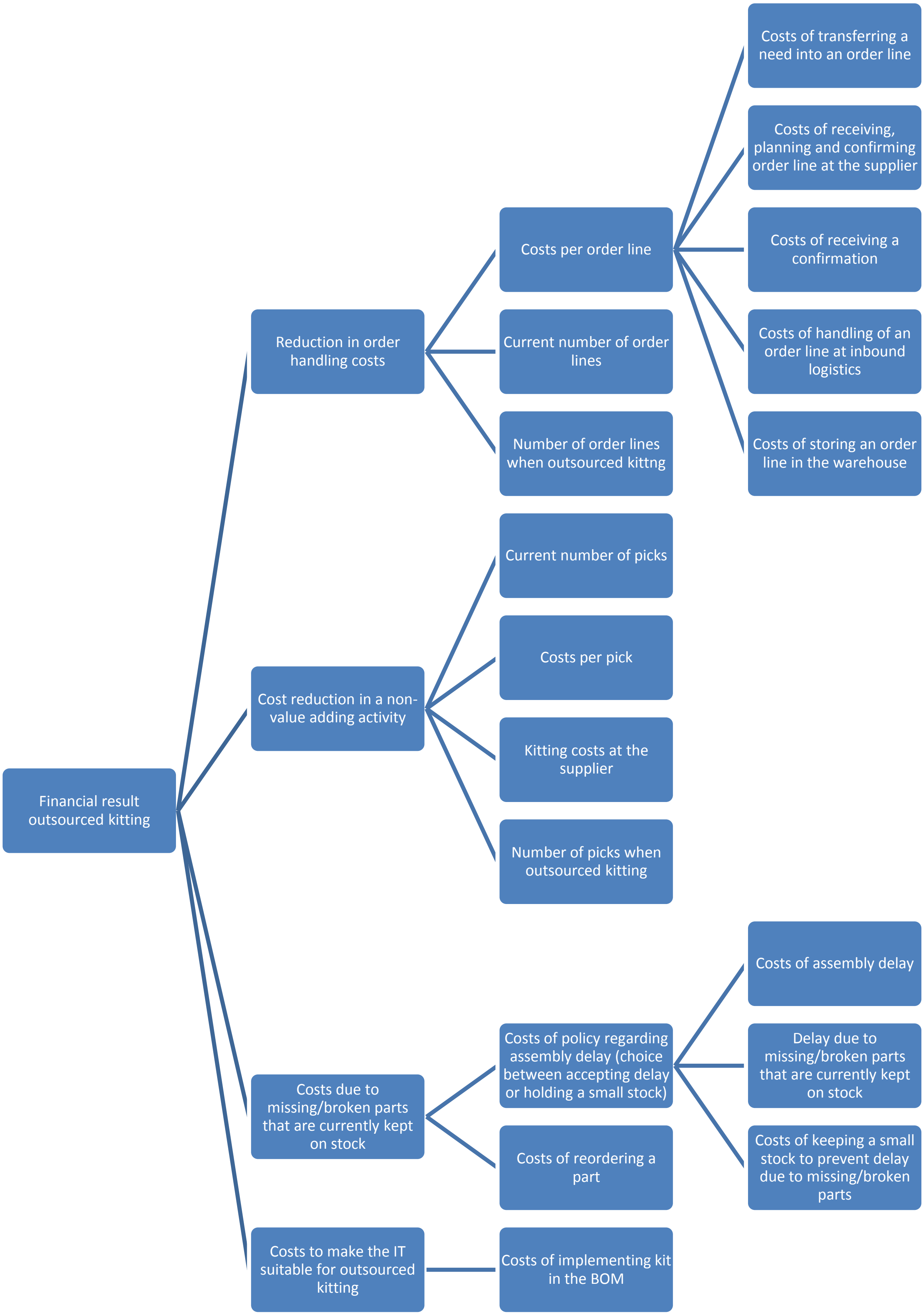

Figure 18 Cost factors regarding outsourced kitting

4.3. Conclusion

This chapter addressed the research question "*What are good alternatives for the problems caused by outsourcing the kitting of parts from the same supplier?*" Outsourced kitting requires some changes in the current process. The following changes must be done when outsourcing the kitting:

- The M-BOM must be present such that the kits can be defined
- Outsource V and F inspections to supplier to prevent movements of kits.
- Supplier keeps a stock policy which is equal to or better regarding the fill rate than Thales stock policy to prevent production/delivery delay.

Besides changes in the processes, the kit must meet some requirements. Its design must facilitate the pick and assembly operations such that it can improve these processes. Subsequently this design must be kept up to date. The kits must have some distinctive features, such that it and its parts are recognized. The kit should have its own number and the parts must be kept in their original packaging. Kits must not incorporate parts that are difficult to kit due to their size or the special handling they require. As last, the kit should have space for other parts of suppliers such that it can move as one kit to the final assembly.

5. Cost analysis

This chapter analyses the costs and benefits of outsourced kitting and so answering the research question *“What are the savings resulting from outsourcing the kitting of parts from the same supplier?”* We start by constructing the cost function using Figure 18. Subsequently we create a method to examine if a part should be outsourced kitted or not. This chapter concludes by using our case supplier, Supplier-X, and case radar, the System-X, to assess the possible gains of outsourced kitting.

5.1. Defining the cost function

This section constructs the cost function to assess the profitability of outsourced kitting for the whole supply chain. It starts with an overview of factors that could be relevant, but are not included. This section continues with formulating formulas per cost factor described in Figure 18. It ends by combining the earlier defined formulas and making cost functions for Thales and the supplier.

5.1.1. Excluded factors

We do not take quantity discounts in account. These discounts are only achieved when parts for two or more radars are ordered simultaneous or in a short time span. Outsourced kitting also requires new agreements on the discounts. The costs regarding the financial administration are not taken into account, since the handling is done on invoice level and not order line level. We also do not take transportation costs into account. Since the parts are needed for the same assembly step, Thales provides its supplier the same delivery dates for these parts. This means that they are shipped together under normal circumstances. If a part is not on-time completed, the supplier has to decide if it is cheaper to hold the other parts or to send them beforehand. Besides, if the supplier delivers many parts to Thales, a part that is finished too late can ride along with another transport. The same reasons can be used for internal transport. We assume that the picking costs of a kit are equal to the picking costs of one of its parts, since the logistic department estimates that the time would be the same. We did not take yield of parts into account. Yield is the most applicable on small and high volume parts, such as bolts, since they can go missing much easier. We assume that when allocating these parts to a system this yield factor is taken into account and are already included in the in-house kit. We also assume that the parts are not ordered in quantities anymore.

5.1.2. Cost formula’s per factor

Figure 18 defines four cost factors, namely reduction in order handling costs, cost reduction in a non-value adding activity, increased costs due to missing/broken parts that are currently kept on stock and increased costs to make the IT suitable for outsourced kitting. To formulate these cost formulas, we discuss these factors one by one.

5.1.2.1. Reduction in order handling costs

According to Figure 18, the parameters influencing the reduction in order handling costs are the current and future number of order lines and the costs per order line. The costs per order line consist of the costs of transferring a need into an order line, the costs of receiving, planning and confirming an order line at the supplier, the costs of receiving a confirmation of an order line, the costs of handling of an order line at inbound logistics and the costs of storing an order line in the warehouse. Calculating the reduction can be done by taking the difference in order lines and multiply this by the costs per order lines. For the parts that are not kept on stock calculating the difference is not difficult. If such a part goes into a kit, it reduces one order line every time a kit is ordered. For parts that are kept on stock, one order line in the current situation can be to supply several kits. If part i currently have an order quantity of Q_i, is used in a kit with the quantity N_i and this kit it is used in has a demand Z per for example a year, then by multiplying Z with N_i results in the total demand for part i in a year. Dividing the total demand by Q_i results in the total number of order lines for part i in a year. By summing all the order lines of the parts that are in the outsourced kit, the current number of order lines can be calculated. This also holds for parts that are not kept on stock, since N_i equals Q_i in these cases. In the situation of outsourced kitting, only the kits need to be ordered. If the demand is Z, then the number of kits that are ordered equals Z. The number of order lines also equals Z. Subtracting these order lines from the current order lines results in the order lines saved per year. Dividing these savings by the demand of kits per year, results in the savings on order lines per kit. Let's denote S_A as the savings on order costs per kit, A as the costs per order line and M as the number of parts in the kit, then savings can be expressed as described in Equation 5.1.Rewriting this equation results in Equation 5.2 and Equation 5.3.

$$S_A = \frac{A * \sum_{i=1}^{M} \frac{Z * N_i}{Q_i} - Z * A}{Z} \qquad (5.1)$$

$$S_A = \frac{A * Z * \left(\sum_{i=1}^{M} \frac{N_i}{Q_i} - 1\right)}{Z} \qquad (5.2)$$

$$S_A = A * \left(\sum_{i=1}^{M} \frac{N_i}{Q_i} - 1\right) \qquad (5.3)$$

To illustrate Equation 5.3, let's take a kit consisting of three parts. The third part is currently ordered in a quantity of 4, so Q_i equals 4, and only one part is used in the kit, so N_i equals 1. The other two parts are currently ordered in a quantity of one and so is completely used in the kit. The summation gives 2.25 as answer (1+1+ ¼). Subtracting the order line for the kit, results in a saving of 1.25 order lines and so saving 1.25*A.

5.1.2.2. Cost reduction in a non-value adding activity

According to Figure 18, the parameters influencing the cost reduction in a non-value adding activity are the current number of picks, the number of picks when outsourcing the kitting, the costs per pick and the kitting costs at the supplier. Subtracting the number of picks when outsourcing the kitting from the current number of picks, results in the picks saved at Thales. Since the parts that are still kitted internally do not cause a difference, only the parts, of which the kitting is outsourced, are relevant. If there are M different types of parts in a kit, then M less picking operations are needed at Thales. Yet the kit itself must be picked, so the total saved picking operations is M-1. Multiplying this with the picking costs results in the savings on the non-value adding activity. However, the supplier could end up with extra costs due to the outsourcing of the kitting. These costs need to be subtracted to calculate the reduction in this non-value adding activity. Let G denote the picking costs, K the costs the supplier gets per kit and S_P as the savings regarding a non-value adding activity, then the reduction in costs can be expressed as described in Equation 5.4.

$$S_P = (M - 1) * G - K \qquad (5.4)$$

To illustrate Equation 5.4, let's take the earlier used example. We got three different types of parts, so the number of picks saved is 2 (3-1). This results in a saving of 2*G-K.

5.1.2.3. *Increased costs due to missing/broken parts that are currently kept on stock*

According to Figure 18, the parameters influencing costs due to missing/broken parts that are currently kept on stock are the costs for reordering a part and the costs of the policy regarding assembly delay. The costs regarding assembly delay caused by missing/broken parts, consists of costs of assembly delay, delay due to missing/broken parts that are currently kept on stock and costs of keeping a small stock to prevent delay due to missing/broken parts. A part does not break or goes missing every time it's ordered. On the other hand these costs need to be included. By taking the chance that a part goes missing/broken and multiplying it with the costs, these costs can be calculated on kit level. If a part goes missing or is broken, it must be reordered. In this case the costs of reordering the part must be multiplied with the chance that a part goes missing/broken to get the costs per kit. We assume that the order costs and the reorder costs are the same, since handling does not differ much. Let p_i denote the chance part i is missing, A the order costs and $C_{A,i}$ as the costs per reordering part i per kit, then the reorder costs per kit can be expressed as formulated in Equation 5.5.

$$C_{A,i} = p_i * A \qquad (5.5)$$

To illustrate Equation 5.5, let's assume that a certain part is missing or broken 5% of the time. To incorporate these costs in the financial overview of a kit, 0.05*A must be subtracted from the gains.

One possible way to deal with the delay caused by missing/broken parts which currently can be replaced by parts from the stock is by accepting the delay. To calculate the costs of the assembly delay, the duration of the delay and the costs of the delay are needed. Since the supplier uses the same stock policy as Thales, the created delay is only the delay that is caused by shipping the item from the supplier's warehouse to Thales. Multiplying this time with the costs of delay per time unit (for example hours) and chance that a missing/broken part occurs, results in the costs for assembly delay per kit. Let T denote as the delivery time, W as the costs per time unit of assembly delay and $C_{W,i}$ as the delay costs for part i, then the assembly delay costs per kit can be expressed as formulated in Equation 5.6.

$$C_{W,i} = p_i * T * W \qquad (5.6)$$

To illustrate Equation 5.6, let's assume that the chance that the part is missing/broken is 5%, the costs of delay is €85 per hour and the delivery time is 5 hours then the costs are €21.25.

Another possible way to deal with the delay caused by missing/broken parts which currently can be replaced by parts from the stock is to keep a small stock. To calculate the costs of this stock, the size of the stock and the holding costs are needed. The stock must be large enough to supply an initial demand. For the initial demand, the quantity of the part per kit, N_i, can be taken. If this quantity equals one, if that part goes broken or is missing, that quantity needs to be restored. If the quantity in the kit is larger than one, it can happen that only a part of the quantity is missing/broken. Keeping the whole quantity on stock is a bit of waste in the situations. Yet in the worst case scenario, the whole quantity is missing/broken and the buffer must be able to handle this quantity. Taking the whole quantity as buffer provides back-up against these situations. The demand during the lead time to replenish the stock is not taken in account. Since these parts are kept on stock at the supplier, these parts can be delivered in a short time window. Taking in account the low production volume of Thales, it results in that the stock is already been replenished before potential new demand can occur. Because the buffer is most of the time equal to its largest size and the chance the buffer is not used, modelling the stock as not used creates a good estimation of the costs. Creating a more accurate function is possible, but it requires data on the chances a part is broken or missing. Although this data can be collected over time, the holding costs of these parts relatively low compared to the other cost factors. Taking a few days not into account, will not result in a great difference. Estimating these costs in this manner does not harm the overall function. If a part is present in multiple kits, the largest quantity that present in these kits, must be taken as buffer. To share the costs of this stock evenly, the costs must be shared among the kits that use this stock. Sharing these costs can be achieved by dividing the costs by the total number of kits during a certain time period (year for example) the part is present in. To calculate the costs per kit, the largest quantity a part is present in a kit must be taken as stock. This quantity must be multiplied with the holding costs to calculate the holding costs per period. Dividing these holding costs by the demand per period of kits in which this part is present, results in the costs of this stock per kit. Let $N_{max,i}$ denote the maximum quantity of part i that goes into a kit, D_i the demand per year of kits that contain part I, H_i the holding costs per year of part i and $C_{H,i}$ as the costs for holding a stock, then the stock costs to buffer against missing/broken parts that currently kept on stock can be expressed as formulated in Equation 5.7.

$$C_{H,i} = \frac{N_{max,i} * H_i}{D_i} \tag{5.7}$$

To illustrate Equation 5.7, let's assume that part i maximum quantity in a kit equal is to 5, the holding costs €1 per year and the part is present in 10 kits in a year, then the costs are €0.50 per kit.

Equations 5.5 till 5.7 can be merged into one function to describe the costs. Yet these costs are only applicable on the parts that are currently kept on stock. To make this function usable for all parts, an if-statement must be included. The choice between keeping a stock and accepting the delay must also be included. Yet this choice can be made which of the alternatives is the cheapest. Describing this choice can be done by using a minimization. Let C_i denote the relevant delay costs of part i, then these costs can be expressed as formulated in Equation 5.8.

$$C_i = \begin{cases} p_i * A + min\left\{p_i * T * W, \frac{N_{max,i} * H_i}{D_i}\right\} \; if \; currently \; kept \; on \; stock \\ 0 \; if \; currently \; not \; kept \; on \; stock \end{cases} \tag{5.8}$$

To illustrate Equation 5.8, let's take the earlier used examples for the Equations 5.5-5.7. Since the costs for the stock (€0.50) are cheaper than accepting the delay (€21.25), the stock is chosen. Adding to it the reorder costs and the results are 0.05*A + €0.50.

5.1.2.4. Increased costs to make the IT suitable for outsourced kitting

According to Figure 18, the parameter influencing the increased costs to make the IT suitable for outsourced kitting is the costs of implementing kit in the BOM. Implementing the kit in the M-BOM only needs to happen once. Spreading the costs among all number of times the kit is used is a bit difficult; since we cannot make estimations on how many times a certain type of radar is going to be sold from now on. It is more interesting to calculate the payback time in systems. This can easily be done by dividing the implementation costs by the savings per kit. If the number of systems that need to be sold is high, then it is not profitable to outsource the kitting. If the number is low on the other hand, then outsourced kitting does not find hinder of these costs. These calculations are done in Section 5.2.

5.1.3. Cost function outsourced kitting

The function to describe outsourced kitting can be formulated by adding the Equations 5.3, 5.4 and 5.8. Equation 5.8 will be expressed in C_i to improve readability. Let S denote the savings of a certain kit, the savings can be expressed as formulated in 5.9. An overview of the parameters is given in Table 1. Rewriting Equation 5.9 results in Equation 5.10.

$$S = A * \left(\sum_{i=1}^{M} \frac{N_i}{Q_i} - 1 \right) + (M - 1) * G - K - \sum_{i=1}^{M} C_i \quad (5.9)$$

$$S = \sum_{i=1}^{M} \left(\frac{N_i}{Q_i} * A - C_i \right) - A + (M - 1) * G - K \quad (5.10)$$

Parameter	Description
S	Savings of an outsourced kit
A	The relevant costs of one order line for outsourced kitting
G	Picking costs at Thales
M	The number of parts in a kit ordered from the supplier
K	The costs of the supplier to assemble a kit
Q_i	Order quantity of part i, where i denotes the parts that are in the kit
N_i	Quantity of part i that goes into the kit
C_i	Costs due to missing/broken parts that are currently kept on stock for part i

Table 1 Parameters for the cost function

To illustrate Equation 5.10, let's take the example kit used earlier. The kit consists of three parts. Two parts are currently ordered in a quantity of one and used in a quantity of one. The third part is currently ordered in a quantity of 4 and per kit one item is used. Let's take €0.50 for the C_i for the third part, €50 for A, €1.50 for G and €10 for K. The summation results in €50+€50+0.25*€50-€0.50=€111.75. The costs reduction on picking results in (3-1)*€1.50=€3. Adding all elements together, results in €111.75 - €50 + €3 - €10 = €54.75.

It could be that for a certain part the costs regarding outsourced kitting exceed the gains of outsourced kitting. In these cases it is wiser to exclude them. This analyse can be done by rewriting Equation 5.10 for a part. Removing the summation, the ordering of the kit, the kitting and the picking of the kit from Equation 5.10, the savings of including part i can be calculated. Let S_i be the savings of part i if it is in an outsourced kit, S_i can be described by Equation 5.11.

$$S_i = \frac{N_i}{Q_i} * A - C_i + G \qquad (5.11)$$

The costs of the kit are not included in Equation 5.11. This formula only is applicable when there is a kit and the question is if the part should be included. Since C_i equals zero when the part is currently not kept on stock, including these parts is always profitable. The usage pf this formula is only interesting to assess if parts that currently are kept on stock, must be included. If S_i is larger than zero, it is profitable to put a part in an outsourced kit, else it is better to order the part in a quantity. Using this property and writing C_i out, kitting is profitable when Equation 5.12 holds.

$$p_i * A + min\left\{p_i * T * W, \frac{N_{max,i} * H_i}{D_i}\right\} < \frac{N_i}{Q_i} * A + G \qquad (5.12)$$

Equation 5.13 can be used to get a rule of thumb. This rule of thumb can be used to get an estimation for the maximum value of p_i. When assuming that the order costs are the dominant factor and other factors have no influence on the costs, then the maximum value of p_i can be calculated by Equation 5.13.

$$p_i < \frac{N_i}{Q_i} \qquad (5.13)$$

This is an interesting property, since it makes p_i dependent on fraction of the quantity used in the outsourced kit. It shows that if a part can be ordered in a large quantity, but only is used for a small fraction in the kit, that it is better to order it in a quantity. Although we made an assumption that the picking costs and costs regarding the delay can be nullified, this property is still useful. Since it is likely that the delay costs exceed in most cases the picking costs, it only leads to more exclusion of parts. Moreover even when delay costs are zero, the picking costs are relative small compared to the order costs. However, if N_i divided by Q_i is small then the delay and the picking costs become more important. This rule of thumb must be used as a quick scan to asses if a part is suitable for outsourced kitting or not.

Calculating the gains for Thales and the supplier individually can be done by splitting Equation 5.10 in a Thales and supplier part. All parameters, except the costs per order line, can be allocated to either Thales or the supplier. The costs per order line are caused by both Thales and the supplier. This problem can be solved by splitting these costs in a Thales part and a supplier part. Let A_T denote the costs per order line at Thales, S_T the savings at Thales, A_S as the costs per order line at the supplier and S_S as the savings at the supplier, then the savings for Thales and the supplier individually can be calculated by Equations 5.14 and 5.15.

$$S_T = \sum_{i=1}^{M}\left(\frac{N_i}{Q_i} * A_T - C_i\right) - A + (M-1) * G \qquad (5.14)$$

$$S_S = \sum_{i=1}^{M}\left(\frac{N_i}{Q_i} * A_S\right) - K \qquad (5.15)$$

As stated in Section 4.1.6, the supplier must use the same stock policy as Thales to buffer against production delays. This results in extra costs for the supplier. However, the supplier could bill these costs to Thales or Thales could use it as a way gain sharing if the benefits of the supplier are higher than those of Thales. Therefore, these costs must not be included.

5.2. Costs savings on our case supplier and radar

This section analyses the costs savings when using kits. The kit configurations can be found in Appendix C. The kits are constructed by grouping the parts using the BOM. We grouped the items that are in the same level and branch together. Subsequently we calculated how many order lines are saved by using outsourced kitting. If this was larger than one, it becomes a kit. From the possible kits, seven are suitable for outsourced kitting. In Table 2 the costs of the corresponding costs are shown. See Appendix A for information regarding the costs of these parameters. Based on the current production schedule, we took the demand per year as X. Supplier-X did not think it would have any extra costs for the kitting activity. Supplier-X receives much more savings than Thales does. These savings are based on an estimate from the supplier, but it would no surprise if the supplier actually has more costs per order line than Thales. The supplier has to confirm these order lines and transfer them to its systems. Comparing this to the situation of Thales, Thales benefits from its ERP that generates the needs/order lines automatically.

Parameter	Description
Not Public	

Table 2 Values of the cost parameters (see Appendix A for more information)

Table 3 and Table 4 contain an analysis of the costs. Table 3 contains the values without the savings of the supplier and Table 4 with the savings of the supplier. The kits are able to repay the initial investment of implementation in the M-BOM in one kit, except kit X and X when only taking the benefits of Thales into account, which needs two kits. Therefore, there is a high safety marge in case some costs or benefits are higher or lower than expected. We took no stock or delay costs in account, since the distance to supplier is marginal. Yet when only taking in account the benefits of Thales, some kits are sensitive to missing or broken parts. Examining the percentages used in a kit from an order quantity in Appendix C, it is noticeable that some parts have percentage of quantity used of 0.02. In these occasions if a part is missing more than once in the fifty, it is better to not kit the part.

Kit number	Number of different part types (M)	Order lines (N_i/Q_i)	Savings without supplier and exceptions	Payback of implementing the kit in the M-BOM in number of radars
Not Public				

Table 3 Cost savings analysis without taking savings supplier in account

Kit number	Number of different part types (M)	Order lines (N_i/Q_i)	Savings with supplier and without exceptions	Payback of implementing the kit in the M-BOM in number of radars
Not Public				

Table 4 Cost savings analysis with taking savings supplier in account

Much of the savings rely on the reduction in the number of order lines. If the processes responsible for these costs are becoming more efficient, these costs decrease, resulting in fewer saving due to outsourced kitting. This means that the payback time increases. The chance of a missing/broken part does not change much, since the order costs are major factor in this calculation. However, in other cases a decrease in order costs also influences the exception costs.

In Figure 19 an analysis of the p_i is made for kit X. The parts in kit X are very different from each other in the ratio of quantities used and current order quantities. There were two different Part-A and eleven different Part-B, yet these has the same quantity ordered and quantity used, so only the first of these is shown. Kitting Part-A in an outsourced kit contributes not much to the cost reduction. Corresponding, these parts have a low margin to buffer against the costs of being missing/broken.

Figure 19 Analysis of p_i for the parts of kit X

As stated in Section 5.1 the stock from Thales moves to the supplier. Although not resulting in extra costs for the supply chain, it reduces costs at Thales, but increases costs for the supplier. For the case example it would mean that approximately €XXX of stock costs per year are moved from Thales to the supplier, assuming constant demand. The stock is calculated by dividing the order quantities by two, resulting in the average stock, and multiplying it with the holding costs. In this particular case the savings of the supplier exceeds this amount and so this increase would probably not be a problem. Yet it could be that in other cases the savings of the supplier cannot compensate for the increase in holding costs. In such cases financing the stock can solve this problem.

The analysis focusses on the parts that are currently kept on stock. These parts are causing the greatest difficulties and costs. Yet the gains for including these parts are marginal. Although including these parts leads to a bit more profit, they result in more exception management and the problems can result in high costs. Excluding these parts would lead to kits that are not exposed to extra risks, while holding the most of its benefits.

Figure 20 contains an overview of the gains and costs per department. The gains and costs are calculated by allocating the implementation costs and costs and savings calculated by Equation 5.10 to the corresponding departments. The purchasing department receives very few saving from outsourced kitting. Regarding the direct savings of outsourced kitting, outsourced kitting does not contribute much to the goal of reducing the costs of the purchasing department. To reach the goal of cost reduction on the purchasing department, outsourced kitting is not useful.

Figure 20 Cost and saving of outsourced kitting per department

The analysis is based on Supplier-X. Since Supplier-X is located near Thales, it is possible to place buffers against missing/broken parts at Supplier-X without creating any production delay. Yet in cases of other suppliers, this will not hold. The costs of assembly delay are compared to the gains of the kit a large cost factor. The profits of described kits are not enough to compensate against a delay of a day. The costs of exception increases in these cases and it will be question if outsourced kitting is profitable in these situations. Keeping a small stock would be better alternative in these cases. Although creating a second stock sounds counterintuitive, it still could be beneficial. When outsourcing the kitting to other suppliers, there are more costs involved to handle the missing/broken parts.

As stated earlier, removing the parts with a small N_i/Q_i ratio does not hurt the financial performance, but it makes the outsourced kits less sensitive for missing/broken parts. When starting outsourced kitting with another supplier, not including these parts in the outsourced kits decreases a lot of risks without sacrificing much gain.

When comparing the gains with the radar, the gains are marginal. The System-X costs several XXX and a reduction of €XXX is not much on this scale. Combining the marginal gains with the low volume of the System-X, which is approximately four per year, outsourced kitting is not a very interesting to implement it for its cost savings.

Supplier-X states that it would not have extra costs for kitting the parts. As stated in Chapter 2, the supplier has to pick the parts anyway. On first sight, the statement of Supplier-X seems plausible. However, parts that are ordered in a quantity can currently be picked in one pick. When outsourcing the kitting, these parts cannot be picked in a quantity anymore, but must be picked every time a kit is ordered. This results in extra picks, leading to increased picking costs at the supplier. Therefore, it is questionable how accurate this cost prediction is.

Another noticeable fact is that the savings are less than the internally done preliminary research. The savings according to this research are €XXX. This research included only the gains of Thales, which means that there are great differences between both researches. The first difference is between the usage of the order lines in the ERP and the product lines in the BOM. Because parts are ordered in quantities, the number of order lines in the ERP is less than in the BOM. The number of lines used in the previous research corresponds with the number of lines in the BOM, while this research used the order lines that are in the ERP. This result in a smaller reduction of the number of order lines. The previous research is performed several years ago. Since this research several processes are automated, resulting in less order handling per order line. This also explains a part of the gap. Some cost factors used in previous research could in our opinion not be contributed to outsourced kitting. Some of them were order based, for example the paying of the bills, while others, for example the inspection, were item based. Excluding them also result in fewer gains when reducing the order lines. The last difference is that we chose to use the direct labour costs, while the previous research included the indirect costs in the labour costs.

As stated in Chapter 1, communication and control could become easier when the parts are in an outsourced kit. It becomes only easier when the communication and control is needed on kit level. A kit combines parts when ordering and moving them. Communication and control becomes easier if the price is missing or the supplier cannot meet the due date. If this happens frequently, kitting could cause a cost reduction. However, solving the cause of the delay and the missing prices could be more beneficial.

Another benefit of outsourced kitting is that enforces the coordination. Since the parts cannot be delivered separately, it ensures the coordination. Although the coordination provided by the outsourced kits is already implemented at Thales, outsourced kitting could support it. If a supplier has issues regarding on time delivery, then the delayed parts cannot be sent individually. This ensures the coordination benefits.

Outsourced kitting also provides the supplier with more information on the assembly process of Thales. In case of prioritising production, the supplier is able to see the effects on the assembly of Thales. If the supplier needs to reschedule parts, then it can see the impact on the assembly process at Thales much easier. Currently the supplier only receives order lines with delivery dates, where a kit provides a linkage between these lines.

Regarding outsourcing of assembly activities, outsourced kitting can also contribute to facilitate this process. An outsourced kit gives the opportunity to let the supplier take over the buying of parts from other suppliers and add those parts to a kit. When successful, the supplier can start with assembling the kit. Using this method, the risks occurring when the supplier starts to buy the parts of other suppliers and the risks occurring when the supplier starts with assembling the kit, do not occur on the same time. So the supply chain will be more stable during the outsourcing activity.

5.3. Conclusion

This chapter analysed the costs and the gains of outsourced kitting, answering the research question *"What are the savings resulting from outsourcing the kitting of parts from the same supplier?*" Taking both Thales and Supplier-X into account, the savings of outsourced kitting are around the €XXX per System-X. These savings create enough margin regarding errors and exceptions. When taking only Thales into account, the gains are €XXX per System-X. Comparing these gains with the costs of a System-X, which is several XXX, the gains are very marginal. Implementing outsourced kitting is not very interesting when only taking the gains into account. However, the side effects of easier communication and control and enforced coordination could create additional gains. Yet these effects are only present when a supplier has performance issues. Alternatives which solve these issues are probably more effective. Outsourced kitting could also be used to share the information on the assembly process. Since outsourced kitting leads to a small saving, it is a suitable alternative to accomplish this sharing. Outsourced kitting could be a useful tool to support the outsourcing of assembly activities. It is questionable if outsourced kitting should be implemented for its direct savings or savings due to easier communication and enforced coordination, but it can be implemented for sharing information of the assembly process or as tool to support the outsourcing of assembly activities. It is questionable if it is profitable for other suppliers. The location of Supplier-X provides some benefits that reduce the costs for part that is currently kept on stock that goes broken or missing. Other suppliers that are not so close located as Supplier-X cannot provide the buffer close to Thales and so resulting higher costs for missing/broken parts. Removing the parts with a low ratio on quantity used compared to quantity ordered can make outsourced kitting at other suppliers more interesting.

6. Conclusion, recommendations and further research

This chapter answers the main research question "*How should Thales Nederland organize outsourced kitting of parts of a single supplier for the same radar?* ". We start with general conclusion, continue with the recommendations and we end with a view on further research.

6.1. Conclusion

This research started by discussing the current situation and the problems that these processes will face when Thales starts with outsourced kitting, answering the research question "*What are the problems in the current situation regarding outsourcing the kitting of parts from the same supplier?*" The following problems are defined as problems that can cause extra costs when outsourcing the kitting:

- Incomplete kits, because the assembly cannot start when not all parts are present and the part needs to be reordered.
- Inspections, since it would create a lot of movement and waiting of the parts.
- Late deliveries, since they can increase due to outsourced kitting.
- Design changes of parts, since the changed part must be traceable.
- Special handlings, since a part with a special handling must be traceable.
- The bill of material, since implementing a kit in the BOM is currently difficult

Delay due to missing/broken parts that are currently kept on stock, since there is no internal buffer for these parts anymore.

Next this research addressed the research question "*What are good alternatives for the problems caused by outsourcing the kitting of parts from the same supplier?*" Outsourced kitting requires some changes in the current process. The following changes must be done when outsourcing the kitting:

- The M-BOM must be present such that the kits can be defined
- Outsource V and F inspections to supplier to prevent movements of kits.
- Supplier keeps a stock policy which is equal to or better regarding the fill rate than Thales stock policy to prevent production/delivery delay.

Besides changes in the processes, the kit must meet some requirements. Its design must facilitate the pick and assembly operations such that it can improve these processes. Subsequently this design must be kept up to date. The kits must have some distinctive features, such that it and its parts are recognized. The kit should have its own number and the parts must be kept in their original packaging. Kits must not incorporate parts that are difficult to kit due to their size or the special handling they require. As last, the kit should have space for other parts of suppliers such that it can move as one kit to the final assembly.

The last part of this research addressed the costs and the gains of outsourced kitting, answering the research question *"What are the savings resulting from outsourcing the kitting of parts from the same supplier?"* Taking both Thales and Supplier-X into account, the savings of outsourced kitting are around the €XXX per System-X. These savings create enough margin regarding errors and exceptions. When taking only Thales into account, the gains are €XXX per System-X. Comparing these gains with the costs of a System-X, which is several XXX, the gains are very marginal. Implementing outsourced kitting is not very interesting when only taking the gains into account. However, the side effects of easier communication and control and enforced coordination could create additional gains. Yet these effects are only present when a supplier has performance issues. Alternatives which solve these issues are probably more effective. Outsourced kitting could be used to share the information on the assembly process. Since outsourced kitting leads to a small saving, it is a suitable alternative to accomplish this sharing. Outsourced kitting could also be a useful tool to support the outsourcing of assembly activities. It is questionable if outsourced kitting should be implemented for its direct savings or savings due to easier communication and enforced coordination, but it can be implemented for sharing information of the assembly process or as tool to support the outsourcing of assembly activities. It is questionable if it is profitable for other suppliers. The location of Supplier-X provides some benefits that reduce the costs for part that is currently kept on stock that goes broken or missing. Other suppliers that are not so close located as Supplier-X cannot provide the buffer close to Thales and so resulting higher costs for missing/broken parts. Removing the parts with a low ratio on quantity used compared to quantity ordered can make outsourced kitting at other suppliers more interesting.

The answer to the main research question, "*How should Thales Nederland organize outsourced kitting of parts of a single supplier for the same radar?*" is that Thales must implement the M-BOM, outsource the visual and functional inspections to the supplier and ensure that the supplier has a stock policy with an equal or better fill rate. Implementing outsourced kitting is only interesting when it is used to share information regarding the assembly process and as tool to support the outsourcing of assembly operations.

6.2. Recommendations

If the decision is made to implement outsourced kitting, some changes are required. As stated in Chapter 4, the following changes must be implemented to facilitate outsourced kitting:

- The M-BOM must be present such that the kits can be defined
- Outsource V and F inspections to supplier

The M-BOM is currently being developed in Windchill and does not need much attention. Yet it could have some advantages to keep outsourced kitting in mind in the development. This could for example reduce the time needed to implement the kit into the M-BOM.

Currently there are no initiatives to outsource the visual and functional inspections. To outsource these inspections successfully, the supplier must do the inspections at the quality Thales requires and Thales must trust these inspections. The first point can achieved relatively easy. If Thales shares it knowledge and train the supplier employees or lend its own, the supplier can gain the required level. If Thales lends its employees to these inspections, the trust from Thales also increases. This is unfortunately not possible for every supplier, but if a supplier is close, it is feasible. If a supplier is further away, trust can be gained by checking the products internally in the beginning, giving feedback to the supplier and start doing it less when the results are good.

The responsibility for design of the kits should be at the final assembly since they work with them. Creating a structure in the design would be beneficial regardless of outsourcing the kitting activity. Yet the outsourcing choice should be at the logistics department since they are responsible for the M-BOM and the inventory management. Therefore, these two departments must responsible for the implementation.

We advise to start implementing outsourced kitting at Supplier-X on the System-X with kits X and X. These kits contain for a large part of parts that are currently not kept on stock. For the initial start-up problems, these savings can compensate. These kits can also be used to collect initial data on p_i. Therefore, these kits are interesting to start with. They can also provide with initial how well the proposed changes are holding and performing. If these kits are performing successful, we advise to start with the other kits and create other kits based on the profitability and kit restrictions.

6.3. Further research

Order quantities, which are used in in-house kitting and line stocking, are an alternative to outsourced kitting regarding the reduction of order handling. Yet if an order quantity of several parts is low, outsourced kitting is a better alternative. So investigating this trade-off more deeply is interesting. Besides, a kit could also contain multiple assembly steps. This would create some holding costs in the supply chain due to waiting of the parts, but could reduce the order costs. If Thales orders for example the System-X as a complete kit, the savings on the order costs are €XXX for Thales only and €XXX for the supply chain. Yet some other issues like delay are more present in this situation. So adding these trade-offs could be very interesting for further research. This research did take in account risk pooling effects at the supplier. If the supplier delivers a type of part to multiple manufacturers, then placing the stock at the supplier could lead to a reduction in holding costs of that part. These effects are not addressed in this research, but could be interesting for further research.

For Thales on the other hand, some other scenarios are probably more interesting to investigate. Sahin and Robinson Jr. (Sahin & Robinson Jr., 2005) talk about the full information sharing and full coordination possibility. Their findings regarding cost reductions are very interesting. We think that this FI/FC situation could be achieved in the future by Thales, certainly combined with Supplier-X. This could be done by setting up a shared logistics department. This department should be responsible for making an integrated planning of both firms. This could create an automatic transfer of orders, better production schedules and probably better communication regarding design changes.

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Appendix A

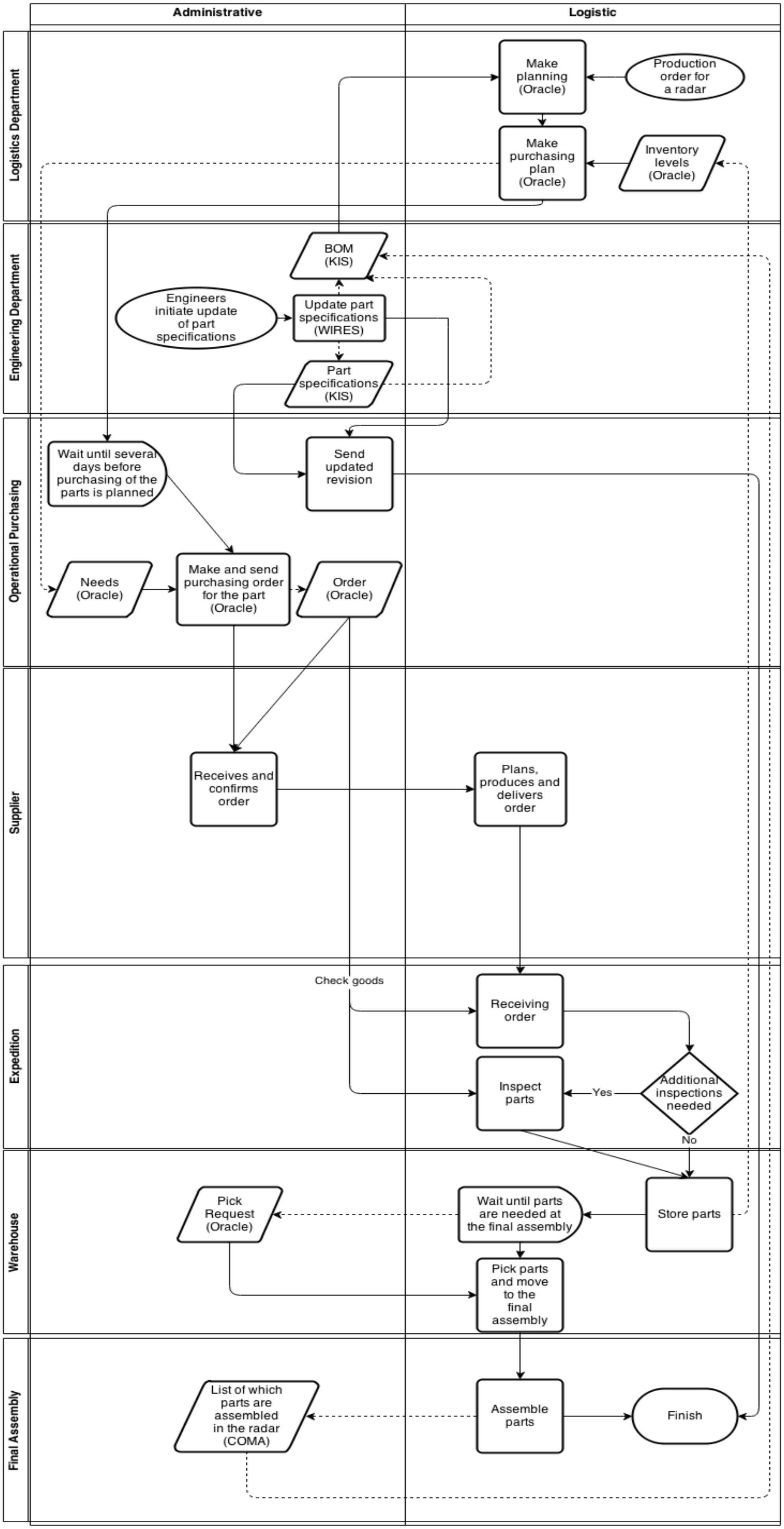
This appendix contains the value of the parameters used in the cost functions. These parameters are retrieved from corresponding departments or involved people.

Not Public

Appendix B

This appendix contains figures which are better readable when using a full page. The figures present in this appendix according to the order they are presented in this appendix:

1. Figure 13 Overview of the regular radar production with responsible information systems


Administrative
Logistic
Logistics Department
Engineering Department
Operational Purchasing
Supplier
Expedition
Warehouse
Final Assembly
Make planning (Oracle)
Production order for a radar
Make purchasing plan (Oracle)
Inventory levels (Oracle)
BOM (KIS)
Engineers initiate update of part specifications
Update part specifications (WIRES)
Part specifications (KIS)
Wait until several days before purchasing of the parts is planned
Send updated revision
Needs (Oracle)
Make and send purchasing order for the part (Oracle)
Order (Oracle)
Receives and confirms order
Plans, produces and delivers order
Check goods
Receiving order
Inspect parts
Yes
Additional inspections needed
No
Pick Request (Oracle)
Wait until parts are needed at the final assembly
Store parts
Pick parts and move to the final assembly
List of which parts are assembled in the radar (COMA)
Assemble parts
Finish

Appendix C

This appendix contains the kit configurations used in this research. It concerns Supplier-X as supplier and the System-X as radar.

Not Public