Linnæus University
Sweden

Master degree project – censored version

Batch size policy
Thule Sweden AB

A case study of the production site in Hillerstorp

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Regarding censorship

Thus project has, according to an agreement with Thule Sweden AB, been censored. No chapter has been removed from this exam but several parts of the data used for calculations have been scrambled. As no conclusion is based on economical figures alone, all of the project's conclusions, recommendations and results are still valid. The censorship is most noticeable when any calculations are shown in the analysis chapters and when empirical raw data in form of numbers are shown. Disregarding this, any reader interested in lean management, reducing lead times and batch sizes effects on costs and inventory management will find the theoretical frameworks, arguments and results interesting and will hopefully be inspired to new ideas regarding other producing companies.

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Our supervisor Peter Berling has contributed in many ways, especially in the calculations of the project and by his expertise within the area of inventory control and logistics. Much appreciated! Helena Forslund has also been an important person when making this project, thank you for the guidance and supervision of the project's process.

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Abstract

Master Degree Project. Business Administration and Economics Programme, Linnaeus University, Logistics, 4FE05E, Spring 2011.
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Title: Batch size policy Thule Sweden AB - *A case study in Hillerstorp*

Background: Thule Sweden AB has currently no clear batch size policy and batch sizes are an area that has been recognized with potential earnings within the company. A project to map two flows (a high volume and a low volume) and suggest a new cross functional batch size policy has been initiated.

Purpose: The purpose of this project is to, with the help of a current state map, propose a new cost effective and cross functional batch size policy for the business unit car accessories and compare this to the present batch size policy to show possible earnings.

Method: This project uses a qualitative approach to show the effect of batch sizes with data supplied from the Thule Sweden AB and researched through the Linnaeus University's recourses.

Findings: Thule Sweden AB should be able to remove several inventories that have been caused by a batch size policy where whole pallets are preferred. A batch size policy where one batch size is used to the semi-finished inventory and another size, part of first batch size, from that inventory until the finished-goods inventory has been suggested as a cross functional batch size policy. This suggestion has been tested and in four different versions was found more cost effective than the current policy. Using smaller batch sizes in the suggested batch size policy decreased inventory levels and lead times. However, the current, larger batch size was more optimal as the holding costs are low and the set up costs are high.

Key words: Batch size, batch size costs, cross functional, inventory control, lean management, production flow, supply chain integration, transportation costs, value stream mapping.

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Abstrakt

Examensarbete. Civilekonomprogrammet, Logistik, Linnéuniversitetet, 4FE05E, Våren 2011.
Författare: Alexander Avander och Erik Robertsson
Handledare: Peter Berling

Titel: Batch size policy Thule Sweden AB - *A case study in Hillerstorp*

Bakgrund: Thule Sweden AB har för närvarande ingen tydlig batch policy och detta är ett område som uppmärksammats som ett område med potentiella förbättringsmöjligheter. Ett projekt har inletts där två flöden (en hög omsättare och en låg) skall kartläggas och generera ett förslag till en tvärfunktionell batch policy.

Syfte: Syftet med projektet är att med hjälp utav en ”current state map” föreslå en ny, kostnadseffektiv och tvärfunktionell batch policy samt jämföra detta med nuvarande policy för att påvisa potentiella förbättringsmöjligheter.

Metod: Projektet använder ett kvalitativt arbetssätt för att påvisa effekter utav batch storlekar. Data hämtas från det undersökta företaget och från tidigare forskningar inom området som samlats genom universitetets resurser.

Slutsatser: Företaget bör kunna eliminera ett flertal lager i sitt flöde som uppstått på grund av en batch policy där hela pallar föredras. En batch policy, där en storlek används till ett komponentlager och därefter en annan storlek som är en jämn del utav den första till slutlagret, har föreslagits som en tvärfunktionell batch policy. Detta förslag är testat i fyra versioner där samtliga var funna mer kostnadseffektiva än nuvarande policy. Att använda mindre batchstorlekar i den föreslagna policyn sänkte lagernivåer och ledtider. Dock var nuvarande, större batchstorleken mer optimal då lagerhållningskostnaderna är låga i förhållande till omställningskostnader.

Sökord: Batch size, batch size costs, cross functional, inventory control, lean management, production flow, supply chain integration, transportation costs, value stream mapping.

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Acronyms

Bio	Billions
CA	Car Accessories
CSM	Current State Map
FSM	Future state map
HR	High runner. The high demand product investigated
I_1	Inventory 1. The inventory placed before assembly.
I_2	Inventory 2. The finished goods inventory.
JIT	Just In Time
Lean	Lean management (includes different versions as lean procurement and lean production).
LR	Low runner. The low demand product investigated
M	Meters
Pcs	Pieces
SC	Supply Chain
SEK	Swedish Krona
SS	Safety Stock
Stdev	Standard deviation
WIP	Work in progress
VSM	Value Stream Mapping

1. Introduction

This chapter starts with a short presentation of Thule Sweden AB and the assignment which this project is based on. Theoretical background about value stream mapping and batch size policy will be described to provide a basis for the problem discussion. Thereafter the project aims will be based on the problem discussion with the purpose of creating a new cross-functional and cost-effective batch size policy for the business unit Car Accessories.

1.1. Presentation of Thule Sweden AB

Thule Sweden AB (Thule) is part of an international group that focuses on developing, manufacturing and marketing of safe, easy and fashionable solutions for people who want to bring their equipment with them utilizing their car (e.g. roof racks, rooftop boxes, bike- and water-sport carriers) (SC Coordinator, 2011). The company aim to be the natural choice for active families, outdoor enthusiasts and professionals that wishes to transport their gear in a simple and fashionable ways (Thule.com, 2011). Thule's vision is thus to offer top products to people with an active lifestyle and a passion for sports (SC Coordinator, 2011).

Figure 1.1. The Thule Vision (www.thule.com, 2011)

Thule's headquarters is based in Malmö, Sweden and has approximately 1000 employees at several production and sales locations all over the world with the major manufacturing sites located in Sweden, Poland, Germany, Italy, Belgium, UK and Brazil (Thule.com, 2011). The turnover for 2009 amounted to 2 Bio SEK (Thule.com, 2011).

1.2. The assignment

The assignment from Thule is based on the absence of a clear batch size policy within the business unit, where batch sizes are identified as an area with possible earnings. The task of this thesis is to map two production flows, from raw material to a finished product, and present a potential optimised batch sizes for the selected flows that are both cross functional and handles demand variation (SC Manager, 2011). Also the assignment includes describing theory on batch sizes effects on costs to give Thule an up-to-date information source and compare that theory with Thule's current batch size policy. The products chosen are a high runner (HR) and a low runner (LR). Both are roof racks and have the same function as shown in figure 1.2.

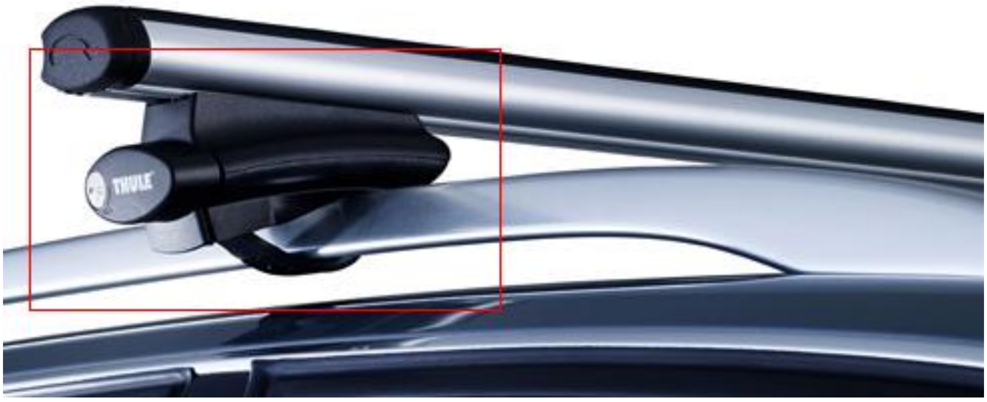

Figure 1.2. Roof rack (www.thule.com, 2011)

Hr is a high volume product and the LR is a low volume with sporadic demand. Although the LR's low volume, both items are considered important articles that need to be kept in stock by Thule (SC Coordinator, 2011).

1.3. Background

As shown in figure 1.3, this study focus on the cross functionality problem of finding an batch size that is suitable to the different departments in Thule to make the product more effective (Sarin and O'Connor, 2009).

- Procurement is responsible of purchase the product from the supplier to the company and is concerned with the problem of guaranteeing that the suppliers would deliver the parts in time and with minimum costs (Aissaoui *et al.*, 2007; Porter, 1985).
- Transportation is responsible for the logistical activities between the departments and has an impact on lead times, movement costs and safety stock (Gupta, 2008).

- Operations are the activities connected with transforming inputs into the final product form, such as machining, packaging, assembly, equipment maintenance and testing (Porter, 1985).
- Warehousing handles the inventory levels in all departments in a value chain and usually focus on inventory levels (Gupta, 2008).
- Cross functionality is close related to supply chain integration and typically involves facilitating communication among different functions (Emery, 2009; Troy *et al.*, 2008).

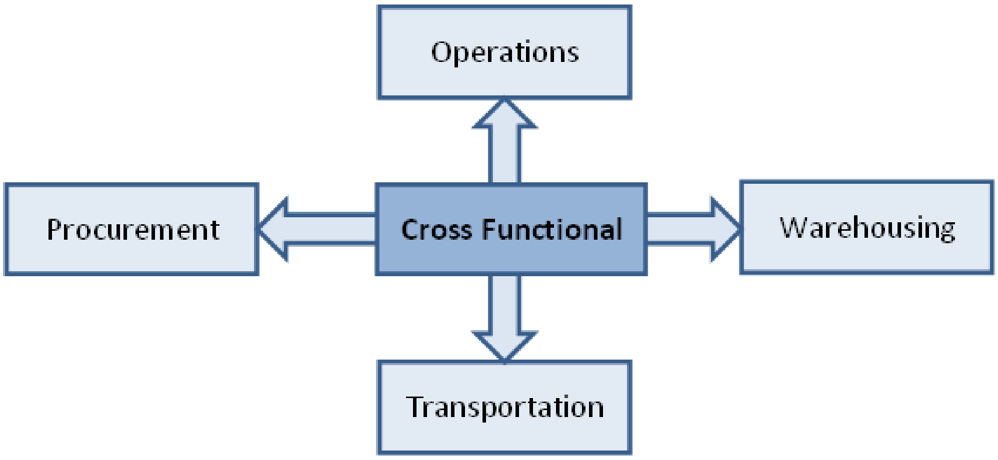

Figure 1.3. The study's focus (own creation, 2011)

Thule Sweden AB agrees with Ishii *et al.*'s (2010) view on batch size and consider a batch as a group of identical products that are purchased or produced together, while the batch size is the number of products included in a batch (SC Coordinator, 2011). By affecting batch sizes, factories primarily desires to achieve shorter lead times in production (Bicheno *et al*, 2001; Karmarkar, 1987), make an impact on the inventory's carrying cost (Gupta *et al*. 2010) and make the production more effective (Ronen and Pass, 2008). Which decision minimizes the total inventory cost for the company is illustrated in figure 1.4 reduce batch size to reduce the carrying costs or increase the batch size to reduce set up costs (Gupta *et al.*, 2010)?

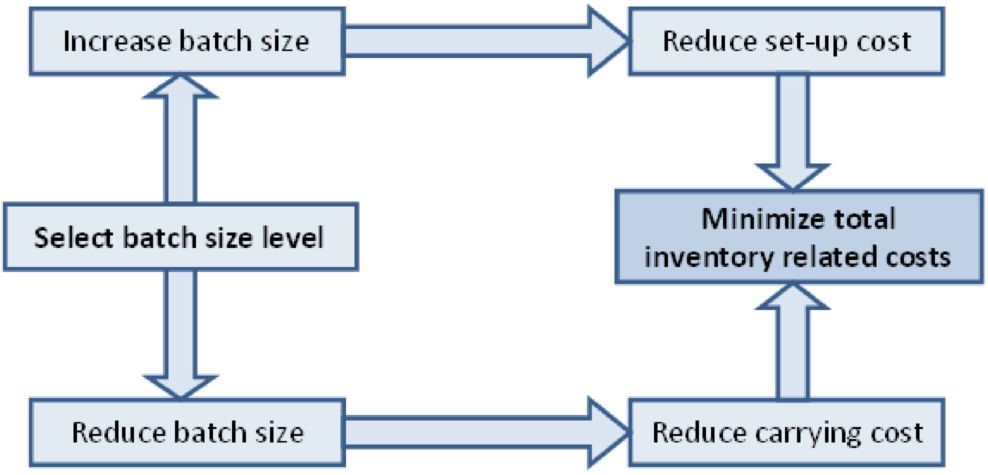

Figure 1.4. Conflict in determining economic batch quantity (Gupta et al. 2010)

There are several managerial philosophies where one of the main goals is to reduce batch sizes. Lean management (lean) aim to reduce waste, lead times and inventory levels by using a pull system where no product is produced or ordered unless a customer has ordered it (Shah and Ward, 2003). Just in time (JIT) aim to deliver items in small quantities to reduce the customers inventory levels and deliver them just before the customer needs a delivery (Khan and Sarker, 2002). Both these philosophies handle reducing batch sizes in one way or another and in this thesis, whenever any of these two are mentioned it should be associated with reducing batch sizes. However, in this project focus will not be on just a batch size but a batch size policy. This implies that there are more to it than just the size.

The production flow from raw material to the customer can be seen as a value stream with both value added and non-value added actions (Rother and Shook, 2003). Value stream mapping (VSM) is a tool connected to lean management, which maps different flows (Singh and Sharma, 2009). This map can then be used to improve the production process and making it more cost effective (Singh and Sharma, 2009). This thesis use VSM to create a current state map (CSM) to map the current flows and this can be the first step to suggest a new batch size policy.

1.4. Problem discussion

As a batch size policy affects the whole production flow within Thule Sweden AB, effective batch sizes must be balanced and cross functional (SC

Manager, 2011). This might lead to difficulties since, for instance, procurement often strives to buy large quantities for a lower price following the economics-of-scale thinking (Ronen, 2008). Another example of a problem is how workers and managers in the production line often tend to oppose changes in the batch sizes (Hirano, 2009). They do not see the positive effects that reduced batch sizes can have, such as lower inventory levels (Hirano, 2009; Schragenheim and Dettmer, 2001) and lean production (Lasa *et al.,* 2008). Instead they only see reduced lead times with higher cost-per-unit (Hirano, 2009; Schragenheim and Dettmer, 2001).

The production flows for the products and the processes within Thule must be mapped so that a new cost effective batch size policy for Thule Sweden AB can be suggested. This would also help with understanding the effect of batch sizes on different departments. A CSM illustrates how flows currently operate and how to improve those existing flows and design better ones in the future (Abdulmaleka and Rajgopalb, 2007). CSM focuses on both the material- and information flow (Rother and Shook, 2003) and this will give a good basis to understand the current flows within Thule.

Batch size theory seems to be sporadic and often uses different names, depending on the type of theory studied. Therefore, to give an understanding of batch sizes effect on costs and inventory levels, fragmented parts from different studies must be gathered together to give a complete view and to allow for comparison with Thule's present batch size policy. Also, theory on cross functionality must be presented.

Aryanezhad *et al*. (2010) mentions that it is very important to take the different variables into consideration when determining how the batch sizes should be calculated. The proper evaluation of an inventory system policy requires evaluation of the batch sizing model used, along with inventory holding cost, setup cost, processing cost and shortage cost (Jamal *et al*., 2004). To compare the current batch size policy and a suggested policy, batch size theory must be analysed in comparison with Thule's current batch size policy. In this part, it is important to evaluate both the theoretical important batch size factors as well as the ones Thule consider important while considering cross functional factors. Also, as focus is on a batch size policy and not a batch size, the project need to evaluate the policy Thule has and not just the single batch size for the investigated flows. This will then be the basis to present a cross functional batch size policy which will then enable the possibility of investigating the policy in a model.

Then it is the matter of how to shape the policy and show it. This project aims to use a model that optimizes Thule's flow while settings of different batch size levels are possible. With the model, the effect of different batch sizes could be calculated and then presented. Although the model in itself might be complicated, the basic idea must be logical and made understandable enough to be considered. After this, the effect on costs must be shown to evaluate the investigated batch policy, for instance by testing different batch sizes. Finally, the current and suggested batch size policy must be compared and any effects must be investigated.

1.5. Project aim

- Map product flows for HR and LR
- Describe Thule's current batch size policy
- Suggest a alternative batch size policy
- Compare the batch size policies

1.6. Purpose

The purpose of this project is to, with the help of a current state map, propose a new cost effective and cross functional batch size policy for the business unit car accessories and compare this to the present batch size policy to show possible effects.

1.7. Limitations

The project will focus on Thule's high season from February the first until the end of May and assume 30 days each month. Value stream mapping will only be used to create a current state map (CSM). When building the model the costs for the items will be estimated based on real data. This project will only discuss the potential of lowering the batch sizes, which is in accordance with lean management, or keeping the batch sizes.

1.8. Further organisation of the paper

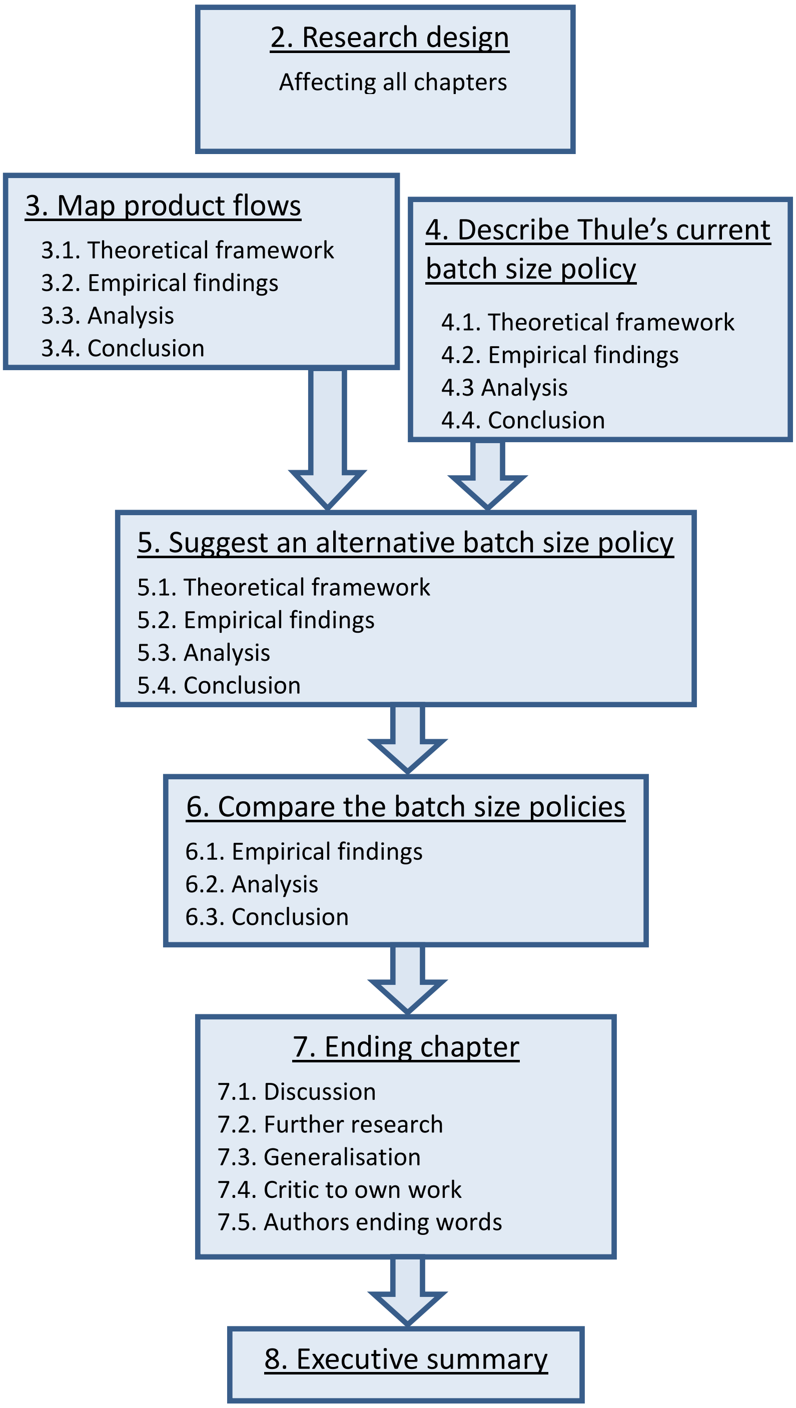

Figure 1.5. Further organization of the paper (own creation, 2011)

Chapter 3 and 4 are constructed with a classical academic structure with theoretical chapter, empirical data, analysis where the two are compared and analysed and a concluding chapter in the end. Chapter 5 does have theory but only in the form of the model used. This causes some issues as some of the points needed for the analysis in chapter 5.3 can be found in chapter 3 and 4. Using a standard academic reference system would thus be somewhat awkward. Instead, references are made to the chapter that contains the information referred to. In chapter 5.2 there are minor information that can be found in previous chapters but has been included for easy reference.

Chapter 6 does not contain a theoretical framework. Instead it is assumed the reader has read through the previous chapters and thus references are only made to chapters to decrease recurrences of arguments already made. The empirical data in chapter 6.1 also has some empirical repetitions which have been included to simplify for the reader. Preambles have only been used when needed and thus have not been included in every chapter.

2. Research design

This part of the study describes the research methodology used. Focus has been put on the actual method to solve Thule Sweden AB's problem, how the data is collected from the company, the validity and reliability of the study and the analysis method used. As this study's originates from Thule Sweden AB, it does not have a chosen scientific approach or view, the selection process is not relevant and the survey design is considered obvious and so these parts are not discussed.

2.1. Research method

According to Bryman and Bell (1995) there are two basic types of studies: qualitative and quantitative. Qualitative studies often focus on a fewer number of cases and tend to generate theory by interpreting the gathered data. On the other hand, quantitative studies focus more on being distant to the studied object and are more often used to test an existent generated theory with data collected from a larger number of cases with some sort of tests of hypothesis (Bryman and Bell, 2005).

In this project, the focus lies in one case, there are no tests of hypotheses, the authors was in close relation to the company and the primary data were collected through means usually connected to a qualitative approach. This study is considered a qualitative study based on Bryman and Bell's (2005) description.

2.2. Data collection

There are two types of data collected in any study; primary- and secondary data (Bryman and Bell, 2005). Primary data is first-hand data collected directly from the source, for instance interviews (Björklund and Paulsson, 2003) and direct observations (Yin, 2007). According to Yin (2007) there are several downsides to this type of information and he suggests countering these with the usage of several data sources that gives the reader a chance to trace the information through the study and compare them.

The secondary data is data collected by other researchers and used in a study to save time, money, increase the quality of the available data and give more time to analyse the data to help comparisons (Bryman and Bell, 2005). Yin (2007) also comments on the advantages of comparing existing data with the current case to improve the analysis. There are some considerations, though; unfamiliarity with the material used, the data's complexity, the data is usually collected to other purposes and the unknown quality of the chosen data give secondary data some drawbacks as they can not as easy be validated, as the primary data collected (Bryman and Bell, 2005).

The primary data was gathered through interviews during the spring of 2011 with the SC Coordinator in Thule Sweden, or interviews where SC Coordinator has been the middle hand to facilitate the choice of whom to address. After the main part of the empirical data was gathered, sporadic visits and contact through mail completed the data collection. The primary data sources are shown in table 2.1 below.

Name	Position in Thule Sweden AB
Anonymous A	Supply Chain Manager
Anonymous B	Logistics and Production Planning
Anonymous C	Production Manager
Anonymous D	Supply Chain Coordinator
Anonymous E	Transportation
Anonymous F	International Product Manager
Anonymous G	Purchasing Manager
Anonymous H	Business Controller
Anonymous I	Production Site Manager
Anonymous J	Production Engineer

Table 2.1. Interviewed persons within Thule Sweden AB (own creation, 2011)

In a qualitative interview it is often more advantageous to let the subject be free to interpret the questions because the interview will often cover more than any beforehand prepared questionnaire. Even though the same person often must be interviewed several times before the data collection is considered to be concluded (Bryman and Bell, 2005).

This study's collected primary data are mostly gathered from interviews, a combination of interviews, direct observations and data collected through the interviewed persons. The interviews were unstructured in the way that only a framework of possible questions was considered beforehand, letting the interviewed focus on key aspects of their expertise. This data was then interpret and scribed to paper form. At a later stage of the project the primary data used was validated by e-mail or phone by all interviewed persons.

The secondary data has been gathered the databases Google Scholar and LibHub. These two databases are considered containing valid researched material and therefore this study did not take any extreme measures to question the secondary data collected. The primary and secondary data was questioned if any inconsistencies between the primary and secondary data were found.

2.3. Scientific credibility

Bryman and Bell (2005) describes a point of view where a qualitative research's criteria of truth are consisted of trustworthiness and authenticity. Focus usually lies in trustworthiness and is according to Bryman and Bell (2005) further split into:

- Credibility: Have measures been taken to make sure that the described reality in the study agrees with the interviewed person's reality? This is usually handled with some sort of validation from the interviewed persons that the information used is correct.
- Transferability: Have the study contributed enough information to give the reader a chance to decide when the study is transferable? The goal is not to have a high appliance on other situations but to make sure the reader can decide when the study can be applied on other cases.
- Dependability: Were the study's processes' well fleshed-out so that other could validate the data used (for instance notes from interviews). Bryman and Bell (2005) address this as an awkward process that demands much time from the evaluating part and thus are seldom used.
- Confimability: Have the researchers acted in good faith and as objective as possible when creating the thesis so that the conclusions can be confirmed?

This project has handled the above criteria as following:

- Credibility: Validation by e-mail and phone has been used. Also the interviewee's answers have been compared and questioned if opposite data has been gathered. The credibility is thus considered high.
- Transferability: Through conclusions, discussions and demonstrated data, the project should give the opportunity to allow the reader to satisfactory evaluate the transferability. The transferability is considered high.
- Dependability: The raw data gathered from interviews has not been included as an appendix in this project. This project has been meant primarily for Thule and their production site in Hillerstorp. As the interviewed persons has been able to validate the data in the form it was presented in the projects empirical chapters, the dependability should be consider high. This also means that the dependability should be lower for readers that do not have in-debt knowledge about Thule manufacturing site in Hillerstorp.
- Confimability: The conclusions in this project have always meant to be based on objective values as this allows Thule to get an outside perspective on the company's processes. By basing all primary data from interviews from Thule some objectivity is lost as their answers heavily weight on the data compared. Although the investigated areas have been examined because of Thule's initiative, the project's final conclusion that suggests keeping the batch sizes on the current level should indicate that objectivity has been held to suitable level.

Authenticity is explained by Bryman and Bell (2005) as (1) to make sure the research give a correct image of the described setting (so that no other subjects consider the explained setting different), (2) to make sure the subjects gets a better understanding of the setting and (3) how other might perceive the setting and if the subjects are better informed so they can better act on the research's conclusions. (Bryman and Bell, 2005)

The interviewed were in different positions in Thule Sweden AB and thus described different perspectives on the company. The subjects different view have been analysed, description of the setting is explained through a CSM and other should perceive the setting as very closely similar to the setting this project has described. Therefore the authenticity is considered high.

2.4. Analytic methodology

According to Bryman and Bell (2005) a qualitative study has two basic ways to use the collected data in an analysis; analytical induction and grounded theory. Analytical induction is a method where the hypothesis is re-examined if the collected data is not confirming the hypothesis and this goes on until the hypothesis is confirmed either by changing the hypothesis or excluding the divergent data for some reason. Grounded theory is the more common method of the two and involves a process where a general thesis is the basis and then data is collected and the thesis is evaluated. After this, there is a continuous comparison between primary and secondary data until the data collected is considered content. Until the final conclusion the steps in building the research is not set in stone and each part can be re-evaluated during the study's course. (Bryman and Bell, 2005)

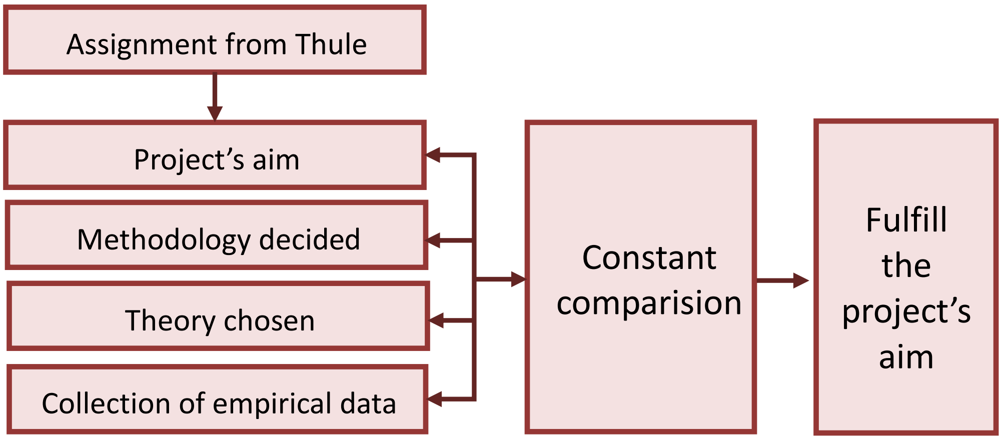

Figure 2.1. Analytic methodology (own creation, 2011)

This study have followed the steps shown in figure 2.1 and the study's theme of constant comparison made it more alike the grounded theory described by Bryman and Bell (2005) than analytical induction. The aim of the project have not been re-evaluated because any data's convergence but because of the process to make the aims as clear as possible.

3. Map product flows for item HR and item LR

3.1. Theoretical framework

The theoretical framework of this project aim starts with general information regarding what VSM is and how to use it as a tool. Thereafter the steps of creating a CSM are described with figures to strengthen the understanding of what inputs should be included and how different systems may affect the mapping of the product flows. In the theoretical chapter the shortage VSM is used which includes both the current state map (CSM) and future state map (FSM). This project will only address a CSM and thus, even if the theory mentions VSM, the project uses CSM instead in the following chapters as it is a must for a VSM and so is always included when theory mention VSM. It will also help the reader to keep track of only CSM instead of both VSM and CSM.

Value stream mapping is used to map all actions from supplier to customer (Abdulmalek and Rajgopal, 2007; Varkey *et al*., 2007) with the help of pre-defined standardized icons that can be seen appendix 1. There are several successful stories about VSM, most commonly known is the Toyota production systems (Hines and Rich, 1997). Example of other studies expressing the value of VSM are; Melvin and Baglee (2008) whom use it successfully to note specific moments where effectiveness was low in a yoghurt manufacturing company and Pan *et al*. (2010) where they reduced the lead time from 21 days to 9 days in a metal machine factory. Lee and Snyder (2006) points out that no mapping technique fits every situation and purpose but it is beneficial to use VSM for high-production, low variety product mixes with few components and dedicated equipment (when only a few products share the same equipment).

Benefits

Of the advantages that are mentioned in VSM theory, the one that is most focused on is reduced lead times (Pan *et al*., 2010; Abdulmalek and Rajgopal, 2007; Varkey *et al*., 2007). Hines and Rich (1997), however, explain VSM as a step to ensure the cross functional effectiveness by including logistics, sales, procurement and manufacturing in the overall effectiveness.

Drawbacks

For VSM to fully work it is crucial it represents an honest representation of the processes. (Pan *et al.*, 2010) There are several studies that point out that some sort of restriction is required, be it part of a supply chain (Abdulmalek and Rajgopal, 2007), practical limitations (Pan *et al.*, 2010) or specific chosen processes (Hines and Rich, 1997). There are more drawbacks with value stream mapping if it succeeds to reduce lead times, for instance increased risk to the workforce as described by Main *et al*. (2008).

Creating a current state map

According to Hines and Rich (1997) creating a current state map starts by making a preliminary list of the processes undertaken and then details about the required items are included. The activities are then categorized depending on their type, the chart is build and finally the distance moved, number of people involved and lead times are recorded (Hines and Rich, 1997). Singh and Sharma (2009) decide to draw the value stream map's outlines first (customer, supplier and production control) and then add relevant data (lead time, process time and number of shifts) to the map. Movement of product is then shown and in between workstations the work in progress stock is shown (Singh and Sharma, 2009). There are thus several ways to go about when using the VSM as a tool (Singh and Sharma, 2009; Hines and Rich, 1997).

Rother and Shook (2003) gives a more thorough walkthrough on CSM which several later studies' VSM is based on (Lasa *et al*., 2008; Abdulmalek and Rajgopal, 2007). They note that some shortcuts needs to be made, where available, and gives an example of how several processes are mapped as a single process when the flow is continuously between the stations (Rother and Shook, 2003). To create a CSM (see figure 3.1) in this thesis we will use Lee and Snyder's (2006) guide, which is slightly newer than Rother and Shook's (2003):

Steps to create a CSM:

1. Draw customer, supplier and production control icons.
2. Enter customer requirements per month and per day. If the customer orders in infrequent batches, note the frequency and batch size.
3. Calculate daily production and container requirements.
   Production should calculate the numbers on containers as well.
4. Draw inbound and outbound shipping icon and truck with delivery frequency. Note full, partial or mixed loads.
5. Draw boxes for each process in sequence, left to right and add data boxes below the process boxes and Timeline for Value-added and Non-Value Added.
6. Add communication arrows and note method and frequencies. This may require considerable investigation.
7. Obtain process attributes and add to data to the boxes.
8. Add operator symbols and numbers, inventory locations and levels in production units, push, pull and FIFO icons, working hours and any other useful information.
9. Calculate lead-times and place them on the timeline. For processes, the lead time is the process cycle time.
10. Calculate total cycle time and lead time. Add all times on the timeline at bottom and place this in an information box.

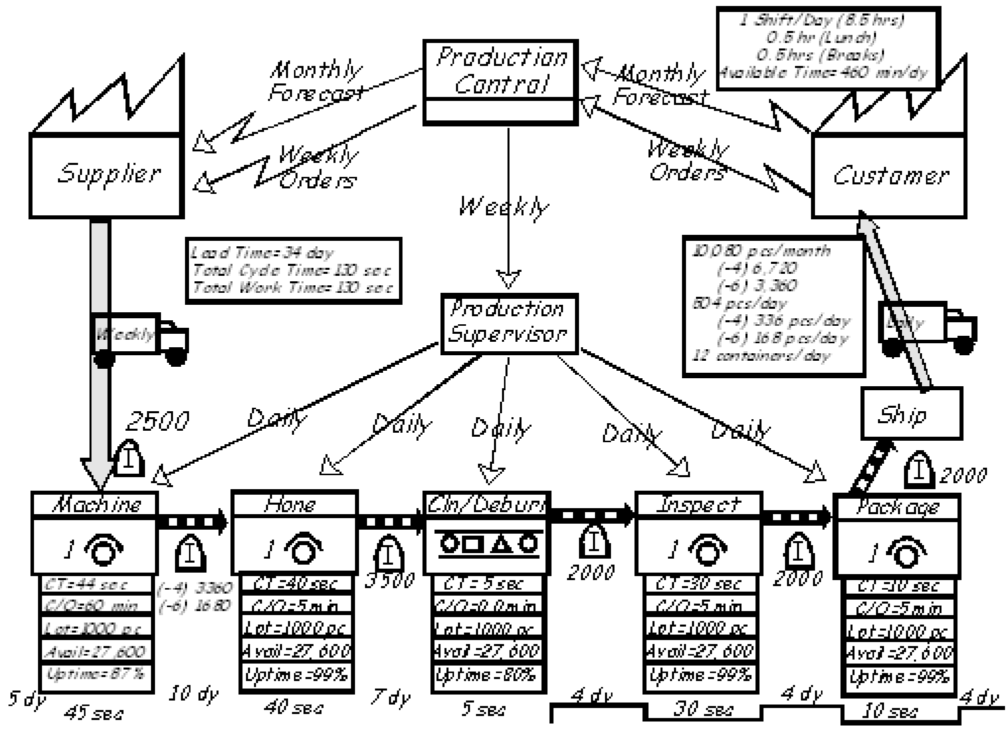

Figure 3.1. Example of a current value stream map (Lee and Snyder, 2006)

Data box information for step 7 commonly includes the following (Lee and Snyder, 2006):

- Cycle Time, the time required to produce a single unit of HR and start on the next unit.
- Person time, the time that a person or operator is occupied to produce a single piece.
- Equipment time, the time equipment or a machine is occupied producing a single unit.
- Availability Time, the total time per day that the workstation is available for production and or changeover on the product family.
- Scrape rate, the average percentage of defective product that must be reworked or scrapped.
- Other, any other useful data such as the number of other products the equipment processes.

Calculating Inventory

To calculate the days of an inventory at each inventory location, we need to estimate the average inventory, because the inventory can be higher or lower. With help of Little's Law we will be able calculate the inventory lead time by using the formula (Lee and Snyder, 2006);

Average inventory / Production rate each time unit
= Inventory lead time expressed in time units

3.2. Empirical findings

The data is sorted by the different steps in creating a current state map with a numerous of data-tables which are explained continuously throughout this chapter. All inventory data is based on the inventory level each Friday (SC Coordinator, 2011). The process to create a CSM for the LR is very similar to the HR and so the empirical data and analyse is more detailed for the HR as it is unnecessary to use the same arguments twice.

3.2.1. Item High Runner

The flow for HR initiates when the safety stock in Thule's distribution centre in Germany is reached. The order is based on the safety stock levels and a forecast model, which means that Thule receive an order when the inventory level in Germany is below a certain level or is expected to increase in demand. Production control decides whether or not a purchase should be made and procurement then receives the order. (Production Manager, 2011) The order is based on the customer requirements per month and daily demand, the data received from Thule are 667pcs per month and 22pcs per day (SC Coordinator, 2011). During this season Thule has normally two shifts working 8 hours each day with a 15 minutes break and 25 minutes lunch in each shift which equals a total working time of 14 hours and 40 minutes (Production Engineer, 2011). The time from order until delivery is estimated to 12 days from the steel supplier in full truck loads (Purchasing Manager, 2011).

The processes in the High runner flow are the following:

1. The press shop, in Hillerstorp, Sweden. Here is the raw material processed into units.
2. Surface Treatment, in Värnamo, Sweden. Where the units are surface-treated.
3. Assembly, in, Poland. Where the units are assembled into 753-3399-02.
4. Packing, in Hillerstorp, Sweden. Where the finished HR are packed.

Production control also determines the daily production calculations at each of the described processes above (Production Manager, 2011).

	Press shop	Surf. Treat.	Assembly	Packing
Cycle time	0,24s	0,075s	6,50s	3,82s
Number of operators	1	-	3	3
Operator time	0,24s	-	19,50s	11,46s
Changeover time	3,36 min	x	x	4 min
Lot size	20 000 pcs	2 240 pcs	4 800 pcs	1 280 pcs
Location Thule AB	Hillerstorp	Outscourced	Poland	Hillerstorp
Input	X1	X2	X3+A1	X4+A2
Output	X2	X3	X4	Item HR

Table 3.1. HR's processes data (Production Manager, 2011)

There is one operator handling the machine press in Hillertorp, three in the assembly in the department in Poland and three in the packing process. (Production Manager, 2011). Some data for the surface treatment is ignored because it is an outsourced process (SC Coordinator, 2011).

The 753-3399-02 the main component in item HR pack where 4 pieces are needed in each finished product. But there are other components that are necessary to complete HR. The 3 components that include the highest costs (beside the 753-3399-02) that is included into the packaging line for HR, is marked in table 4.2 below (Production Manager, 2011).

Material nr.	Quantity	Unit	Cost	Name
853-3593	X	PCS	X	X
508-0001	X	Meter	X	X
70102	X	1000	X	X
5552590001	X	PCS	0,85	X
753-0158-08	X	PCS	1,68	X
753-3399-02	X	PCS	17,30	X
753-20064	X	PCS	2,02	X
501-6620-06	X	PCS	X	X
501-6882-04	X	PCS	X	X
520-0481-05	X	PCS	X	X
5552573001	X	PCS	X	X
520-0104	X	PCS	X	X
70201	X	1000	X	X
			X	

Table 3.2. Material costs included in a HR (Production Manager, 2011)

Table 3.3 includes data for the components. The main flow for the HR includes the raw material that is translated into the components. These components are being packed with the so called extra components into the finished HR after the packing process and lastly in the central warehouse (Production Manager, 2011).

These three components (except for the 5552590001) are used for more products then the HR (SC Coordinator, 2011). Therefore table 4.3 includes data for the demand specific needed for the HR and the percentages of the next process along with the percentage of the production for HR.

	1. X1 62-2500335	2. X2 853-20182	3. X3 753-3399-02	A1 753-20064
Avg. Inventory, Hillerstorp	5 610	3 797	786	1 650
Avg. inventory, Huta	x	x	1 680	x
Total demand of this item	3 775	2 941	3 024	2 765
Amount produced	28 317	28 317	13 311	23 950
Safety stock level	x	667	x	x
Amount for HR	14 390	14 200	12 000	12 000

demand				
% of production to next HR step	100%	60,34%	84,23%	58,02%
% of production to HR	50,82%	50,82%	84,23%	58,02%
Time from order to delivery	12 days	x	x	7 days

	B1 753-0158-08	C. C1 5552590001	4. HR HR	5. HR HR
Avg. Inventory, Hillerstorp	3 331	215	161	x
Avg. inventory, Duisburg	x	x	x	288
Total demand of this item	100 067	3 008	3 008	356
Amount produced	100 067	3 008	3 008	x
Safety stock level	x	x	x	352
Amount for HR demand	3 008	3 008	x	x
% to next HR step	3%	100%	x	x
% of production to HR	3%	100%	x	x
Time from order to delivery	24 days	4 days	x	x

Table 3.3. Data to calculate inventory levels and demand (SC Coordinator, 2011)

The table below includes all the transport lead-time between different the processes to the Central warehouse in Duisburg (Transport, 2011).

Transport time from Press shop to Surface Treatment	1 day
Transport time from Surface Treatment to Hillerstorp stock	1 day
Transport time from Hillerstorp stock to Assembly	2 days
Transport time from Assembly in Huta to Packing in Hillerstorp	2 days
Transport time from Packing to Central warehouse	1 day

Table 3.4. Transportation lead-time data (SC Coordinator, 2011; Transport, 2011)

3.2.2. Item LR

Although the LR is a low demand product it is an important item that always must be in stock (SC Coordinator, 2011). The ordering of the raw material and production process of the item is similar to the HR, although the forecasts of LR are not presented to the suppliers (Production Engineer, 2011). The demand from customers during the period was 1,67 pcs each month and 0,055pcs each day, assuming 30 days each month. The working times are the same as for the HR and the delivery time from supplier of the X1 is 12 days. (SC Coordinator, 2011)

The LR processes are: (Production Engineer, 2011):

1. The Press shop. The raw material is pressed into a X1.
2. Surface Treatment. Where the X1 are surface-treated. This is the same as for the HR and so not shown below in table 3.4.
3. Bag pack. Here the X2 included in the final product are packed for the packing process.
4. Assembly. Where the X3 are assembled with other components that goes into packing.
5. Packing. Where the components from previous operations and the last components to LR are packed.

Production control decides when to initiate an operation to manufacture (Production Engineer, 2011).

	Press shop	Bag Pack	Assembly	Packing
Cycle time	0,5s	5,8s	10,4s	3s
Number of operators	0,5	1	1	3
Operator time	1s	5,8s	10,4s	9s
Changeover time	12 min	3,33 min	4 min	4 min
Lot size	20 000	x	x	50 pcs
Input	X1	X2+A1	X3+A2	X4+A3
Output	X2	X3	X4	LR

Table 3.5. LR process data (SC Coordinator, 2011)

The information in table 3.5 is the same as for the HR and calculated the same way. Note the operator time that is lower then the cycle time as the operator only needs to be active half of the cycle time. All of the above operations are placed in Thule's production site at Hillerstorp. The lot sizes in Bag pack and Assembly have been marked x, because of an assumption that Thule only uses production batches according to the orders received. This argument is strengthen by the fact that these processes do not have any finished goods inventory since they are being inserted at packing process directly (Production Engineer, 2011)

The total amount of products in the complete LR is presented below in table 3.6 along with the component costs. The orange rows indicate the three different processes in making a LR. The four green coloured rows are the components that are chosen, since they are the components with the highest costs as seen below. Note that, for instance, the X1's price of 6,42 SEK is for X pieces and not for a single piece.

Material nr.	Quantity	Unit	Cost	Name
Bag pack				
853-0446-08	X	PCS	X	X
853-0532-10	X	PCS	6,42	X
853-0929	X	PCS	X	X
853-1852-02	X	PCS	X	X
918-0622-54	X	PCS	X	X
919-0640-54	X	PCS	X	X
508-0350	X	Meter	X	X
Assembly				
753-0158	X	PCS	X	X
853-0920	X	PCS	10,27	X
853-0923	X	PCS	X	X
853-0930	X	PCS	X	X
508-1015	X	PCS	X	X
Packing				
753-1109	X	PCS	12,23	X
853-0182-02	X	PCS	X	X
853-0922	X	PCS	X	X
853-0924	X	PCS	X	X
501-4619	X	PCS	X	X
500-2000-04	X	PCS	X	X
500-0179	X	PCS	6,44	X
504-0002-05	X	PCS	X	X
504-0010	X	Meter	X	X
520-0104	X	PCS	X	X
			X	

Table 3.6. Material and costs included in a LR (Production Engineer, 2011)

Table 3.7 below contain all the necessary data to calculate inventory levels throughout the LR product flow based on the four components chosen in table 3.6. As LR is a low demand item several of the data presented for the HR in table 3.3 is ignored as any effect the total demand from each operation is not sufficient to affect any cost relevant to batch sizes. The percentage of an items dedication to the LR is presented as this is used to calculate the average inventory in Hillerstorp.

	1. X1 63-2501480	2. X2 853-0532-10	A.1 853-0920	B.1 753-1109
Avg. Inventory, Hillerstorp	1 040	79	758	1809
Safety stock level	x	x	x	x
% of production to LR	0,97%	10%	8,68%	100%
Time from order to delivery	12 days	x	6 days	20 days

	C.1 500-0179	LR 101024
Avg. Inventory, Hillerstorp	10	7
Safety stock level	x	x
% of production to LR	100%	100%
Time from order to delivery	20 days	x

Table 3.7. Data to calculate inventory levels and demand (SC Coordinator, 2011)

On the contrary from the HR the LR has a small amount of lead time between the different operations. The processes are all placed in Hillerstorp and the transportation times between the operations have therefore been ignored, with the exception of lead times between Thule and Supplier A (assumed the same as for the HR). The finished products are placed at a finished goods inventory until the shipment to the customer. (Production Engineer, 2011)

3.3. Analysis

In the analysis a CSM will be created for each of the two products. In chapter 3.3.2 the figures that show the different steps will not be shown for the LR as for HR in chapter 3.3.1. This is because most of the explanation is done in chapter 3.3.1 and it is unnecessary to repeat the same arguments.

3.3.1. Item HR

The start of a CSM – step 1-4

Creating a current state map starts by making a preliminary list of the processes undertaken and details about the items required (Hines and Rich, 1997). The first process for the flow of HR initiates the when the safety stock in Thule's distribution centre in Germany is reached, an order is then sent to Thule in Hillerstorp (Production Manager, 2011). The average demand of the HR is 667 pieces each month and 22 pieces each day (SC Coordinator, 2011). Also, the total amount of available manpower time is included.

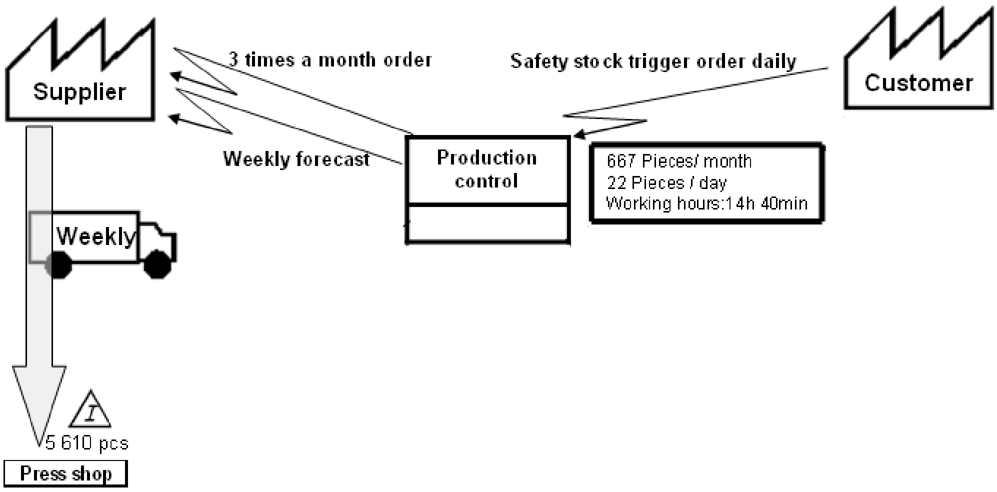

Figure 3.2. Current state map steps 1-4 (own creation, 2011)

When the information has reached the production control the information is used to start the procurement process of the raw material needed for the HR (Production Manager, 2011). Thule orders three times a month and purchases based on weekly forecasts. Each purchased batch of raw material is placed in the raw material stock until production orders are given from the production control (SC Coordinator, 2011). The first step in creating a current state map is illustrated in figure 3.2 above, this is made by drawing the CSM outlines first (customer, supplier and production control) and then add relevant data

(Singh and Sharma, 2009). This has been more detailed done by using step 1-4 in Lee and Snyder's (2006) CSM model.

Map the processes – step 5-8

Step 5-8 in Lee and Snyder's (2006) CSM model is to map the processes that the HR takes before being a finished product and the specific operation's data required in the data boxes (figure 3.3). Step 8 includes adding the inventory locations and levels (Lee and Snyder, 2006). The average inventory levels have been provided by the SC Coordinator (2011) as well as the percentage of the production of each material used to the HR. The average inventory levels used in this CSM is therefore the average inventory level dedicated to the HR.

The central warehouse in Duisburg has an average inventory of 288 pieces (SC Coordinator, 2011), and the time in inventory for the HR are 13 days before reaching the end customer. The lead time to the customer is ignored to focus on the manufacturing process' different steps and warehousing costs:

Lead time in inventory for HR in central warehouse:

Average inventory / (total customer demand / days during the period) = 288 / (2669 / 120) = 13 days

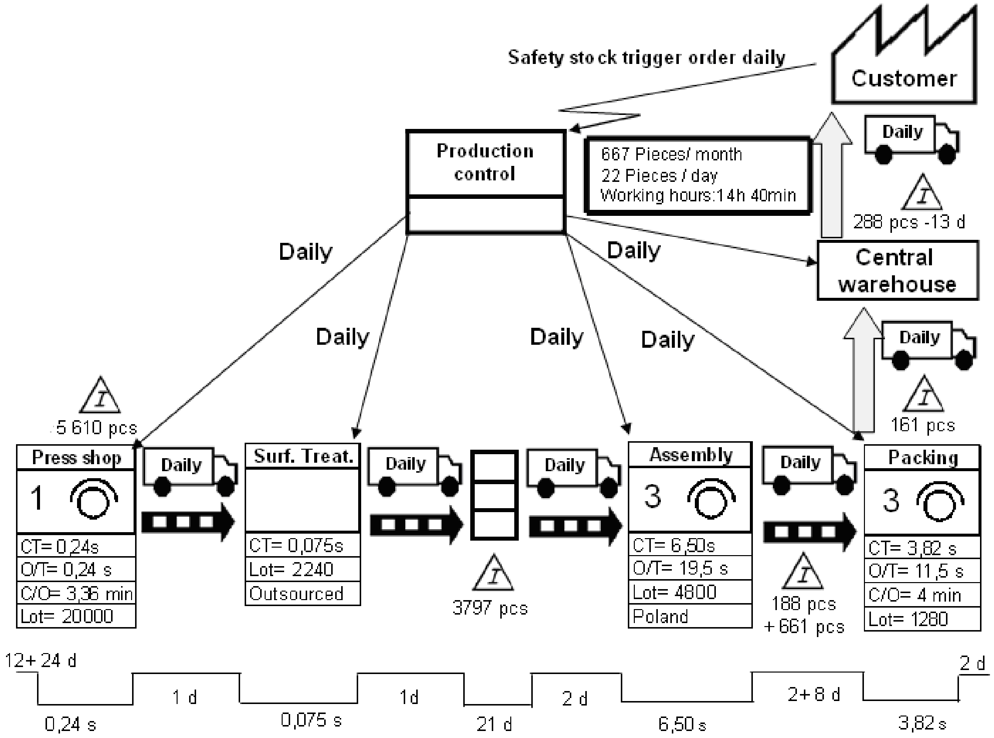

Figure 3.3. Current state map steps 5-8 (own creation, 2011)

Calculate the lead times for the main component – step 9-10

Transportation lead time is inserted in the CSM as shown in table 3.4. The lead time of 24 days before the press shop is calculated by the following formula (Lee and Snyder, 2006):

> **Lead time in inventory from order to press shop:**
>
> Average inventory / (total demand from press shop / days during the period)
> = 5 610 / (28 317/120) = 24

The data in the Press shop is the data provided by Thule (SC Coordinator, 2011). The scrap rate and available time is not included in the conclusions regarding batch size policy and thus is ignored in the CSM.

Between the Press shop and Surface treatment there should be an average inventory level but as the loop-truck make two pick up's each day and Thule's system does not have this number (SC Coordinator, 2011) the average inventory here is therefore considered negligible. This goes in line with Pan *et al*.'s (2010) point to make an honest representation of the value stream and take practical limitations into considerations.

The next process is the Surface treatment which is done externally at Supplier A (Production Manager, 2011). As an outsourced operation, Thule has less power over that process and so the data does not need to be as detailed as other processes. When the X1 arrive at Thule they are stored at a semi-finished inventory before being sent to the Poland department (SC Coordinator, 2011). Each X1 has a time in inventory of 21 days, calculated by using Little's law (Lee and Snyder, 2006) as was done with the steel before.

Lead time in inventory from arrival at stock until shipped to Huta:

Average inventory / (total demand from press shop / days during the period) = 3 797/ (22 060/120) = 21 days

Normally, the time between two operations is shown as a single movement but in this case we have chosen to show the time in inventory specifically as it can be considered substantial. It should be noted that this inventory also satisfy the demand of 15 other items (SC Coordinator, 2011).

The Assembly is the process with the highest cycle time in the flow (Production Manager, 2011) and is therefore considered the bottleneck (Koo *et al*, 2007; Lee and Snyder, 2006). However, this bottleneck is place in Poland and might not be the primary concern of the flow in Hillerstorp. The Assembly operation is, however, a part of Thule and so the information shown should include an assessment of the cost to produce a single item and so the total operator time is included. The total operator time is 19,5 seconds which is simple to calculate (Lee and Snyder, 2006):

Operator time in Huta:
Cycle time · numbers of operators = 6,50 · 3 = 19,5 s

The average inventory level in Poland is unknown but the safety stock level is known at 224 pieces and instead of making a guess, this project uses the safety stock level as the average inventory as it is known:

Lead time in inventory from assembly to arrival at Hillerstorp:
Average inventory / (total demand from Packaging / days during the period) = 224 / (14 285 / 120) = 1,88 days

Lead time in inventory until packaging:
The inventory in Hillerstorp uses the same demand rate from Packaging as Huta: 785 / (14 285 / 120) = 6,6 days

Total lead time:
From Assembly until Packaging is estimated to 8 days

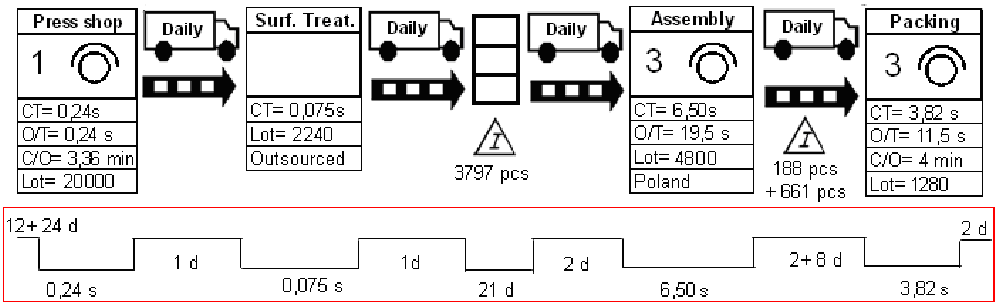

Figure 3.4. Process and transportation lead times (own creation, 2011)

In Packaging, the batch size of each series is 170pcs and the average inventory after packing is 170pcs (SC Coordinator, 2011). The time in inventory for HR is in inventory for 1 day before the 1 day transport to Germany, giving a total lead time of 2 days (SC Coordinator, 2011). Note that this is not calculated. The average inventory is based on amount in stock each Friday during the period but the inventory at hand is always depleted and shipped to Germany at first opportunity (SC Coordinator, 2011). This is considered similar to Rother and Shook's (2003) suggestions of shortcuts where we can ignore the average time in inventory as Fridays are not regular shipping days to Germany.

Lead times and inventory for the extra components – step 9-10

The packing process in Hillerstorp requires extra components that are needed in the packing of the final product (Production Manager, 2011). These extra components have been added to the Lee and Snyder's (2006) CSM model of a current state map to increase the understanding of the HR flow. The lead time for the 753-20064 is:

Lead time in inventory for 753-20064:

Average inventory / (total demand from Packaging / days during the period) = 1 650 / (20 739 / 120) = 10 days

For the next component (753-0158-08) there is an issue. The main problem is that the item is used in several hundred products and therefore the total demand of this article is extremely time-consuming to find (SC Coordinator, 2011). The demand of HR and the total amount of 753-0158-08 are produced is available, however. With this we can instead use the HR's demand of this item and then use it to calculate the average inventory dedicated to HR and then estimate the average lead time for the 753-0158-08. The lead time for the last item included in the CSM, the 5552590001, is calculated the same way as the 753-20064 (described above). The transportation lead time is supplied SC Coordinator (2011) from table 3.3.

HR demand in relation to 753-0158-08's total production:
Amount of HR produced / total amount produced of 753-0158-08
= 3 008 / 100 267 = 0,03

Amount of average inventory dedicated to HR:
Average inventory of 753-0158-08 · 0,03 = 3 331 · 0,03 = 100

Lead time in inventory for 753-0158-08:
Average inventory / (total demand from Packaging / days during the period) = 100 / (3 008 / 120) = 4 days

Lead time in inventory for 5552590001:
215 / (3008 / 120) = 9 days

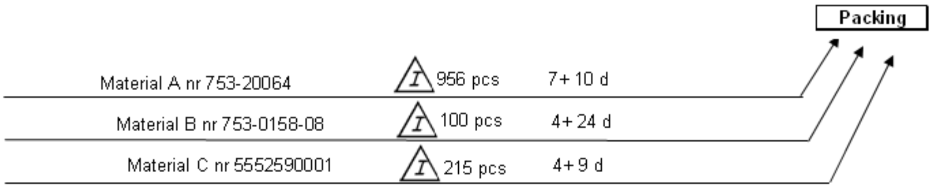

Figure 3.5. Data for extra components into packing process (own creation, 2011)

Implication of the HR's CSM

CSM is beneficial to use for high-production, low variety product mixes with few components and dedicated equipment (Lee and Snyder, 2006). As we have seen in the mapping of HR, this product fits the condition above, even though the number of components most likely can not be considered low. The CSM is mostly used to reduce lead times (Pan *et al*., 2010; Abdulmalek and Rajgopal, 2007; Varkey *et al*., 2007). As the total lead-time of one unit of the HR throughout the flow is either in inventory and transport a total of 86days (see figure 3.6), not counting the operation cycle times, the road to a just-in-time or lean production is further down the road but the CSM is good step towards it (Pan *et al*., 2010; Abdulmalek and Rajgopal, 2007; Varkey *et al*., 2007).

Another interesting point shown in the CSM is that we can clearly see a tendency of the Bullwhip-effect in the presented flow. The first inventory has a total time in inventory of 24 days, semi-finished inventory has 21days and the finished-goods inventory at central warehouse has 13 days. This means that first inventory can meet 24 days of demand for the following process and so on. This is what Hines and Rich (1997) sees as an outcome of the CSM, a step to ensure the cross functional effectiveness by including logistics, sales, procurement and manufacturing in the overall effectiveness and the importance of it is clearly shown at in this CSM.

As two of the inventories in the CSM will be important in latter chapters a specific definition is used for these. The inventory before Assembly is the semi-finished inventory and will be called inventory 1 (I_1 for short). The central warehouse's inventory is the finished-goods inventory and is called inventory 2 (I_2).

The stock at I_2 has an average inventory level that cover 13 days of demand. If the inventories between Assembly and Packaging are removed, the inventory level at the I_2 covers the lead time between I_1 and until delivery at I_2. Removing these stocks would decrease lead time with 8 days. I_1 has a long time in stock (21 days). This stock must, however, satisfy the demand of several other articles and so it is probably hard to decrease this stock. With the average time of 21 days I_1 should cover for the lead time from order of raw material until Surface treatment is completed and transported back to Thule. If these two inventories are the only ones in the system, the lead time will decrease with 32 days.

In short – according to the CSM for HR the only two needed inventories are I_1 and I_2 (figure 3.7). This is, of course, without considering different costs associated with the batch size's costs presented in chapter 4.1.

3.3.2. Item LR

The start of a CSM – step 1-4

The CSM for LR is based on the same steps defined by Lee and Snyder (2006) that was made in chapter 3.3.1. The first four step's data used is the demand of 1,67pcs during each month which calculates to 0,055pcs each day (SC Coordinator, 2011). The working hours are the same as in the HR and an order is received when production control decides to produce a batch (Production Engineer, 2011). A notation should be made as the LR is a slow moving item that orders are seldom placed (SC Coordinator, 2011), the delivery frequency from the supplier is not included. The data for lead times between the suppliers and delivery to Hillerstorp have been presented in table 3.7 and is included in the CSM as made for the HR.

Map the processes – step 5-8

Lee and Snyder's (2006) latter steps are done as in the previous chapter for the HR. Bag pack and Assembly are placed at a mutual time with a push system to the Packing-line. The finished LR are then packed in the packing-line and sent to the local warehouse (Production Engineer, 2011). The processes' data boxes are then filled with the relevant data. As the processes Bag pack and Assembly are placed together, they are shown in the CSM with the same cycle time, based on the cycle time of the Assembly process since it is the one with the longest lead time.

Next, the extra articles and material used for the final product are added in the stream as drawn and argued for the HR. With the exception of the X2 (semi-finished inventory), there are no inventories between any operations and as the time between the operations (again with the exception semi-finished inventory) are negligible as well as the average inventory.

Calculate the lead times – step 9-10

The lead times for the average inventory are calculated with Little's law (Lee and Snyder, 2006). Note that the average inventory level is using the amount of the average inventory that is dedicated to the LR. This means that the amount of X1 dedicated to LR is 0,97% of the average inventory and it goes 8 pieces for each sold LR.

Average time in inventory for X1 until Press shop:
(Average inventory level · percentage dedicated to LR) / (daily demand of LR · amount of item in each LR)
= (1040 · 0,97%) / (0,55 · 8) = 23 days

Average time in inventory for X2 until Bag pack:
= 18 days

Average time in inventory for X3 until Assembly:
= 18 days

Average time in inventory for A1 until Packing:
= 4342 days

Average time in inventory for A2 until Packing:
= 161 days

Average time in inventory for LR until delivery:
= 130 days

The lead times from order to delivery is also included as taken from the empirical data. The lead times to the finished goods inventory are considered one day as it is picked up by the loop truck and so is a practical estimation. (SC Coordinator, 2011)

As the stream of the LR is simpler and more locally placed than the HR, the CSM can also include the article number of the item at each location as the CSM will still not feel too complex to understand. Also, although four different streams are shown, the CSM will be understandable for the reader to recognize the points made in the following analysis. For the finished CSM of the LR's stream, see figure 3.8.

Implication of the LR's CSM

As with the HR, the inventory before Assembly (and Bag pack) is considered Inventory 1 and will be shortened to I_1. The warehouse which holds finished-goods inventory is Inventory 2 (I_2). This will simplify the text for the reader.

The fact that the LR is a slow moving item and that the operations is on more levels than the HR should make a CSM harder to produce and give a basis to improvement (Lee and Snyder, 2006). However, the product is rather simple to illustrate. The CSM therefore gives a good understanding of the flow and its problems. The sporadic and low demand of LR is making the batch sizes runtime shorter and closer to set up time and work against lean management.

Although the item is considered an important article (SC Coordinator, 2011) the question arises, whether the product must be in stock or should be made to order, or perhaps to be kept at inventory only at the warehouse? When viewing this CSM in chapter 3.4.2, there are rather high inventory levels. The economical loss of not being able to deliver instantly must be relatively high to go beyond the inventory holding costs. Also, if scheduled correctly, a batch of a X pieces should be able to be shipped within 2 days. Make-to-order is possible for this item, from I_1. That is, under an assumption that the production can focus on this item instantly. During the high season this is not an option and inventory is therefore a must (SC Coordinator, 2011).

The average demand each day is not actually normally distributed (SC Coordinator, 2011). Orders come in at equal 50 batches from customer and so equals of X are produced in the flow (Production Engineer, 2011). This sporadic demand does make it more difficult to decrease inventory levels, but if other products which have a similar demand situation could get a forewarning of 20 days from customer there would be no need for any inventory. For this type of small moving items the cost savings for not being in need of any inventory in Thule would be significant.

As for the HR the only inventories worth considering are the semi-finished inventory (I_1) and the finished goods inventory (I_2). The choices existing are to make to order until I_1 (and keep inventory at I_2) or keep inventory at both I_1 and I_2. Also, if the raw material inventory is removed the lead time would decrease with 23 days, further strengthen a lean production.

The most noticeable with the LR's flow is long inventory lead times. The average time a single roof cover is in stock is almost 12 years. In this case there is nothing to do but there might be other items with similar demand where the same problem might arise if left alone. The cost of the inventory holding costs of Roof covers amount to X SEK each day (7,5%*X/360*X=X). This is an unnecessary cost. And this is the cost for the Roof cover alone, ignoring the other components for the LR. A cost of X SEK each day (or about X SEK each year) might not sound so much, but if there are 50 similar components within the plant, the total holding costs will be substantial.

3.4. Conclusion

3.4.1. Item HR

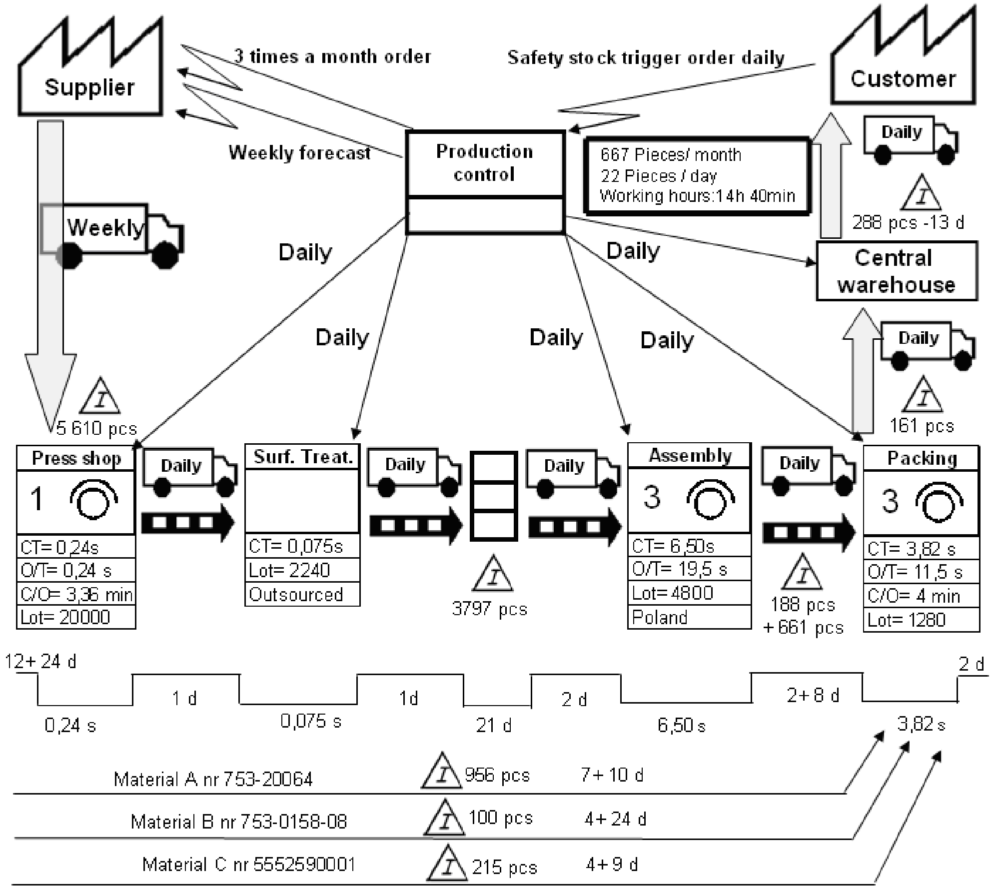

Figure 3.6.Current state map for HR (own creation, 2011)

- The CSM show a noticeable bullwhip effect in the company.
- The CSM shows that I_2's level covers the lead time from I_1 until delivery to I_2 if the inventories between Assembly and Packaging are removed.
- If the stock of raw material is removed, I_1 covers the entire lead time from order until delivery from the Surface treatment.
- Removal of the raw material and the inventories placed between Assembly and Packing decrease the total lead time with 32 days.
- The only inventories needed in the stream are I_1 and I_2 as shown in figure 3.7.

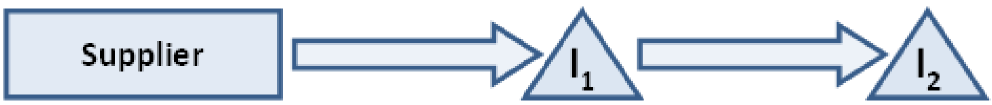

Figure 3.7. Supplier to I_{1-2} (own creation, 2011)

3.4.2. Item LR

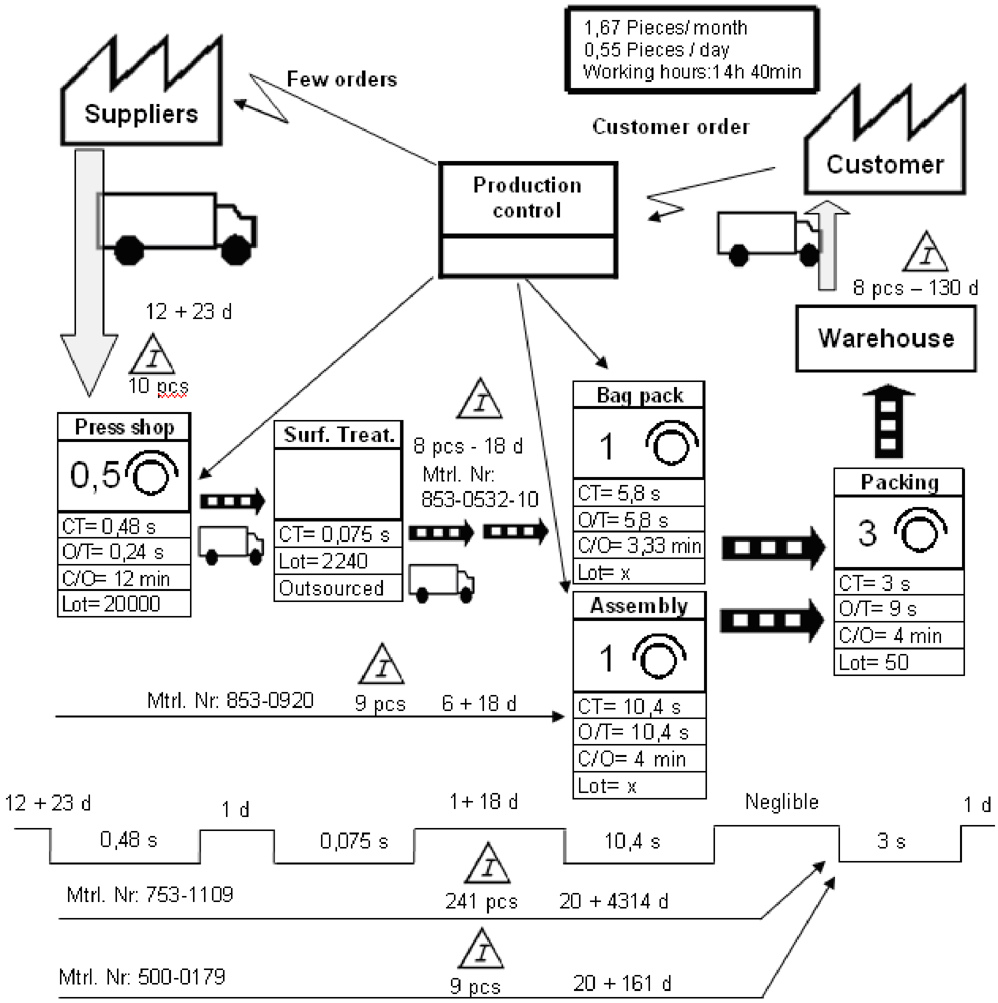

Figure 3.8.Current state map for LR (own creation, 2011)

- The low and sporadic demand works against lean management.
- It is questionable whether the cost for not having the item in inventory is high enough to overshoot the holding costs or if a make to order policy should be taken. The potential savings for a make-to-order policy would be considerable.
- The only inventories needed in the stream are I_1 and I_2 as shown in figure 3.7. This will decrease the total lead time with 23 days.
- The inventory lead times are exceptionally high at some locations. The cost of the Roof cover alone amounts to X SEK each day.
- There might be other items with similar demand where the long inventory lead time issue also might arise if left alone.

4. Describe Thule's current batch size policy

4.1. Theoretical framework

This chapter is based on general batch size theory regarding procurement, transportation, operations and warehousing. These departments have specific costs that will be affected by smaller batch sizes and are described in this chapter. Theory regarding cross functionality and integration will also be explained to be a basis to describe Thule's current batch size policy. For easy reading the theoretical framework is summarized in chapter 4.1.6.

4.1.1. Procurement

Companies tend to spend up to 55% of earned profits on purchased materials and so is a key department for the firm's performance and market value (Burke *et al.*, 2007). There are more to consider than spend money (Piercy and Rich, 2009). A lean-focus in procurement can result in inventory reduction (Piercy and Rich, 2009), quality improvements (Bonavia and Marin, 2006), reduction in material procurement cycle time (Bhasin and Burcher, 2006), smaller batch sizes (Browning and Heath, 2009), more reliable delivery and long term supplier relationships (Wilson and Roy, 2009). Chen (2000) mention that even if lean is advantageous, raw material tends to be ordered in full truckloads to qualify for quantity discounts.

Procurement is, according to Aissaoui *et al*, (2007), depended on the sourcing situation. With single sourcing (few suppliers), all suppliers can fully meet the buyer's demand and partnerships should be built with these suppliers to achieve shared benefits in the supply chain (Burke *et al.*, 2007). The importance of selecting and maintaining close relationships with a few, reliable and high-quality vendors in a lean environment is also mentioned by Ho *et al.* (2010) and Lee (2009). Multiple sourcing (many suppliers) is used wither when none of the suppliers are able to satisfy the buyer's total demands, when the company wishes to receive the lowest price or when procurement strategies aim at avoiding dependency on a single source (Aissaoui *et al.*, 2007).

Procurement costs in relation to batch sizes

Procurement costs are the order cost that arrives each time an order is placed and consists of a variable plus a fixed component (Nahmias, 2009; Jonsson, 2008). With smaller lot sizes the total order cost increase, assuming the same total order quantity (Nahmias, 2009).

Variable order cost: This cost take into account the purchasing or producing cost of the item (Nahmias, 2009). If there is a possibility of quantity discount, the total variable cost will decrease when increasing the ordered batch (Chen, 2000).

Department	Cost	Effect	Reason to the effect
Procurement - buy smaller lots	Variable order cost	↑	Reduces quantity discount

Table 4.1. Effect of variable order costs and smaller batch size (own creation, 2011)

Fixed order costs: This includes the costs for placing an order that are independent on the order size, for instance administrative costs (Jonsson, 2008). When estimating the fixed order cost, only costs that are connected to the ordering decision should be taken into consideration (Nahmias, 2009). As it is independent from the order size, it will increase if the amount of placed orders is increased (Jonsson, 2008).

Department	Cost	Effect	Reason to the effect
Procurement - buy smaller lots	Fixed order cost	↑	Increase the amount of orders placed

Table 4.2. Effect of fixed order costs and smaller batch size (own creation, 2011)

4.1.2. Transport

To understand the effect of batch sizes on transports its worth mentioning Khan and Sarker's (2002) description of JIT, also shared by Rhodes *et al.* (2006), where small produced batch sizes is one of the key elements for a successful JIT. But small batch sizes' also mean more movement of items and in the traditional JIT the supplier of raw material is often located in close proximity of the manufacturing facility and is capable of receiving and delivering raw material in smaller quantities (Khan and Sarker, 2002). Also the supplier is usually dedicated to the manufactory or warehouse in question

(Rhodes *et al.*, 2006). The supplier is generally a single source of material as mentioned by Burke *et al.*, (2007) as in the lean management where small batch sizes are usually bought from a few suppliers who can deliver in small quantities at the correct time and place (Wilson and Roy, 2009; Aissaoui *et al.* 2007). In contrast, Chen and Lee (2008) built a model where the normal optimal solution is outshined if batches to the same destination can be grouped.

Transportation costs in relation to batch sizes

The specifically costs related to transportation contains three major variables; the movement cost of the item, the pipeline cost and the safety stock cost (Gupta, 2008).

Movement costs: This is the cost related to the costs of moving the item from one location to another, for instance the price of the transportation from supplier to the company (Gupta, 2008). Smaller batch sizes increases movement costs (each transportation add a fixed cost just as the fixed order cost do), unless the cost is completely dependent on the shipment quantity (Khan and Sarker 2002; McCann, 2001). Gupta (2008) also argues that transportation costs should be considered fixed and so should ignore the costs dependent on the shipment quantity.

Department	Cost	Effect	Reason to the effect
Transportation - smaller batches in transit	Movement cost	↑	Increased number of transportations

Table 4.3. Effect of movement costs and smaller batch size (own creation, 2011)

The pipeline cost: Is the cost for holding inventory in transit and if the total amount transported or the lead time does not change, neither does the pipeline cost (Nahmias, 2009). It is otherwise the same as inventory holding costs (Gupta, 2008) and is further discussed in chapter 4.1.4.

Department	Cost	Effect	Reason to the effect
Transportation - smaller batches in transit	Pipeline cost	↕	Depend on how lead times and amount of transport changes

Table 4.4. Effect of pipeline costs and smaller batch size (own creation, 2011)

The safety stock cost: This is the part of the inventory that protects the company from demand variability during lead times (Kelepouris *et al*., 2008) and from the bullwhip effect (Lee *et al.*, 2004). To reduce the bullwhip effect and thus decrease the necessary safety stock, Lee *et al*. (2004) mentions smaller batch sizes as one of the means as well as decreasing lead times. The advantageous effect of smaller batch sizes on the bullwhip effect is also argued by Geary *et al*. (2006). The size of safety stock is heavily dependent on the variation on lead times to receive another order at the warehouse and by decreasing this variation the average stock level decreases but it should be noted that with smaller batches there are more chances for variation of lead time to occur (Nahmias, 2009).

Department	Cost	Effect	Reason to the effect
Transportation - smaller batches in transit	Safety stock	↓	Reduce bullwhip effect and more reduction if lead time decreases with smaller batches.
	Safety stock	↑	More chances for the SS to be depleted

Table 4.5. Effect of safety stock costs and smaller batch size (own creation, 2011)

4.1.3. Operations

Operations costs in relation to batch sizes

Gupta *et al.* (2010) explains the basic conflict of batch sizing and production: shall we aim to decrease holding costs or set up costs? A bit more complicated is it according to Jamal *et al*. (2004) where it is explained that the costs involved are work-in-progress costs, set up costs, processing costs, and shortage costs. Numerous parts of the operation is affected by the batch sizes; over production (Laínez *et al.*, 2009; Wang *et al.*, 2005) and bottlenecks (Pinedo, 2009).

Work-in-progress holding costs: Is the holding costs of inventory during the manufacturing operation (Nahmias, 2009). If the batch size is halved the average time as work in progress is also halved, assuming that no item moves on until the batch is completed (Nahmias, 2009). It is otherwise the same as holding costs and is further explained in chapter 4.1.4.

Department	Cost	Effect	Reason to the effect
Operations - schedule smaller batches	Work in progress	↓	See holding costs

Table 4.6. Effect of WIP costs and smaller batch size (own creation, 2011)

Processing costs: These costs occur whenever a single piece is produced (Jamal *et al.*, 2004) and thus are part of the order cost (Nahmias, 2009). The total processing costs are decreased per item in a larger batch size (Xiong and Schoenung, 2010) as according to the standard economy of scale-mindset explained by Searcy and Flynn (2008) where the fixed costs decreases in relation to each single items total cost if batch sizes are increased.

Department	Cost	Effect	Reason to the effect
Operations - schedule smaller batches	Processing costs	↑	Part of order cost

Table 4.7. Processing costs effect on smaller batch size (own creation, 2011)

Set up costs: This is the cost for setting the machine for next-in-line production (Nahminas, 2009),. It is often set as disregarding the size of the batch size making the cost correlated to number of batches and so increases with each extra batch (Aryanezhad *et al.*, 2010). Bichecno *et al.* (2001), point out the fact that if the number of times a machine is set up is increased, the workforce tend to be more effective and thus will start to decreasing each set up's time. Workforce agility is commonly described as a strategy that facilitates profitability in rapidly changing, and uncertain production environments (Qin and Nembhard, 2010). A lack of workforce agility has been reported as one of the main reasons that some enterprises have difficulty keeping up with markets and technological changes (Sherehiy *et al.*, 2007).

Department	Cost	Effect	Reason to the effect
Operations - schedule smaller batches	Set up costs	↑	Chance that workforce learns faster set ups Trade off to holding costs

Table 4.8. Effect of set up costs and smaller batch size (own creation, 2011)

Shortage costs: Are the costs related to not being able to meet a customer's demand directly (Nahmias, 2009). Shortage costs (penalty costs) will be discussed in chapter 4.1.4 warehousing.

Department	Cost	Effect	Reason to the effect
Operations - schedule smaller batches	Shortage costs	↕	Depend on how fill rate is changed

Table 4.9. Effect of shortage costs and smaller batch size (own creation, 2011)

Overproduction costs: In contrast to shortage costs its worth mentioning overproduction cost as described by Laínez *et al*. (2009) where the cost for overproduction is the extra inventory holding costs. By reducing lead times in production the replenishment times improves, and making the production more respondent to demand uncertainties while lowering inventories (Arnheiter and Maleyeff, 2005). Overproduction costs can also be included in the interest rate used to calculate holding costs as done by Nahmias (2009) and Kwak *et al*. (1991) in chapter 4.1.

Department	Cost	Effect	Reason to the effect
Operations - schedule smaller batches	Overproduction	↓	Less overproduction from shorter production lead times

Table 4.10. Effect of overproduction with smaller batch size (own creation, 2011)

Bottle necks: A costly part of a manufacturing process it bottlenecks that often exists in each process and several studies comment on the importance of dealing with bottlenecks (Pinedo, 2009; Koo et al., 2007; Lee and Snyder, 2006). Identifying bottlenecks is a rather simple process: a bottle neck is the process with the longest cycle time (Koo *et al*, 2007; Lee and Snyder, 2006). Ronen and Pass (2008) describe two ways to deal with a bottleneck in manufacturing companies; (1) get the utilisation of the machine as close to 100 percent as possible and (2) reduce the time the machine is devoted to non value added activities. Pinedo (2009) state that maximising a manufacturing company's output is often the same as maximising the efficiency of the bottleneck. Koo *et al*. (2007) also describe the basic batch size problem but recognize that the waiting at the bottleneck-machine often stands for the most part of the manufacturing's lead time. This, in turn, shows on the importance of choosing the correct batch size that makes sure the bottleneck machine always operate and still minimize the waiting time at the machine (Koo *et al*., 2007).

Department	Cost	Effect	Reason to the effect
Operations - schedule smaller batches			
	Bottleneck	↓	Decrease WIP lead time
		↑	Reduced utilization of bottleneck

Table 4.11. Bottleneck effect on smaller batch size (own creation, 2011)

4.1.4. Warehousing

The warehousing handles the inventory levels in all departments in a value chain and as seen above, the cost for holding inventory is always present in other departments (Piercy and Rich, 2009; Gupta, 2008; Jamal *et al*., 2004)

Batch sizes affect inventory levels in different ways, Sarker and Parija (1996) mentions the statistically effect smaller shipments has on the customers inventory level. That is, between two companies in a supply chain (or between departments), if one part can deliver smaller batches then the inventory level have a tendency to drop (Sarker and Parija, 1996).

Lean principles imply a target of near zero buffer inventories which force managers to appreciate the risks of stock outs and supply chain failures (Polito and Watson, 2006). Lynn (2005) warns about the risk to firms of dangerously under buffered international supply chains. Too narrow focus on order fulfilment activities, lack of bargaining power with larger suppliers, lack of managerial time and attention, lack of resources for integration are other risks (Wilson and Roy, 2009).

The effect of inventory is one of the most basic costs that are included in most research regarding batch sizes (Gou *et al*., 2008; Bicheno *et al*. 2001; Moinzadeh and Lee, 1986) and the cost for holding inventory is always present in other departments (Piercy and Rich, 2009; Gupta, 2008; Jamal *et al*., 2004). Lean management is an example of how to take measures against inventory costs and has been developed, beside minimizing waste, to minimize inventory (Jonsson, 2008) and to minimize batch sizes to such a degree that make-to-order is possible (Arnheiter and Maleyeff, 2005).

Warehousing costs in relation to batch sizes

Nahmias (2009) explain three types of costs in a warehouse when minimizing the costs generated by inventory levels. These are holding costs, order costs and penalty costs (Nahmias, 2009) where the holding costs are described as the single largest logistic-related cost (Jonsson, 2008).

Holding costs: The basis of the holding cost is the value in percentage that is put in relation to the value of the item and is called by Nahmias (2009) the annual interest rate. By studying Kwak *et al*. (1991) and Nahmias, (2009) the following components can be considered when determining the interest rate:

- Cost of capital – opportunity cost of alternative and also includes several accounting measures such as rate of return, return on assets and the minimum rate that makes an investment attractive to the company.
- Cost of insurance and taxes.
- Risk of theft.

- Risk of breakage, spoilage, deterioration and obsolescence.
- Cost of storage space.

Some of the above mentioned costs included above can be calculated or included as separate costs, for instance obsolescence (overproduction) (Laínez *et al*., 2009). The annual interest rate is dependent on these costs and is simply added to the percentage to get a quantifiable cost of inventories (Nahmias, 2009).

To calculate the holding costs this percentage is used in relation to the value of the product. Based on Nahmias (2009) the following example is presented: If article X costs 100 SEK and the holding cost is 37% then the company's holding cost for that certain item is 100*0,37 = 37 SEK for every year. If one period is one month an acceptable estimate is 37/12 = 3,08SEK (Nahmias, 2009).

According to Nahmia's (2009) proposed calculation regarding holding costs to change the holding costs with different batch sizes, the amount of average inventory or the lead time per item must also be changed (Nahmias, 2009). According to Bicheno *et al*. (2001) the inventory holding cost also tends to be underestimated.

Department	Cost	Effect	Reason to the effect
Warehousing - order smaller batches	Holding costs	↓	Trade off to set up costs Often underestimated Inventory tend to decrease

Table 4.12. Effect of holding costs and smaller batch size (own creation, 2011)

Order costs: Are the costs for placing orders to produce or bought and has been discussed in chapter 4.1.1. Order costs at the warehouse is a representation of other departments cost to produce or purchase an order (Nahmias, 2009).

Department	Cost	Effect	Reason to the effect
Warehousing - order smaller batches	Order costs	↑	See variable and fixed order costs

Table 4.13. Effect of order costs and smaller batch size (own creation, 2011)

Penalty costs or shortage costs: Is the cost that occurs when a demand can not be instantly fulfilled and shows the increased chance that the customer instead chooses a competitor (lost sales) (Seifbarghy and Jokar, 2005), that the firm loses good-will (Nahmias, 2009) or even looses the customer completely (Jonsson, 2008). Nahmias (2009) and Jonsson (2008) agree that estimating penalty costs are difficult and neither proposes any solution to estimate them and suggests that using a target fill rate is more widely used.

Department	Cost	Effect	Reason to the effect
Warehousing - order smaller batches	Penalty- or shortage costs	↕	Depend on how fill rate is changed

Table 4.14. Penalty/ shortage costs effect on smaller batch size (own creation, 2011)

4.1.5. Cross functional batch sizes

Cross-functional integration typically involves facilitating communication among different functions (Emery, 2009; Troy *et al.*, 2008). By increasing both communication frequency and the flow of information in the organization several benefits appear, for example, hospitals with a high level of cooperation across functions are characterized by a high level of informal communication and successful project teams (Troy *et al.*, 2008).

Supply chain management and cross functional integration is close related as both consists primarily of information sharing (Emery, 2009; Mitra and Singhal, 2008). There are studies that mention the correlation of increased integration and increased stock value and thus showing on one of the economical benefits of integration between departments (Mitra and Singhal, 2008). The more internal benefits consist of enhanced value to the customers, reduced errors and waste, improved performance and reduced cycle time and improved usage of resources (Emery, 2009).

The dangers with cross functionality can be increased costs (Brettel *et al.*, 2011), that it will not always lead to more effective and efficient results (Troy *et al.*, 2008), high complexity (Brettel *et al.*, 2011) and the difficulty to see the results of increased cross functionality (Vaart and Donkas, 2007). Also, to achieve total coordination between different parts in a supply chain there is a need of being demand driven and not lot sized (Chandra and Kumar, 2000).

Emery (2009) describes six variables that affect the effectiveness of integration and cross functionality within a company:

1. Shared goals: Refer to the degree to which the departments agree to entrust resources. This is a necessary condition to the exchange of information (Emery, 2009). Trust is also considered one of the key aspects to successful supply chain integration by Zhao *et al*. (2008). Fawcett *et al*. (2007) put a focus on strategic cooperation which focuses on minimizing suboptimal activities between departments. Fragmented goals are also mentioned by Richey *et al*. (2009) who gives an example where the department's goals dictates that the sales department should increase sales while the warehouse must decrease the inventory levels.

2. Process understanding: Refers to the employee awareness of both the strategic processes and the departmental interdependencies necessary to perform the function (Emery, 2009). This is also explained by Yüksel and Dagdeviren (2010) who describe Kaplan and Norton's (1996) balanced scorecard, which shows the importance of linked departments and to make sure that all parts in a company know their contribution to the financial result and the effect of other departments.

3. Integrative devices: Is the organization's administrative arrangements to formally establish an environment for integration (Emery, 2009). Brettel *et al.* (2011) gives the example of costs associated with integration through increased frequency of meetings to facilitate information flows and joint decision making. The systems must be able to handle integration regarding information (Jayaram and Tan, 2010).

4. The communication variable: Includes both formal and informal transactions between functions for the purpose of improving process performance (Emery, 2009). According to Moye and Langfred (2004), the general consensus is that information sharing between functions in a company improves on performance. Welker *et al*. (2008) mention a correlation between internal information sharing and internal integration.

5. The reward system: Refers to the degree to which an organization places rewards and accountability on the performance of cross-functional integration measure (Emery, 2009).

6. Conflict resolution: Is the approach organizations use to settle differences between functional interests as they relate to performance of strategic processes (Emery, 2009). Employee satisfaction and success can suffer if workloads increase and working with other employees who have different perspectives on work and goals can generate conflict over resources, technical issues, salary, and personnel assignments (Troy *et al.*, 2008).

4.1.6. Summary of batch sizes effect on costs

Department	Cost	Effect	Reason to the effect
Procurement - buy smaller lots	Variable order cost	↑	Reduces quantity discount
	Fixed order cost	↑	Increase the amount of orders placed
Transportation - smaller batches in transit	Movement cost	↑	Increased number of transportations
	Pipeline cost	↕	Depend on how lead times and amount of transport changes
	Safety stock	↓	Reduce bullwhip effect and thus safety stock
	Safety stock	↑	More chances for the SS to be depleted
Operations - schedule smaller batches	Work in progress	↓	See holding costs
	Processing costs	↑	Part of order cost
	Set up costs	↑	Chance that workforce learns faster set ups Trade off to holding costs
	Shortage costs	↕	Depend on how fill rate is changed
	Overproduction	↓	Less overproduction from shorter lead times
	Bottleneck	↓	Decrease WIP lead time
		↑	Reduced utilization of bottleneck
Warehousing - order smaller batches	Holding costs	↓	Trade off to set up costs Often underestimated
	Order costs	↑	See variable and fixed order costs
	Penalty- or shortage costs	↕	Depend on how fill rate is changed

Table 4.15. Summary of department costs (own creation, 2011)

4.2. Empirical findings

The primary data is collected in this chapter and is sorted as in 4.1 for easy comparison. As Thule does not have the knowledge of all theoretical batch size costs these costs have not been split in this

4.2.1. Procurement

The amount to purchase is decided based on the forecasts, the current offered price (which can greatly vary with the amount to be bought) and the amount that fits in a pallet and sometimes on available stock at the supplier (Purchasing Manager, 2011).

The suppliers are located both locally and further away and the choice of supplier is dependent on the type of material to be purchased. Plastic components and surface treatment are often purchased locally whilst steel, fasteners and special components mainly are sourced further away. (International Product Manager, 2011) Thule has a high demand on the quality on the steel which limits the number of suppliers' available and gives a focus on good relations and collaboration with the suppliers. Thule usually aims to decrease the number of suppliers and they are monthly evaluated. (Purchasing Manager, Thule 2011)

Procurement costs in relation to batch sizes

The total product cost is determined at the development process and is followed up at a final checkpoint after first year on the market. After this, if any article has increased significantly the costs are evaluated to find the cost driver. For any other articles total cost that has increased too much is evaluated. The main part of the total cost is the purchase price, operation times and the batch sizes when determining the total cost at the initial calculations. (International Product Manager, 2011) During the ongoing purchase process the main focus is the variable order cost and does not include fixed order costs when determining purchased batch size (Purchasing Manager, 2011). It is worth noting that orders have a tendency to be often changed (20-50 percent of the times) but a project is ongoing for improvement of forecasts and communication (Purchasing Manager, 2011). Although the articles have a life cycle three to ten years (and sometimes up to 20) the products costs are evaluated only when increased costs are noted (International Product Manager, 2011).

4.2.2. Transportation

If the suppliers do not decide the transportation type to Hillerstorp, it is usually Thule's regular truck making the transports (Purchasing Manager, 2011). The suppliers are often placed more locally for plastic components than for the steel, for accurate deliveries (Purchasing Manager, 2011). This truck also makes the pick-ups and deliveries for surface treatment. To Poland the shipments are booked whenever needed. The transportations to Germany are made three times a week with everything produced up to that point and when the truck is full. The transport times do not have a large variation, based on the standard routes (Transportation, 2011).

The sizes of the batch from the suppliers are decided by the procurement (Purchasing Manager, 2011). The typical sizes in shipment are complete pallets which simplify loading (Transportation, 2011). In Thule's system the amount of items that is considered a full pallet is shown (SC Coordinator, 2011). Other sizes are in accordance with the amount produced at a certain stations (Production Manager, 2011).

Transportation costs in relation to batch sizes

The effects of batch sizes and transportation costs are not normally investigated, or included in normal batch size determination, except when the total transportation costs are increased either when budgeting (Production Site Manager, 2011) or when an item's total cost is investigated (International Product Manager, 2011). Transportation costs are known but are not used as dedicated to certain items or batches (SC Coordinator, 2011). The pipeline costs are not mentioned except as a part of the main lead time and inventory holding costs (Logistics and Production Planner, 2011). The impact that shorter lead times have on stock levels are known in the company but not a primary factor when deciding batch sizes (Production Site Manager, 2011; Logistics and Production Planner, 2011).

4.2.3. Operations

The factory's production is controlled by a production planning department in Thule. These departments are the ones deciding when a certain product shall be scheduled for production and shipped to the central warehouse in Germany. Operations wish to have a focus on lean management and so work for decreasing inventory levels. (Production Site Manager, 2011)

Operation costs in relation to batch sizes

Work in progress holding costs are recognized as one of the more interesting aspects of batch sizes as well as that the time in each operation is decreased if smaller batches are used and as a part of the holding costs (SC Manager, 2011). One of the basic rules in production is that no run time should be shorter than the set up time. In operations the set up time has generally a high priority and with the help of models the set up time has been decreased to half of what it was three years ago. (Production Site Manager, 2011)

The processing costs are calculated in systematically depending on manpower needed in each station and any overhead costs, including selling back metal that can be reused. The costs for each produced item can easily be seen in the used system. (Business Controller, 2011) Thule's stand on shortage costs can be found in chapter 4.2.4.

Thule does not calculate the cost of overproduction unless there are some special circumstances (Business Controller, 2011) and the SC Manager (2011) gives an example of how old products needs to be removed from the warehouse as newer models are produced. Overproduction is, however, a reason for lean management in the company (Production Site Manager, 2011). Thule has several bottlenecks but the main issue considered is the Packing-operation which has a high number of articles going through and creates a scheduling problem (Production Manager, 2011). This together with being a three man station (both for operation and set up) makes it a priority for effectiveness of Thule's operations (Production Manager, 2011).

4.2.4. Warehousing

As mentioned before the goal for the production site is a lean mindset (Production Site Manager, 2011). Reduction of inventory is therefore a must when planning but leads to problem as the production facility can not handle the amount of demand during the investigated period which is the high season in the company. Here Thule is dependent of having items on stock to meet demand (SC Coordinator, 2011).

Warehousing costs in relation to batch sizes

The interest rate of 7,5% set in the company is based on that Thule's owners has strong bargaining power (Business Controller, 2011) but can be considered low (Logistical and Production Planner, 2011). Regarding order costs the company only focus on purchase price and does not have a calculated order cost for each order placed and so ignore the fixed order costs for a focus on the variable order costs (Purchasing Manager, 2011). Shortage costs are effectively ignored because the difficulty of estimating them (Business Controller, 2011) and instead the company uses a target fill rate when setting inventory order points and safety stocks (Logistics and Production Planning, 2011).

4.2.5. Cross functional batch sizes

To make sure information is shared at Thule there are several regular meetings for production planning and several other follow-up meetings where the result of the last week's production is discussed and spread (Production Site Manager, 2011). Thule's different departments have different goals and only share the goals at higher levels that can cause some fracture (Purchasing Manager, 2011; Transportation, 2011; Logistics and Production Planner, 2011). In some cases goals and planning material needs to be found in the system and is not delivered (Transportation, 2011) and in other the goals are clear, as on the production floor (produce this amount of correct articles and a bonus come), but it might be in contrast to other departments goals (produce smaller batches) (Production Site Manager, 2011).

4.3. Analysis

4.3.1. Procurement

Thule's focus on price (Purchasing Manager, 2011) is in line with Chen's (2000) arguments that Thule has a price advantage when placing larger orders for quantity discount and the importance of procurement's actions for the company (Burke *et al.*, 2007). Assuming high costs of the raw material, a price focus lowers the purchase costs. At the same time it may lead to larger inventories (Piercy and Rich, 2009), increase the handling time of the specific raw material (Bhasin and Burcher, 2006), miss out on quality improvements (Bonavia and Marin, 2006) and ignore possible smaller batches (Browning and Heath, 2009). It is important to have in mind that the demand for the product must be in accordance of the usage of the material to avoid large batches of raw material inventory that will not be used in a long time which works against lean principles (Aissaoui *et al.*, 2007).

Aissaoui *et al*,'s (2007) point that ordered batches also should take account of the sourcing situation. This is in contrast to the price focus in Thule's procurement department and demand on high quality raw material (Purchasing Manager, 2011). If it is a single sourcing the main focus should be on shared benefits (Burke *et al.*, 2007) but as the forecasts should not be considered completely reliable and Thule tends to change the orders the focus are on prices instead. The price focus is more fitting when the company does not wish to depend on a single source and it can be assumed that playing suppliers against each other is a good way to lower prices (Aissaoui *et al.* 2007). Thule's need for high quality material limits the amount of suppliers available (Purchasing Manager, 2011) and should impress the importance of close relationship with the suppliers as Ho *et al*. (2010) and Lee (2009) states instead of a price focus. It should be noted that Thule's size might also give it a bargaining power to encourage the suppliers to develop closer relationships.

Procurement costs in relation to batch sizes

Variable and fixed order costs: According to Nahmias (2009) and Jonsson (2008) Thule's purchase department focus on price will most likely decrease the total variable cost (Chen, 2000). The fixed order cost should normally decrease with larger batches (Jonsson, 2008) but orders from procurement gets extra fixed costs as orders are often changed after the initial order (Purchasing Manager, 2011), but it is unlikely that this effect would substantially increase the total fixed order costs. The focus on variable order costs gives larger batch sizes with the effect seen in table 4.15 on other departments. It should be noted that fixed order costs are not calculated in Thule regularly (Purchasing Manager, 2011) therefore the purchase department can not use it to evaluate an optimal purchased lot size and so must take purchase decision based on the variable costs where price is the most significant factor. This also leads to discounts (Purchasing Manager, 2011).

4.3.2. Transportation

The JIT thinking applied to transportation described by Rhodes *et al.* (2006) and Khan and Sarker (2002), includes small batch sizes with more movement of items. According to Khan and Sarker (2002) the supplier should be located in close proximity of the manufacturing facility and should be capable of receiving and delivering raw material in smaller quantities to draw benefit of the JIT mindset. In the case with Thule the suppliers tend to be closer for plastic details and further away for steel raw material (International Product Manager, 2011), but the lead times from the suppliers are known and are fairly accurate (SC Coordinator, 2011). The costs for transports are not focused on and are basically ignored except when noticeable increased (International Product Manager, 2011). This means that the effect of any changes in batch sizes could be considered negligible on movement costs with Thule's present policy regarding transportation and batch sizes.

Basically, Thule's transportations consists of the loop-truck that makes its run no matter the amount transported, that the supplier often plan the transportations and that the transports to Germany are on set intervals (Transportation, 2011). The transportation routines and sizes are practically the same no matter the size of the batches. The supplier ship the purchased amount, the loop truck makes its pick ups twice each day and the shipment to Duisburg is sent whenever the truck is full (Transportation, 2011). This can also be used as an argument that transportation costs are usually ignored or considered fixed as Gupta (2008) argues.

Interesting is that all departments often seems to use whole pallets when transporting occurs (Transportation, 2011) and that the system contains information regarding whole pallets. As in the case of the HR, transportation occurs after every operation (SC Coordinator, 2011). This means that when Thule decides the amount to produce in one batch, the amount is usually decided by the number of units that can be placed on a full pallet for easy loading. This is interesting as the transportation costs seem to often be ignored.

This might make them ignore other concerns regarding batch size such as any advantage of mutual batch sizes in a system. The question is if it is possible to use lean for Thule with smaller than pallet-sized batches as the supplier needs to be dedicated to Thule (Wilson and Roy, 2009; Aissaoui *et al.* 2007).

Transportation costs in relation to batch sizes

Movement costs: Should increase if smaller batch sizes are used (Gupta, 2008; Khan and Sarker, 2002; McCann, 2001). Thule's present batch sizes effects on movement costs described by Gupta (2008) are hard to evaluate as the costs are evaluated only when the total cost is increased in budgeting (Production Site Manager, 2011) or when an item's total cost is investigated (International Product Manager, 2011). If the supplier can ship smaller lots for no extra transportation costs, the loop truck still makes its pick-ups and the transportation to the central warehouse keeps on going on routine, the only cost in increased movement should be whenever a transport needs to be booked.

The pipeline cost: Should be affected by smaller and larger batches if the batch sizes change the lead time (Nahmias, 2009). This might be the case if the supplier has a make to order policy although the effect should not be extensive. Since Thule ignore this specific cost when deciding batch sizes (Production Site Manager, 2011) the value of using small batches should be difficult to detect.

The safety stock cost: The positive effects of shorter lead times are known in Thule (Production Site Manager, 2011; Logistics and Production Planner, 2011) but not taken into account when deciding batch sizes and thus ignore any potential winnings from shorter lead times. When focusing only on price while selecting batch size, the safety stock should be higher than needed, to avoid the problems with high lead time variation. If the supplier would be selected depending on their skill to deliver on time, the safety stock level should be decreased (Kelepouris *et al*., 2008) and lower batch sizes could be used (Khan and Sarker, 2002). This is directly proportional to the daily demand from customers – if the customer demand is 200 items and the supplier can guarantee a delivery in 4-6 days instead of 3-10 then the safety stock can be decreased with the demand of 4 days (Nahmias, 2009). This would also decrease the bull whip effect and further decrease the safety stock level needed (Geary *et al*., 2006; Lee *et al*., 2004). A price focus that uses larger batches will also lead to fewer times the safety stock is needed (Nahmias, 2009) and thus could be decreased also with larger batches. This effect on the safety stock is most likely hard to estimate correctly and so could be ignored.

4.3.3. Operations

In addition to Porter's (1985) description of what is included in operations Thule also includes production scheduling in this department (Production Site Manager, 2011). This department decides when to start operations and with what quantities (Logistics and Production Planner, 2011). This department has weekly meetings where the goal is to have a lean management production and to have an operational status that follow the production plan to a specified degree (Production Site Manager, 2011). Two things are notable at this point; (1) the lean mindset has a larger impact in this department than the others and (2) the weekly meetings means that the outcome in any changes in a batch size policy can be assessed at an early stage. Therefore this means that it is theoretically possible to try out different batch sizes and early see the result and restore any change that does not produce a better result.

Operation costs in relation to batch sizes

Laínes *et al*. (2009), Nahmias (2009), Pinedo (2009), Wang *et al*., (2005), Jamal *et al*. (2004) and Mejabi (2003) all mentions costs which can be seen as problematic when deciding batch sizes, presented below;

Work in progress holding costs: WIP is recognized as an important area for batch sizes (SC Manager, 2011). It does go hand in hand with lean thinking to create smaller batch sizes and as Sarker and Parija (1996) describe, the inventory levels tend to drop with smaller batch sizes. Nahmias' (2009) description is that the holding costs are changed when the average inventory level or lead times are changed. Each process' smaller batches' increases the total set up time (if a batch is halved, the set up time is doubled) and gives a higher lead time for each article. However, Thule's set up time is rather low and the extra total time in WIP for an extra set up is negligible. If a batch size in an operation is halved the WIP is halved for each batch and so is the waiting time for the next article in line.

Set up costs: Are increased with each extra batch (Aryanezhad *et al*., 2010) and this extra cost should be larger than any gains from Bichecno *et al*.'s (2001) point that the workforce becomes faster at resetting the machines. Thule has in the last three years halved the average set up time (Production Site Manager, 2011) and this is a way to keep up workforce agility (Qin and Nembhard, 2010) and oppose the dangers of not keeping up with technological changes (Sherehiy *et al*., 2007). This also gives the advantage of making smaller batches more attractive. When developing new set up-tools the experience and suggestions from the workforce might reduce set up times even more.

Processing costs: The Business Controller (2011) has added several costs in the calculation system and is based on producing a single item, much like suggested by Jamal *et al*. (2004). The cost of manpower, insurances, set up costs and machine costs are put into the calculation, so each process the article goes through will add a value to the item (Business Controller, 2011). This will most likely not show how the processing costs are decreased per item in larger batches as explained by Xiong and Schoenung (2010) and thus the process will not show any economy of scale for each item (Searcy and Flynn, 2008). The economy of scale advantages will most likely be seen on periodic result reviews but on an item basis the cost per item actually should at the very least counteract larger batches and encourage lean management.

Shortage costs: Are discussed in chapter 5.3.4.

Overproduction costs: Any costs for overproduction in Thule are ignored on regular basis and only considered when anything out of the ordinary happens (Business Controller, 2011), as in the instance when old products are removed from stock (SC Manager, 2011). This is partly an example of Laínez *et al*.'s (2009) example where the extra holding costs is the cost of overproduction. Wang *et al*. (2005) holds another part as the cost for overproduction is the reduction in price which, in the example given by the SC Manager (2011), is rather massive considering they had to remove the stock for that item. To minimize this cost Arnheiter and Maleyeff (2005) suggests reducing lead times in production to improve replenishment times and thus lower the inventory. This is in line with Thule's current aim for lean management (Production Site Manager, 2011). Improvement of replenishment times can also be done with reduced WIP.

Bottlenecks: Is an existing problem in most processes (Pinedo, 2009; Koo *et al*., 2007; Lee and Snyder, 2006) and Thule's processes' are not an exception. However, while Koo *et al*. (2007) and Lee and Snyder (2006) consider the bottleneck as the activity with the longest cycle time, Thule considers Packing as the main issue (Production Manager, 2011). As in the HR the Assembly has the longest cycle time but as it is placed in Poland could be ignored (the Packaging has the longest cycle time after that). The LR also has Assembly as the bottleneck, if considering the cycle time but can be argued that it does not have the same scheduling issues at Packing. In the Packing line there are a high number of articles that will go through and this brings scheduling problems (Production Manager, 2011) and it is logically that this is considered the bottleneck for Thule.

To solve the bottleneck, theory gives two basic solutions; (1) maximize the utility and (2) make sure it does not do anything other than what it should (Ronen and Pass, 2008) and in both cases the solution initially seems to be larger batch sizes. It should be easier to maximize an operations efficiency if larger batch sizes are used, especially when considering that it should be easier to schedule one large batch out of ten instead one small batch out of a hundred. Meanwhile the lead time for all articles should go up, in accordance with arguments made for the work in progress. To remove non value added activities (such as set up time) a larger batch size should at first be considered a solution, but the set up time is small when weighted against total work in progress time and so might not actually cause a problem. This is interesting as Thule's Assembly line and Packing line both could be considered bottlenecks (Production Manager, 2011) (see chapter 3.4). As the bottleneck often stand for the largest part of the manufacturing lead time (Koo *et al.*, 2007), and if Thule's scheduling process is capable enough, lowering batch sizes to make sure more different articles can go through could be the best way to tackle the Packing machine as this would lower the inventory levels (Sarker and Parija, 1996) and reduce the bullwhip effect (Geary *et al.*, 2006) that comes with lowered lead times.

4.3.4. Warehousing

Thule's Production Site Manager (2011) is one of the people that argue for a lean management which in turn means a preferred zero inventory level (Polito and Watson, 2006). Inventory does cost even during other departments in form of holding costs (Piercy and Rich, 2009; Gupta, 2008; Jamal et al., 2004) but it is clear that many studies on batch sizes argues for a positive impact on warehousing costs if the batch size is reduced (Gou et al., 2008; Bicheno et al. 2001; Moinzadeh and Lee, 1986) and several studies argue for minimizing inventory levels (Jonsson, 2008) and to have a production site where make-to-order is preferred (Arnheiter and Maleyeff, 2005).

To reduce inventory one way is, in short, to reduce batch sizes between different actors in a supply chain (Sarker and Parija, 1996). It does not take much effort to assume that if two different departments within Thule also decrease the delivered batch size the total inventory level should be lowered. That is, if the Press shop produce half sized batch sizes instead of full size the average inventory should drop and thus lower the inventory costs. Note should be taken to Lynn’s (2005) and Wilson and Roy’s (2009) warnings about to low inventory levels.

Warehousing costs in relation to batch sizes

Holding costs: Are one of the two main parts of batch sizing issues (Nahmias, 2009; Kwak *et al*., 1991) and the basic part to evaluate this cost is the annual interest rate (Nahmias, 2009). Thule’s interest rate is set at 7,5% (Business Controller, 2011). As the interest rate could be considered low (Logistical and Production Planner, 2011) the company should have more in stock (Nahmias, 2009). However, Bicheno *et al*. (2001) warn that inventory holding costs tends to be underestimated which wakes the question whether 7,5% is accurate for Thule regarding the actual inventory costs. If the goal is to have a lean management the effect of smaller batch sizes should be more noticeable if the interest rate is higher. That is, if it is assumed that it is easier to act on large numbers than small.

Order costs: Consists of a variable and fixed value (Nahmias, 2009; Jonsson, 2008). It should be noted that order costs seems to be connected to warehousing-decisions but it represent the cost for other departments (in this case the Procurement, Transportation and Operations) to place an order (Nahmias, 2009). The order cost is therefore not directly taken from warehousing, but represent the costs of other departments. The fixed order costs are not taken into account when deciding batch size, while ordering but some of the variable order costs are (Purchasing Manager, 2011). Each decision to order is thus only based on the ordering department.

Shortage costs: In accordance to several researches opinion (Nahmias, 2009; Jonsson, 2008) the shortage costs in Thule are unknown and estimated because of the difficulty level (Business Controller, 2011). The central warehouse instead uses a target fill rate when making any production decisions (Logistics and Production Planning, 2011). With a high difficulty level and unidentified cost for lost sales it is almost impossible to estimate, without any kind of approximation model. The shortage cost should therefore on several researchers' opinions (Sarker *et al*., 2008; Zhao, 2008; Seifbarghy and Jokar, 2005) be ignored when making batch size decisions. This should make it easy to see if Thule has been successful in reaching the fill rates.

4.3.5. Cross functional batch sizes

One of the problems mentioned by both Emery (2009) and Richey *et al*. (2009) is the fragmented goals that often exist in companies. In Thule's case the procurement focus on price without taking into consideration the cost this will add to other departments (Purchasing Manager, 2009). Transport costs are not normally investigate (Production Site Manager, 2011), not used as dedicated to certain batches or items (SC Coordinator, 2011) and transportation lead times are not included when deciding batch sizes (Logistics and Production Planner, 2011) and thus can be considered taken for granted. Operations aim for a lean management (Production Site Manager, 2011) and inventory costs might be underestimated (Logistics and Production Planner, 2011).

The problems that are associated with integrations can be hard to overcome and can be one explanation of any lack of cross functionality (Brettel *et al*,. 2011; Troy *et al.*, 2008; Vaart and Donkas, 2007) but the potential economical earnings should overcome this with higher stock value (Mitra and Singhal, 2008), overall improved performance (Emery, 2009; Moye and Langfred, 2004) and decreased suboptimal activities (Fawcett *et al*., 2007). A way to integrate the batch size better could be to use a single batch size from supplier to I_1 and another batch size from I_1 until I_2. This would decrease any need for extra inventories in the system. Setting the second batch size as an equal part of the first (for instance half of the first part) would give a batch size in the system that is integrated with more departments. The only problem is transportation (which tends to be ignored) that might be forced to handle less than optimal pallets when loading and storing but it is uncertain how much this would affect the transportation costs. If there is a possibility to deliver mixed pallets (pallets with leftovers from other products that does not fill a pallet) this cost should be minimal.

Process understanding does not seem to be a problem. The empirical data in the previous chapters show that knowledge of other department's routines should be considered high, but this could improve with some system that gives a better understanding, integration and communication. For instance, a version of Kaplan and Norton's (1996) balanced scorecard might be useful to make sure all departments know their effect on the company's financial result (Yüksel and Dagdeviren, 2010).

Although Thule has steady systems for information sharing (SC Coordinator, 2011) and regularly meetings (Production Site Manager, 2011), there seems to be a lack of systems with the capability of help choose the right cross functional batch sizes and formal and informal information sharing that Jayram and Tan (2010) states are appropriate to distribute this information. This can be one of the causes to the lack of coordination of the batch size.

4.4 Conclusion

Department focus, benefits and drawbacks of Thule Sweden AB's current batch size policy		
Purchase focus	**Benefits**	**Drawbacks**
Price focus	Decreases purchase order costs	Encourage large batches and works against lean
Few vendors	According to lean	Few vendors are worse for price focus
Order costs unknown	-	Purchase can only base their decision on price
Transport focus	**Benefits**	**Drawbacks**
Assumed constant transportation costs	Extra transportation costs of smaller batches negligible	Slow reacting on transportation costs
Whole pallets	Easier to transport	Larger batch sizes then necessary
Lead times ignored when deciding batch sizes	-	Longer lead times and larger batch sizes then needed
Operations focus	**Benefits**	**Drawbacks**
Lean production	Lean	Can not see the effect of lean
Reduce WIP with Lean	Faster replenishment times, smaller batch sizes	Increase set up cost
Lowered set up times	Allow smaller batch sizes and increased workforce agility	-
Item-based processing costs	Encourage lean	Negative for economy of scale thinking
No focus on overproduction	Ignore variables that are very resource demanding to estimate.	If focused on will, encourage smaller batch sizes and reducing lead times
Reduce bottlenecks	Focus on reducing set up time and maximizing utility	-
Warehousing focus	**Benefits**	**Drawbacks**
Reduction of inventory	Lowered costs, smaller batch sizes, closer to lean	Risk of stock outs
Interest rate of 7,5%	Low inventory costs	Could be underestimated, suggests higher inventory level, work against lean
No focus on order costs	-	Hard to se batch size decisions effect on company
No focus on penalty or shortage cost	Target fill rate is easier to set then calculate penalty cost	Hard to know if the target fill rate is accurately set
Cross functionality	**Benefits**	**Drawbacks**
Focus on own goals	Easy to see each departments result	Sub optimization, weaker lean, hard to see the departments part of the overall result
High process understanding	increase chance of integration	-
No usage of tools capable of making cross functional batch decisions	-	Low coordination in batch size, larger batch size, bullwhip and sub optimization

Table 4.16. Conclusion of Thule's batch size policy (own creation, 2011)

- Thule seems to use whole pallets as the only coordinated batch size in the production stream. Otherwise the departments has a tendency to focus on own goals. This should cause "spills" that needs to be held in inventory until next batch is ordered and causes several inventories that should not be needed.
- To coordinate a cross functional batch size there is a possibility to use a batch size from supplier to I_1 (BS_1) and another from I_1 until I_2 (BS_2) as in figure 4.1. The second batch could be an equal part of the first one for simplicity.

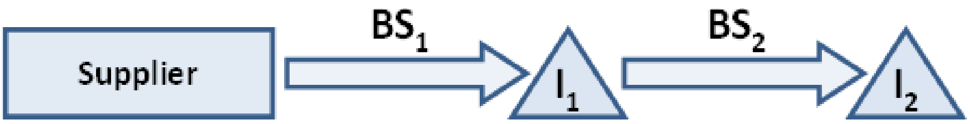

Figure 4.1.Batch sizes BS_1 and BS_2 (own creation, 2011)

5. Suggest an alternative batch size policy

Chapter 4 ended with a suggestion of using a batch size until I_1 and a part of that batch size from that inventory until I_2. However, the focus on order quantities in chapter 4 will not be sufficient. The effects of the reorder point when coordinating inventories to must also be considered to evaluate a batch size policy. Chapter 5 focuses on a model that utilizes batch sizes as suggested in chapter 4 and calculate the optimal reorder points. This chapter will therefore discuss the implication of various batch sizes effect on reorder points in this policy. The economical effects will be investigated in chapter 6.

5.1. Theoretical framework

This chapter is based on describing the inventory control model by Berling and Marklund (2011). The model's basic function and its connection to Thule are briefly explained here. Instead of a more fully completed theoretical chapter, this project have chosen to explain the different steps taken in more detail in chapter 5.2 as this will help any who wishes to build the model. The examples of calculations given are based on the symbols the referred theory has used. Thus, when referred to Nahmias, the reader can look for the symbols given here and find the same symbols in Nahmias (2009). Parallels to Thule will be drawn further into the chapter and will primarily be based on the HR since it gives a better understanding o f the model.

The model which will be used for inventory coordination and batch size policy suggestion is based on a traditional two level distribution with a warehouse that supports a number of retailers with a focus to practical implementations (Berling and Marklund, 2011) as shown in figure 5.1 below.

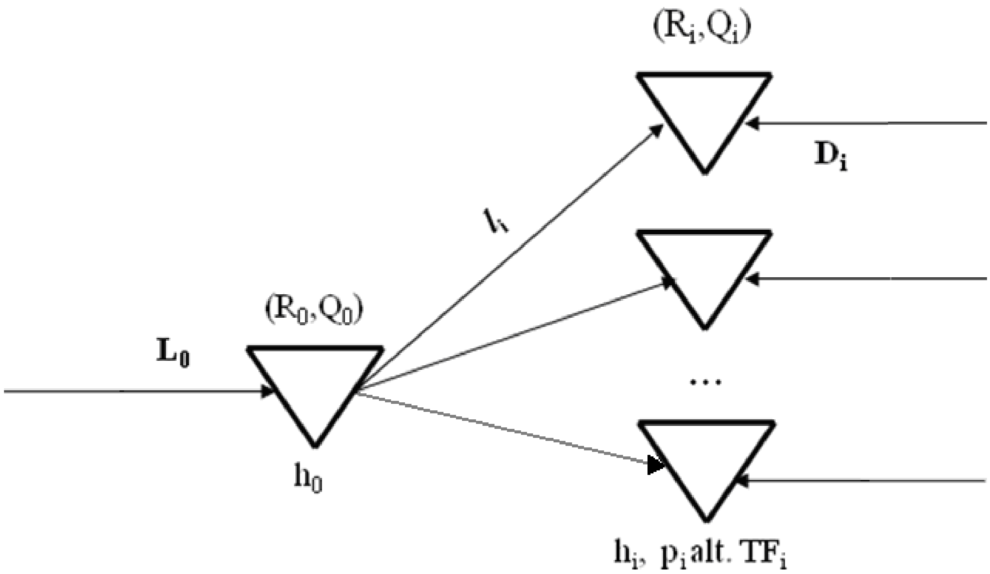

Figure 5.1. Inventory control model (Berling and Marklund, 2011)

The model will from now on be adapted to fit Thule to simplify for the to target audience of this project and give the readers an idea of what the model does and how it will affect the coordination of the inventories in Thule's product flows. In Thule's case of the HR there is only one retailer, Thule's central warehouse in Germany that controls the flow. The warehouse in the model which is equal to Thule's semi-finished inventory is, as decided in chapter 3.3 called inventory 1 (I_1) and the models retailer will be translated into Thule's finished-goods inventory (I_2). When using these terms we can also apply the terms to both products. With the same concept as shown in figure 5.2.

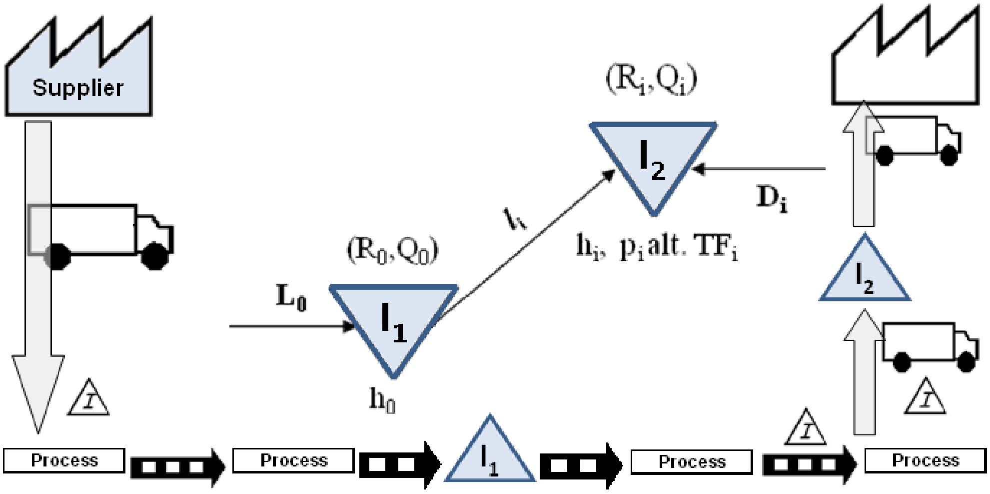

Figure 5.2. Modified model definitions (based on Berling and Marklund, 2011).

Many of the formulas used in the model appear in standard text-books which give the model a high recognition value and a good basis to create policies for inventory and material flow while still being adaptable (Berling and Marklund, 2011).

Basic notations used in the Berling and Marklund (2011) model:

TF_i	=	target fill rate at I_2 i
Q_0	=	I_1order quantity
L_0	=	Lead time to I_1 (assumed constant)
R_0	=	Reorder point at the I_1
h_0	=	Holding cost per unit and time unit at the I_1.
Q_i	=	Order quantity at I_2 i, expressed in number of units (assumed to be constant and predetermined)
l_i	=	Transportation time between $I_1$and I_2
R_i	=	Reorder point for I_2 i.
h_i	=	Holding cost per unit and time unit at I_2 i.

Since we are using a very complex model, we have rephrased some of the five steps that are described by Berling and Marklund, (2011) to create a better understanding. The method is based on the determination of how much it costs when the I_1 not is be able to deliver units to I_2 (step 1). When this cost in known it is time to determine the lead time demand from order to the I_1 (step 2), which is a basis for the calculations in step 3 where the optimal reorder point of I_1 is calculated. Step 4-5 is almost the same as step 2-3 but for the I_2 instead. When all steps are made we will have a suggestion to determine the order quantities and the best mutual batch size in the system (Berling and Marklund, 2011).

The model's five steps rephrased to fit this project:

1. Determine the cost when I_1 not is able to deliver to the I_2. β.
2. Determine the lead-time demand at I_1. $\mathbf{D_0(L_0)}$.
3. Determine the optimal reorder point at I_2, $\mathbf{R_0}$.
4. Determine the average lead-time demand to I_2, $\boldsymbol{\mu_{Di(Li)}}$ and $\boldsymbol{\sigma_{Di(Li)}}$.
5. Determine the optimal reorder point at I_2, $\mathbf{R_i}$.

Step 1: This step is to estimate the cost when I_1 is not able to deliver to I_2 when ordered. So the cost estimated is the cost for extra inventory at I_2 and shortage costs that occurs because of any lower service from I_1 (Berling and Marklund, 2011).

$$\beta_i = h_i \left(g(Q_{i,n} . p_{i,n}) \cdot s_{i,n}{}^{k(Qi,n\ .\ pi,n)}\right.$$

$h_i = c_i \cdot h\% /$ amount of time units in a year
$Q_{i,n} = 100 \cdot Q_i / (\mu_i \cdot l_i)$
$p_i = TF_i \cdot h_i / (1-TF_i)$
$p_{i,n} = h_i / p_i$
$s_{i,n} = 100 \cdot \sigma_i / (\mu_i \cdot \sqrt{l_i})$
$g(Q_{i,n} . p_{i,n}) = T1$ (Appendix B, based on values of $Q_{i,n} . p_{i,n}$)
$k(Q_{i,n} . p_{i,n}) = T2$ (Appendix B, based on values of $Q_{i,n} . p_{i,n}$)

Step 2: To determine the $D_0(L_0)$, at the central warehouse it is possible to use the standard formulas in addition to the model (Berling and Marklund, 2009). Suppose lead time (τ), is a random variable with mean (μ_τ) and variance (σ^2)

and that demand always has a mean ($\mu\tau$) and variance ($\nu^2\tau$). Then it is shown that demand during lead-time has mean and variance (Nahmias, 2009):

$$\mu = \lambda\mu \cdot \sigma^2$$
$$\sigma^2 = \mu_t \cdot \nu^2 + \lambda^2 \cdot \sigma^2_t$$

Step 3: The optimal reorder point can be calculated from a standard formula that is based on the following formula where reorder point (R) is expected demand during lead time (λL) + the safety stock (SS) (Nahmias, 2009).

$$Serv^2 = \beta_i/(h_0+\beta_i)$$
$$h_0 = C \cdot h\%/12/Dm$$
$$R = SS + \lambda \cdot L$$
$$SS = \sigma \cdot L^{-1}\big((1- Serv^2) \cdot (Q/\sigma)\big)$$

With this the optimal service rate, the reorder point and safety stock level at I_1 can be determined (Berling and Marklund, 2009).

Step 4: For this Berling and Marklund (2011) suggests estimating the mean ($\acute{L}i$) and variance ($\sigma_L I_2$) because of the lack of feasible ways to compute it and so suggest using the following formula to estimate it.

$$\mu_{Di(Li)} = \mu_i \acute{L}_i$$
$$\acute{L}_{i(Ro)} = E[B_o(R_0)]/\mu_o + l_i$$
$$E[B_o(R_0)] = (\sigma_0'^2/WQ_0) \cdot [H(x) - H(-X)]$$
$$H(x) = 0,5 \cdot [(x^2+1) - (1-\Phi(x)) - x\varphi(x)]$$
$$H(-X) = 0,5 \cdot [(X^2+1) \cdot (1-\Phi(X)) - x\varphi(X)]$$
$$x = SS_0/\sigma_0'$$
$$X = (SS_0+WQ_0)/\sigma_0'$$
$$\sigma_{Di(Li)} = \sqrt{}(\sigma_i^2 \cdot \acute{L}_i + \sigma_{Li}^2 \cdot \mu_i^2)$$

Step 5: The determination of the reorder point (R) at the retailer is made by using the same formulas as in step 3 (Nahmias, 2009). With the difference that L in the following formula is set regarding to the determination of the lead-time demand to each retailer in step 4. Thus $L = \acute{L}_i$.

$$R = SS + \lambda \cdot L$$
$$SS = \sigma \cdot L^{-1}\big((1- Serv^2) \cdot (Q/\sigma)\big)$$

5.2. Empirical findings

The empirical data is based on data given by the SC Coordinator (2011) as well as the empirical data presented in 3.2. Therefore, the data presented has to some extent already been treated. Although repeating information this will give the reader the chance to evaluate the model without being referred to several empirical chapters. The assumptions that have been made to why certain data is used are also explained here. Data that depends heavily on assumptions are presented in the analysis.

5.2.1. Item HR

The basic data needed for the analysis of the HR have been collected and is shown below in table 5.1. These are the basic values that show Thule's present batch size. These values can be changed to see different results as argued in chapter 5.3 Analysis.

TF_{HR}	95%	Target fill rate at I_2 i
h%	7,5%	Percentage of holding costs / year
D/year	365	Amount of time units each year
Q_0	20 000	I_1 order quantity, expressed in units
L_0	12	Lead time to I_1 (assumed constant)
C_0	4,4	Cost of item at I_1
μ_0	1 032	Demand rate at I_1 / week
σ_0	467	Standard deviation of demand rate at I_1 / week
Q_{HR}	5 150	Order quantity at I_2 i, expressed in number of units (assumed to be constant and predetermined)
l_{HR}	15	Transportation time between I_1 and I_2 i (assumed constant)
c_{HR}	6	Cost of item at I_2
μ_{HR}	89	Demand rate at I_2 / day
σ_{HR}	112	Standard deviation of demand rate at I_2 / day

Table 5.1. Basic model data for the HR (SC Coordinator, 2011)

The data used is the one given from Thule (SC Coordinator, 2011). The cost at I_1 (C_0) is an estimation based on data given from Thule where four units are worth 17,4SEK and the assembly increases its value of 0,08SEK. Before the Assembly, the four units are worth 17,3SEK. An rough estimation has been done and a single unit (including some costs for other articles) which has been rounded off to 4,4SEK. The cost at the retailer (c_{HR}) is based on the HR's total value of 24,3SEK and in units thus 24,3/4 = 6SEK.

The demand rate each day is given by Thule (SC Coordinator, 2011) and the average demand and standard deviation each day has been calculated with weekend days (where no sale is registered) counted as 0pcs. The demand rate each week is also based on the same data but recalculated through dividing with the percentage of units that goes into the HR.

5.2.2. Item LR

As with the data presented in table 5.1, the data below represent the basic data used to calculate Thule's present batch policy in an optimal situation.

TF_{LR}	95%	Target fill rate at I_2 i
h%	7,5%	Percentage of holding costs / year
D/year	365	Amount of time units each year
Q_0	10 000	I_1 order quantity, expressed in units
L_0	15	Lead time to I_1 (assumed constant)
C_0	5,3	Cost of item at I_1
μ_0	326	Demand rate at I_1 / week
σ_0	149	Standard deviation of demand rate at I_1 / week
Q_{LR}	400	Order quantity at I_2 i, expressed in number of units
L_{LR}	2	Transportation time between I_1 and I_2 i (assumed constant)
c_{LR}	10,7	Cost of item at I_2
μ_{LR}	0,456	Demand rate at I_2 / day
σ_{LR}	36,5	Standard deviation of demand rate at I_2 / day

Table 5.2. Basic model data for LR (SC Coordinator, 2011)

As a slow moving item, less time has been focused on bringing out the exact data for the item. The assumptions in the table are as following: Q_{LR} is the amount of raw material used in a single pallet. The cost at the I_2 is the LR divided with 8 and then the cost is estimated to be half that for C_0.

Q_0 is based on the 0,97% of raw material that goes to the LR and the standard deviation is calculated as the same percentage of the demand each week as in the HR. This give a weekly demand of 46,6*7= 326pcs and a standard deviation of 149. The order size is based on the smallest amount of pallet (Q_{LR} = 400pcs) and set as Q_0 = 10 000pcs.

Also needed in the following analysis is the size of pallet as this product is only produced in the smallest batch size available. 50 Pieces of the LR goes into one pallet and this is the order size from the customers and also the size produced at each stage (SC Coordinator, 2011).

5.3. Analysis

The analysis is in more detail explained than the theory presented in 5.1. The reader should notice that all of Nahmia's (2009) symbols used have been translated to versions more suitable to Berling and Marklund's (2011) model. Instead of using a traditional reference system, this chapter only refer to Nahmias (2009) when needed and all other parts should be considered as referred to Berling and Marklund (2011).

5.3.1. The building of the model

The model is build in excel and follows the steps explained by Berling and Marklund (2011). To build the same model, the reader can exchange any formula by the appropriate cell in excel. As said in chapter 5.1 the CSM of the HR is used as a basis to suggest an alternative batch size policy according to this project aim, so we will only use the needed variables for the HR as an example in this chapter.

Q	Q_{HR}	WQ_0	l_{HR}	L_0	TF_{HR}	h%	D/year	c_{HR}	C_0

Table 5.3. Initial data filled in by the company (own creation, 2011)

The data needed for the model is the basic information needed to start the calculations and they are presented in table 5.2. Q is set after the model is completed and Q_{HR} is based on the amount of order quantity from I_1. l_{HR}, L_0, c_{HR} and C_0 is taken from the CSM. TF_{HR} and h% are policies set by the company. D/year can be set as 365 or 360 depending on whether the company wishes to calculate with an average of 30 days each month. With this data the model can calculate:

$q_{HR} = Q_{HR}/Q$
$Q_0 = WQ_0/Q$
$h_0 = C_0 \cdot h\%/\text{"D/year"}$
$h_{HR} = c_{HR} \cdot h\%/ \text{"D/year"}$

The data needed next for the model is the demand data. The demand data for the I_1 is based on daily data but the demand data for metal plate's inventory is based on weekly data as the production from the metal plate's inventory is not on single items but rather in batches. When this data is received the calculation for the standard deviation is easy to calculate with excel (shown in table 5.3).

μ_0	σ_0	μ_{HR}	σ_{HR}	σ in excel; =stdev(all cells with demand data)

Table 5.4. Demand data needed and stdev formula (own creation, 2011)

Step 1

The optimal backorder cost needs the two tables taken from Berling and Marklund (2006) which in turn needs the following data which is calculated as:

$P_{HR} = TF_{HR}/h_{HR}/(1\text{-}TF_{HR})$
$P_{HR,n} = p_{HR}/h_{HR}$
$Q_{HR,n} = 100 \cdot Q_{HR}/(\mu_{HR} \cdot l_{HR})$
$S_{HR,n} = 100 \cdot \sigma_{HR}/(\mu_{HR} \cdot \sqrt{(l_{HR})})$

With this table B1 and B2 provided by Berling and Marklund (2006), found in appendix B, can be used and then be calculated as follows (note that the data form table 2 is the data actually used, without calculations):

$T1$ = Data from table B1 $\cdot 10^4$
$T2$ = Data from table B2

The final part of step 1 is to calculate the optimal induced backorder cost at I_1.

$\beta_{HR} = h_{HR} \cdot (T1 \cdot s_{HR,n}{}^{T2})$

Step 2

The standard deviation of lead time (σ_τ^2) can for simplicity be set as 0. Although the lead time to I_1 of course varies, the variation must be of a high degree to affect the conclusions drawn. The calculations needed for the next steps are the standard deviation of demand during lead time.

$$\sigma_0'^2 = L_0 \cdot (\sigma_0/7)^2 + (\mu_0/7)^2 \cdot \sigma_\tau^2$$
$$\sigma_0' = \sqrt{(\sigma_0'^2)}$$

Step 3

Using Nahmias' (2009) description of service level and shortage costs it is possible to estimate the preferable service level at I_1. As Thule only has one central warehouse the following expression is valid: $\beta i = \beta$. The optimal service level is calculated as following (Nahmias, 2009):

$$Serv_2^* = \beta_i/(h_0 + \beta_i)$$

With this the model receives the optimal fill rate at I_1. Using basic calculations of a service level according to Nahmias (2009) the following formula is used to show the present reorder point. To help the readers the formulas that should be written in excel are also included:

$$Serv_2 = 1-(\sigma_0' /WQ_0)[L(SS_0/\sigma_0') - L((SS_0+WQ_0)/\sigma_0')]$$

In excel $L(SS_0+\sigma_0')$
$= NORMDIST(SS_0/\sigma_0';0;1;0) -(SS_0/\sigma_0') \cdot (1-NORMDIST(SS_0/\sigma_0';0;1;1))$

In excel $L[(SS_0+WQ_0)/\sigma_0']$
$= NORMDIST[(SS_0+ WQ_0)/ \sigma_0';0;1;0] -[(SS_0+ WQ_0)/ \sigma_0'] \cdot [1-NORMDIST((SS_0+ WQ_0)/ \sigma_0';0;1;1)]$

At this level the safety stock (SS) is empty and should be filled in by the company to find $Serv_2^*=Serv_2$. Next is the reorder point which also can be found in Nahmias (2009).

$$R_0 = SS_0+\mu_0 \cdot L_0$$

Remember that L_0 is assumed constant, that this version of the model assumed a constant lead time to I_1 and that it also assumed the standard deviation of lead time (σ_τ^2) to 0. Thus Nahmias' (2009) estimation should be considered accurate enough. With this R_0 is found.

Step 4

I_2's demand during lead time is harder to estimate. Chances are that the metal plate's inventory can not always deliver at once to I_2 and so must include an estimation of the extra lead time for I_1 to deliver when they do not have it in stock.

To start first the estimated chance that the inventory level is negative must be estimated.

$E[IL-] = \sigma_0'^2/WQ_0 \cdot [H(x)-H(X)]$
Where $H(x) = 0{,}5 \cdot [((SS_0/\sigma_0')^2+1)-(1-\Phi(SS_0/\sigma_0'))- SS_0/\sigma_0'\varphi(SS_0/\sigma_0')]$
Where $x = SS_0/\sigma_0'$
In excel this is written as = 0,5 · ((x²+1) · (1-NORMDIST(x;0;1;1)) - x · NORMDIST(x;0;1;0))
And $H(X) = 0{,}5 \cdot [(X^2+1) \cdot (1-\Phi(X))-x\varphi(X)]$
Where $X = (SS_0+WQ_0)/\sigma_0'$
In excel = 0,5 · ((X²+1) · (1-NORMDIST(X;0;1;1))-X · NORMDIST(X;0;1;0))

With this estimation the average lead time ($\acute{L}_{HR}'$) to I_2 can be traced.

$$\acute{L}_{HR}' = l_{HR}+E[IL-]/(\mu_0/7)$$

The standard deviation of demand during lead time to I_2 is according to Nahmias (2009):

$$\sigma_{HR}' = \sqrt{(\sigma_{HR}^2 \cdot \acute{L}_{HR} + \sigma_{LHR}^2 \cdot \mu_{HR}^2)}$$

Again the deviation of lead time (σ_{LHR}^2) is set as 0 and although the safety stock and reorder point at I_2 is affected by this, the general conclusions will not likely be changed because of this assumption.

Step 5

This step is essentially the same as in step 3, where the safety stock and reorder point for I_1 was set. The service level does not need to be estimated as it is instead set by the company's policy at I_2.

To investigate the fill rate and compare target fill rate with this the rest of the formula are used as in Step 3 with the exception that it now is I_2 in focus.

$Serv_2 = 1-(\sigma_{HR}'/Q_{HR})[L(SS_{HR}/\sigma_{HR}')-L((SS_{HR}+ Q_{HR})/\sigma_{HR}')]$
In excel $L(SS_{HR}+\sigma_{HR}')$ = NORMDIST(SS_{HR}/σ_{HR}';0;1;0)
-(SS_{HR}/σ_{HR}') · (1-NORMDIST(SS_{HR}/σ_{HR}';0;1;1))
In excel $L[(SS_{HR}+Q_{HR})/\sigma_{HR}']$ = NORMDIST[($SS_{HR}+ WQ_0)/\sigma_{HR}'$;0;1;0]-[($SS_{HR}+Q_{HR})/\sigma_{HR}'$] · [1-NORMDIST(($SS_{HR}+Q_{HR})/\sigma_{HR}'$;0;1;1)]

Now, set SS_{HR} so that $Serv_2 = TF_{HR}$. And then calculate the reorder point for I_2.

$R_{HR} = SS_{HR}+\mu_{HR} \cdot \acute{L}_{HR}'$

At this stage the R_0, R_{HR}, $Serv_2^*$ for I_1 and safety stocks at each location should be set.

Notations on the model

Some notations should be made regarding the model built to give an understanding of restrictions and advantages of the model.

1. The model assumes unlimited production. That is that Thule can produce enough to satisfy demand during the high season. In reality, however, there is a need to build inventory beforehand (chapter 4.2.4) therefore a make-to-order policy is impossible with current facilities.

2. The model assumes perfect, known lead times. As procurement most likely needs to buy raw material to be secured a couple of days before scheduling the first operation there will be a slightly higher inventory level than calculated. This can, however be met with either estimating the average inventory as high or increasing the cost of the item.

3. Basic material calculated is based on the raw material. Both of the investigated products have more material during the production that lies in inventory. If these materials also uses the amount needed to be purchased (by integrating them in the cost at the model's central warehouse, for instance) the lowered inventories would most likely further decrease the holding costs. The result has partly taken this into account but is hard to estimate with the restrictions of the available time.

4. Assumption of normal distributed demand. The formulas taken from Nahmias (2009) all assume this and although Berling and Marklund's (2011) model could be used to handle a non normal distributed demand the model now built instead assumes normal distribution during the period for simplicity. Specifically for the LR, the result will not be optimal. Two advantages comes from this assumption, though; during the investigated season the normal distribution of demand is not a bad estimation and the second is that for Thule's size, normal distribution makes the calculations on a larger scale simpler.

5.3.2. Item HR

The lead times are set as 16 days for I_1 and 12 days for I_2. This includes the time for any operations (estimated one day for each when including some spill time between operations). If halved batch sizes are used the lead time to I_1 is decreased to 15 days (the operations should be able to be made in one day with half the size) and 9 days from I_1 to I_2. If any batch size is changed the data for the lead times must also be considered.

Target fill rate is assumed to be 95% and interest rate is set at 7,5%. The cost of each item is somewhat more awkward. The cost of a unit is approximately 4,4SEK at I_1 and cost of a unit at I_2 is 6SEK (including all costs) if divided to each unit in a HR. The cost does, however only make an impact on the reorder points and safety stocks at the inventories and only in such a small scale that the cost can easily be estimated and still produce the same general conclusions. The value of the item is of course more at the I_2 than at I_1.

The demand data has been given by the SC Coordinator (2011) and the standard deviation of demand for each day and week is based on this data. The average demand each day is based on the total demand split into days during the period which is assumed to be 30 days each month (total 120 days).

After the data above has been filled in and the steps from the analysis have been followed and the safety stock has been changed so that the reorder point are expressed in equal 100pcs, the model shows the following results for the HR:

I_1 should have:

- An optimal target service level of 27 %.
- A negative safety stock level of -14562pcs.
- R_0 = -1300pcs

I_2 should have:

- A safety stock level of 4283pcs
- R_{HR} = 18200pcs

The model suggests having low reorder point at I_1 and a much higher at the I_2. The model thus suggests having larger inventories at I_2 than at I_1. Remember that the model take into account the extra lead time that occurs whenever I_1 can not ship to I_2.

Setting a negative safety stock might produce some issues with company policies and thus setting a zero safety stock level at I_1, might be a more logical choice. This would also allow the company to ignore the safety stock in their systems, simplifying logistical decisions. Also this also will increase the inventory levels during the high season which is in accordance to Thule’s need to have larger inventories during the high season (SC Coordinator, 2011). This also deal with some of the warnings that Lynn (2005) and Wilson and Roy (2009) mentions in chapter 4.1.4. The basic suggestion for SS at I_1 is therefore 0 with minimum changes to give an equal 100pcs on the reorder point. This is tested below in table 5.5. Also note that Thule's current batch size has been translated to 5000pcs instead of 5120pcs to represent the policy suggested in chapter 4.4.

Next it can be interesting to see what happens when the batch size from the I_1 to I_2 is halved in the system. Thirdly the reorder point at the I_1 is set as 0 (order when stocked out) and last a policy where the system uses halved batch sizes is investigate as stated below:

1. $Q_0 = 20000$, $Q_{HR} = 5000$ and $SS_0 \approx 0$
2. $Q_0 = 20000$, $Q_{HR} = 2500$ and $SS_0 \approx 0$
3. $Q_0 = 20000$, $Q_{HR} = 5000$ and $R_0 = 0$ by changing the SS
4. $Q_0 = 10000$, $Q_{HR} = 2500$ and $SS_0 \approx 0$

Tested batch sizes for the HR				
Column	**1**	**2**	**3**	**4**
Order Q_0	20 000pcs	20 000pcs	20 000pcs	10 000pcs
Order Q_{HR}	5 000pcs	2 500pcs	5 000pcs	2 500pcs
Semi finished inventory (I_1)				
Lead time/d	16	16	16	15
Optimal $serv_2$	27%	29%	27%	30%
Actual fill rate	97%	97%	34%	94%
R_0	13 300	9 900	0	9 900
Finished goods inventory (I_2)				
Lead time d	12	9	12	9
SS	3 506	4 410	4 129	4 259
R_{HR}	14 200	15 100	17 500	14 300

Table 5.5. Tested batch sizes for the HR (own creation, 2011)

The results show that the present batch sizes are not optimal in the model (column 1). Halving the Q_{HR} (column 2) gives a lower reorder point at I_1 and a slightly higher at I_2 with a higher safety stock. When setting the reorder point at the I_1 to 0 (column 3), the total amount of inventory is lower than any other policy but a notation should be made that the holding cost of each item at this location is higher and a make-to-order policy is hard to achieve. Halving both batch sizes (column 4) would give lower inventory reorder points at both I_1 at the cost of slightly lower actual fill rate and a slightly higher reorder point when compared to the first to columns. It should be noted that the fill rate is in both cases much higher than optimal because the assumed SS_0 of 0.

The lead time for I_1 is marginally better with halved batch size and thus suggests that the cycle time is not an issue and instead a focus on supplier lead times are suggested more important. The effect of smaller batches on lead after I_1 is more noticeable. This is logical as after I_1, the two bottlenecks in operations are placed.

Of the investigated batch sizes the current batch size is not optimal in the model, when using low inventories as the deciding factor. Reducing the ordered batch size from the I_2 to half gives lower reorder point at the I_1 but a higher inventory if the first batch size is also halved. The third option might be the most economical efficient but is hard to achieve during the high season. Thus is the fourth option the one that should give the lowest inventory levels and is closest to a lean management policy.

5.3.3. Item LR

The lead times are set as 15 days for I_1 and 2 days for I_2. This includes the time for any operations (until I_1 the lead times are assumed the same as for the same batch size for the HR). If halved batch sizes are used the lead time to the I_1 is not decreased (the operations should be able to be made in one day in both cases) and still be at 2 days from I_1 to I_2. Thus, if the batch size changes it will not effect the lead times noticeably.

As the LR is a slow moving article, the standard deviation for the demand each day is high. Only one day in the period has the item been sold and in the quantity of 50pcs. As for the HR, the safety stock is assumed to be set as 0.

As the variation of demand is extremely high (1000%), the model is not optimal as it assumes a normal distribution of demand. Because the short lead time and low demand each day the model suggests a extremely high $Q_{LR,n}$

and the following calculations is based on the highest numbers in Berling and Marklund's (2006) tables.

The tests of batch sizes is (assuming the safety stock set at 0 at the I_1):

1. Q_0 = 20000, Q_{LR} = 400 and SS ≈ 0
2. Q_0 = 20000, Q_{LR} = 40 and SS ≈ 0
3. Q_0 = 20000, Q_{LR} = 400 and R_0 = 0 through SS
4. Q_0 = 10000, Q_{LR} = 200 and SS ≈ 0

Tested batch sizes for the LR				
Column	**1**	**2**	**3**	**4**
Order Q_0	20 000pcs	20 000pcs	20 000pcs	10 000pcs
Order Q_{LR}	400pcs	40pcs	400pcs	200pcs
Semi finished inventory (I_1)				
Lead time/d	16	16	16	15
Optimal $serv_2$	98%	98%	98%	98%
Actual fill rate	99%	99%	73%	98%
R_0	5 500	5 300	0	5 160
Finished goods inventory (I_2)				
Lead time d	2	2	2	2
SS	2	68	23	27
R_{LR}	9	75	37	34

Table 5.6. Tested batch sizes for the LR (own creation, 2011)

The present batch size (column 1) is the one with the lowest inventory at I_2. Thule uses a single pallet of 400 as the customer purchase quantity and batch size for I_2 (SC Coordinator, 2011) and this shows that the present batch size is to large. If the system allows smaller batches, as in the second column, the inventory at I_2 is higher but the total inventory should be lower than the present batch size. Using a make-to-order policy (column 3) does not give larger reorder points than a smaller batch for I_2. With the low and sporadic demand that the LR has, this policy might be feasible as there are several products with higher demand that also shares this inventory. That is, the decision to make a LR can be made when the next batch at I_1 is produced. After an order from customer it should take some time before next order and during this time the inventory would thus be low. With halved batch sizes (column 4) the total inventory sums up to the second lowest level and has negligible effect on lead times.

Changes of batch sizes to the I_1 does not noticeable change the lead time and so suggests that the lead time from supplier until delivery is the best way to improve the flow. Neither version suggests a reorder point over 400pcs at I_2, which is one pallet of 50pcs LR. Practical limitations in the form of that customers order complete pallets suggests that minimum batch in the system should be 400. It should be noted that the short lead time from $I_1 – I_2$ is low and thus suggests a make-to-order policy.

In total there is no point of having any batch size that is considered large at I_2 and changing Q_0 show negligible effect on lead times. If the customer could order less than a pallet the reorder point and safety stock should still be less than a single pallet of the LR. This suggests that the optimal decision would be to produce this item only on order. The batch policy where I_1 has a make to order-policy also gives the result closest to a lean management production with lowest inventory levels.

5.4. Conclusion

5.4.1 HR

- The model's optimal solution for Thule's current batch size policy is having a negative reorder point at I_1.
- Setting the reorder point to 0 at I_1 gives the best result when the goal is to have as low inventories as possible. This is not achievable during the high season, though.
- For improvement of lead times to $I_{1,}$ focus should lie at minimizing supplier lead times. For I_2, smaller batch size has a greater effect on lead times.
- Halving the batch sizes give the total lowest reorder points and safety stocks. The halved batch sizes give results most suitable for lean management.

5.4.2 LR

- Because the small amount of demand and high demand variation the model is not fully sufficient to calculate optimal reorder points.
- Except for a make-to-order policy for I_1, as long as the minimum batch sold to customer is 50pcs LR (400pcs in the model) the batch size show negligible effect on lead times and inventory levels.
- The short lead times between I_1 and I_2 show that a make-to-order-policy is also available for I_2.
- The model's result suggests that a complete make-to-order for the I_1 is preferable for the LR as this gives the lowest inventory level and is closest to a lean management.

6. Compare the batch size policies

This chapter will compare Thule's current batch size policy with the suggested ones from chapter 5, in hopes of computing the most advantageous policy. This chapter does not contain any theory because it is based on the results in chapters 3-5. The effect of the batch size policy on the HR will be discussed in chapter 6.2.2 together with the LR but only the HR will be compared with calculated costs in chapter 6.2.3 and 6.2.4. The conclusions from chapter 5 regarding the LR show that any changes in policies give minor results in inventory reduction as long as the ordered volume from customers remain whole pallets. This implies that the cost effect of the policy is minor for the LR and is therefore not calculated.

6.1. Empirical findings

The data used to compare the policies in this chapter have been added here, including the data that can be found in previous chapters. This is because it will be easier for the reader to follow the comparisons made and have the data close at hand.

Avg. $Inv._1$	5 610	Avg. raw material inventory
Avg. $Inv._2$	3 798	Avg. second inventory
Avg. $Inv._3$	189	Avg. inventory in Poland (after assembly)
Avg. $Inv._4$	662	Avg. inventory in Hillerstorp (before packing)
Avg. $Inv._5$	1 154	Avg. inventory in Thule's central warehouse
C/T_{press}	0,24	Cycle time in seconds for 1 pcs in press shop
$C/T_{surf.treat}$	0,075	Cycle time in seconds for 1 pcs in surface treatment
$C/T_{assembly}$	6,5	Cycle time in seconds for 1 pcs in assembly
$C/T_{packing}$	3,8	Cycle time in seconds for 1 pcs packing
$Setup_{press}$	72	Set up cost at Press shop
$Setup_{packing}$	98	Set up cost for at Packing
$Days_{period}$	120	Days during the investigated period
h%	7,5%	Percentage of holding costs / year
$D_{raw\ material}$	28 317	Produced amount of units during the period
D_{HR}	10 676	Demand of HR:s during the period, expressed in units
Days/year	365	Amount of time units each year

Table 6.1. Data for batch size policy comparison (SC Coordinator, 2011)

6.2. Analysis

This chapter will investigate the costs of inventories, set up costs, inventory coordination and optimisation of the product flows from a batch size policy perspective There are some data that needs to be estimated which have been summarised in the table 6.2.

6.2.1. Data needed to be analysed

In table 6.2, the lead times ($L_{order-I1}$ and L_{I1-I2}) are estimations dependent on the chosen batch sizes in each of the two flows. BS_1 is from order to leaving semi-finished inventory (I_1) and BS_2 from leaving I_1 to finished-goods inventory (I_2) as shown in chapter 4.4. The costs (C_1-C_5) have been estimated to fit a realistic increase from raw material until finished HR. The estimation is considered fair and will not affect the project's general conclusions.

$L_{order-I1}$	x	Lead time from order until leaving I_1 (depending on batch size)
L_{I1-I2}	x	Lead time from I_1 to I_2 (dependent on batch size)
BS_1	x	Batch size to I_1 (need to be set)
BS_2	x	Batch size to I_2 (need to be set)
C_1	4	Cost of item at raw material stock
C_2	4,4	Cost of item at semi finished goods inventory
C_3	4,8	Cost of item in Poland (after assembly)
C_4	4,8	Cost of item in Hillerstorp (before packing)
C_5	6,1	Cost of item at Thule's central warehouse

Table 6.2. Estimated values for policy comparison (own creation, 2011)

6.2.2. Implications of the batch size policies

Thule's present batch size policy causes leftovers at each station, especially with the bullwhip effect in mind, as the batch sizes are not mutual (chapter 3.4). The suggested batch size policy propose using a single batch size up to the semi-finished inventory in both cases and then a smaller, equal part of the first batch size for the rest part of the production (chapter 4.4).

In the CSMs for Thule's two investigated products there are three inventory locations for the HR (chapter 3.4), that are removed from the system and one for the LR (chapter 3.4). For the LR, the model basically suggests using a single full pallet as this is the smallest amount ordered by the customer from Thule's I_2 (chapter 5.4).

The suggested batch size policy proposes ordering material on demand, for both products, instead of ordering to an raw material inventory (chapter 3.4) and as the ordering from the supplier does not have the same kind of restriction as the latter parts of the production this is a possibility even in the high season (chapter 3.4). This type of policy will also show a greater importance of joint ventures to reduce lead times between supplier and Thule (chapter 4.4).

For the LR there are minor advantages of smaller batch sizes through the latter part of the production (chapter 5.4) but for the HR the latter part of the production consists of two bottlenecks (chapter 5.3) and so the WIP is greatly reduced with smaller batches (chapter 4.4).

The model shows two different batch sizes in the system and this imply that different departments can focus on a larger proportion of the production than the present policy (chapter 5.4). Procurement can focus on purchasing the optimal amount for the products from supplier until the semi-finished inventory. The finished-goods inventory can order for an optimal quantity from the semi-finished inventory location while considering the set up costs of the two bottlenecks. Thus will procurement be integrated with operations and transportation and warehousing will also be integrated with operations and transportation. At the same time transportation is already integrated with operations as they are presently setting their batch policy according to pallets (chapter 4.4) and this is illustrated in figure 6.1 below.

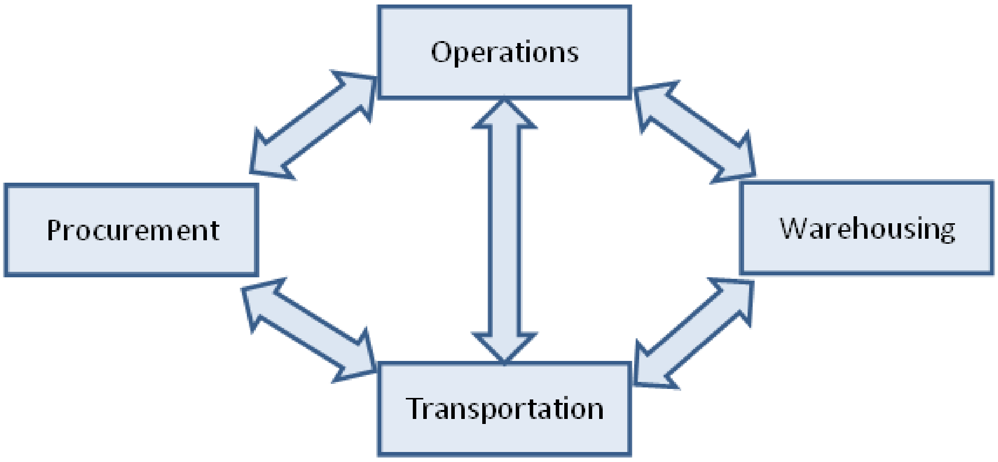

Figure 6.1. Cross functionality with our batch size policy (own creation, 2011)

6.2.3. Cost of the three removed inventory locations

When it comes down to costs, the model assumes that three inventory locations are removed (chapter 3.4). Assuming no raw material inventory, if the costs on the metal plates at the raw material inventory are set as 4SEK and 4,8SEK after Assembly the savings will be:

$$5610 \cdot 4SEK \cdot 7{,}5\%/365 \cdot 120$$
$$+189 \cdot 4{,}8SEK \cdot 7{,}5\%/365 \cdot 120$$
$$+662 \cdot 4{,}8SEK \cdot 7{,}5\%/365 \cdot 120$$
$$= \text{amount saved in SEK}$$

Amount saved in SEK / total holding costs during the period
= 53%

6.2.4. Comparison of a single item cost with different policies

It is rather easy to compare the current batch size policy and the tested by taking the holding cost for the item each day, total lead time and the setup cost for one metal plate. By using the cost of an item at each location based on information from Thule, the only costs that are explained in chapter 4.1.6 that will not been considered are; fixed order costs (not used by Thule) and movement costs (assumed constant during the high season). This will show the cost applied to a single item through the system.

The lead time for order to Assembly is based on the CSM in chapter 3.4.1 which gives 45 days in inventory plus the lead time calculated in chapter 5.3

(16 days). The inventories have a total of 21 days of lead time and 12 days transportation and operation time (chapter 3.4.1). The batch sizes are set as BS_1 = 20000 and BS_2 as 5120 as the CSM shows for the Press shop and Packing (chapter 3.4.1). The cost from order to assembly uses the cost of 4,3SEK and as this will be used for all comparisons. The second cost used is the average of 4,8SEK and 6SEK as it is more important to get a more correct estimation of the holding costs since more material is put in at these operations.

Flow: Order to Assembly
$4,3SEK \cdot 7,5\%/365 \cdot (L_{order\text{-}assembly}) + Setup_{press}/BS_1$
$= 4,3 \cdot 0,075/365 \cdot (61) + 69/20000 =$ X,XXSEK

Flow: Assembly to central warehouse
$5,5SEK \cdot 7,5\%/365 \cdot (L_{assembly\text{-}I2}) + Setup_{packing}/BS_2$
$= 5,5 \cdot 0,075/365 \cdot (33) + 98/5120 =$ X,XXSEK

Total cost flow of current batch size policy: 100% SEK

For the model's batch size the average inventory is unknown, since we have not integrated the model to Thule's system and can not see the full effects of the suggested batch size. Therefore we must estimate the average inventory. By using the reorder point plus any SS higher than 0, the estimation should be considered high. Where the reorder point is set as 0, a quarter of the reorder point is used as there will be some time where I_1 is in the negative until delivery. The average inventory level should then be the reorder point plus the safety stock divided by the demand of either raw material or the HR expressed in units. The costs are the same as used in the current batch size policy above. The rest of the data is based on information from Thule (SC Coordinator, 2011).

Tested batch sizes for the HR				
Column	**1**	**2**	**3**	**4**
Order Q_0	20 000pcs	20 000pcs	20 000pcs	10 000pcs
Order Q_{HR}	5 000pcs	2 500pcs	5 000pcs	2 500pcs
Semi finished inventory (I_1)				
$Setup_{press}$	72	72	72	72
R_0	13 300	9 900	0	9 900

Average inventory	13 300	9 900	5 000	9 900
$D_{raw\ material}$/day	1 770	1 770	1 770	1 770
Lead time/d	16	16	16	15
Days in inventory	8	6	3	6
Finished goods inventory (I_2)				
$Setup_{packing}$	98	98	98	98
Lead time d	12	9	12	9
SS	3 506	4 410	4 129	4 259
R_{HR}	14 200	15 100	17 500	14 300
Average inventory	17 706	19 510	21 629	18 559
D_{HR}/day	89	89	89	89
Days in inventory	27	29	32	28
Cost of each item	77%	92%	78%	93%
Lower cost %	23%	8%	22%	7%

Table 6.3. Single item cost compared with current policy (own creation, 2011)

The policy that is most cost effective compared to the present batch policy is the one that uses Thule's current batch size (column 1). Halving I_2's (column 2) batch size gives does not make any noticeable effects on the total inventories levels. A make-to-order policy (column 3) also gives substantial effect on the costs but highest inventory level at I_2. Halving the batch sizes (column 4) give a better result than the current batch size policy, but the lowest result when comparing these batch sizes.

6.2.5. Comparison of total inventory costs for the period

It can also be interesting to see the total average inventory costs and set up costs during the entire period as well and compare these. The costs considered are the same in chapter 6.2.4.

HR's costs of average inventories:
$=C_{1\text{-}5} \cdot \text{Avg. Inv.}_{1\text{-}5} \cdot h\%/\text{year}$
Total set up costs = $D_{raw\ material}/BS_1 \cdot Setup_{press} + D_{HR}/BS_2 \cdot Setup_{packing}$

Current batch size policy holding costs
= (4 · 748 · 0,075/365
+4,4 · 3798 · 0,075/365
+4,8 · 187 · 0,075/365
+4,8 · 662 · 0,075/365
+6 · 1154 · 0,075/365) · 120
= 100% SEK each day

Current batch size set up costs
= 28 317/20 000 · 69+10 676/5 120 · 98= 100% SEK

Total cost of current batch size policy during period = 100% SEK

The assumptions here are the same as for table 6.3 in form of the average inventory and costs of each item.

Tested batch sizes for the HR				
Column	**1**	**2**	**3**	**4**
Order Q_0	20000pcs	20000pcs	20000pcs	10000pcs
Order Q_{HR}	5000pcs	2500pcs	5000pcs	2500pcs
Semi finished inventory (I_1)				
$Setup_{press}$	72	72	72	72
R_0	13 300	9 900	0	9 900
Average inventory	13 300	9 900	5 000	9 900
$D_{raw\ material}$	28 317	28 317	28 317	28 317
Cost at I_1	33	33	33	33
Finished goods inventory (I_2)				
$Setup_{packing}$	732	732	732	732
SS	3 506	4 410	4 129	4 259
R_{HR}	14 200	15 100	17 500	14 300
Average inventory	17 706	19 510	21 629	18 559
D_{HR}	10 676	10 676	10 676	10 676
Cost at I_2	46	46	46	46
Total holding cost	44%	43%	41%	42%
Total set up cost	102%	172%	102%	206%
Total cost	56%	68%	53%	74%
Lower cost %	44%	32%	47%	26%

Table 6.4. Total inventory costs compared (own creation, 2011)

Here the make to stock policy (column 3) is the one that mainly decreases the total cost compared to the current batch size policy. When comparing the models, the holding costs are not far from each other when comparing the batch sizes the set up costs clearly, and unsurprisingly, vary between the batch sizes.

The result of table 6.3 and 6.4 shows that smaller batch sizes should not be the main goal for Thule at their present situation. The removal of the extra inventories and the usage of a cross functional batch size have a much higher impact than also using smaller batch sizes. Neither of the examples shows that smaller batch sizes are better than the make to stock- and current batch size (column 1 and 4). Thus have shorter lead times low effect on the total costs. This can be explained by the interest rate of 7,5% and the set up costs. It should be noted that the Assembly-line in Huta does not have a set up costs and thus show tremendous potential when lowering WIP with smaller batch sizes (figure 4.4), if only this line is considered.

Thus the main goal for Thule should be to remove the extra inventories and use a cross functional batch size policy which uses a two stage system with one semi-finished inventory, one finished-goods inventory and their current batch size.

6.3. Conclusion

- The model's removal of three inventory locations while optimizing the flow for the HR amounts to 53% less in cost during the period in holding costs. For this to work the system must have a cross functional batch size in the system.
- When comparing one item's costs, the present batch size is 23% more cost effective than the current batch size policy whereas the halved batch size only is 7% lower in cost.
- Total costs during the period shows that, even with a high estimation of the average inventory, if the model uses the current batch size the costs is reduced by 44%. Best result gave the make-to-stock policy with 47% and lowest improvement gave the halved batch sizes with 26%.
- The result shows the impact of lead times is low because of the interest rate and the set up costs as a major cost.
- The final conclusion is that Thule's present goal should be to use a two inventory policy with cross functional batch sizes instead of focusing on reducing the batch size.

7. Discussion

7.1. Implication of conclusions

The impact of a basic CSM is much higher than anticipated. As a tool it is highly descriptive in its basic form and can be very effective in decreasing lead times and noticing high inventory levels. It also gives suggestions to process' improvements and routines. Although only two products were investigated, the CSM showed that there were unnecessary inventories placed in the flow, gave inspiration to reducing lead times and build a foundation for the suggested batch size policy.

When examining Thule's current batch size policy, three things are worth mentioning; (1) the tendency of investigating product's costs when it is noticeable increased. For the products with low demand, the cost might not be shown as high when comparing two different periods as the cost might already be high. If so, it is doubtful if the cost will dramatically increase again in a noticeable way. Thus there might be more low runners with unnecessary high costs that will not be noticed. (2) Lead times from the supplier have so far not been in focus, although this is one of the main elements of lean management and will likely change in the future. (3) Transportation costs are more or less assumed constant and this is interesting as many batch sizes are set so that they should fill entire pallets.

Thule's use of pallets as a coordinated batch size seems like a logical choice initially. But the departments have a tendency to focus on their own goals and cause "spills" within the flow where components needs to be held in inventory. The solution to this is to have a batch size policy that uses a fewer number of batch sizes, with equal parts of each other in the system.

By removing the extra inventories and using a two stage inventory system (semi-finished inventory and finished-goods inventory) two constant batch sizes can be used and can be set as one size until the semi-finished inventory and as a part of the first batch size from that inventory until the finished-goods inventory. This will also increase cross functionality of the batch sizes.

When focus on shortening lead times, the first part until the semi-finished inventory should be prioritised on supplier delivery lead times. The second part can use smaller batch size, if shorter lead times are interesting as this part of the production contains the bottlenecks.

Through the calculations of the costs, smaller batch sizes showed not to be optimal (although lower in cost than current policy) but instead the current batch size was the most profitable in the model used. A make-to-stock policy should lower the cost even more but is unlikely to attain during the high season. In figure 7.1 we have illustrated the setting of the batch size level according to our findings. Thule should keep their current batch size level and focus on reducing the set up costs. The holding costs must be higher valued or the set up costs lowered for Thule to consider using smaller batches in the system and the main gaining of the suggested batch size policy is the cross functionality and the removal of extra inventories. In the case of the Assembly-line in Poland, though, the smaller batch sizes will produce a lower average WIP cost by reducing batch sizes.

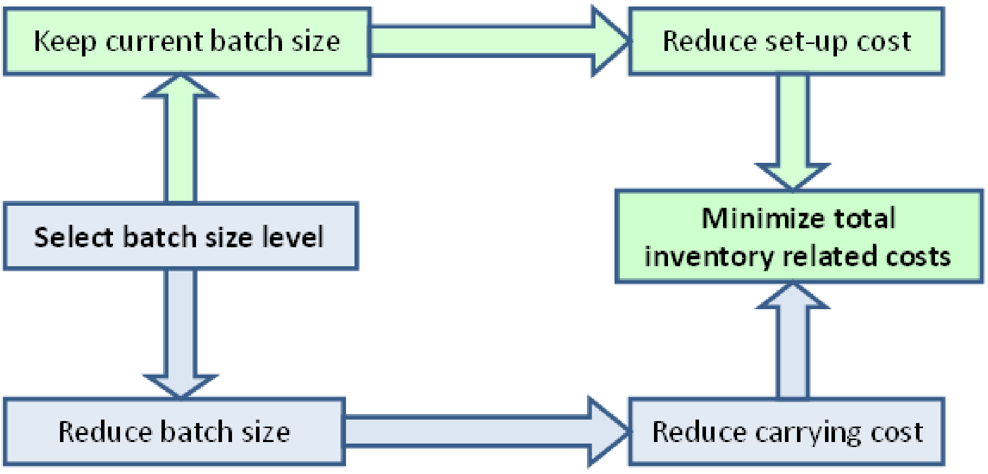

Figure 7.1. Thule's selection of batch quantity (Based on Gupta et al. 2010)

The conclusion is that the batch size policy of this project recommends a policy that uses only two sizes that are optimal for the entire production flow in the company, as in figure 7.2 and that this will give a cross functionality as shown in figure 7.3.

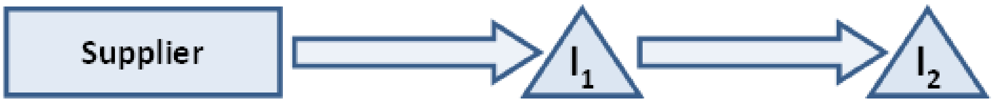

Figure 7.2. Suggested batch size policy (own creation, 2011)

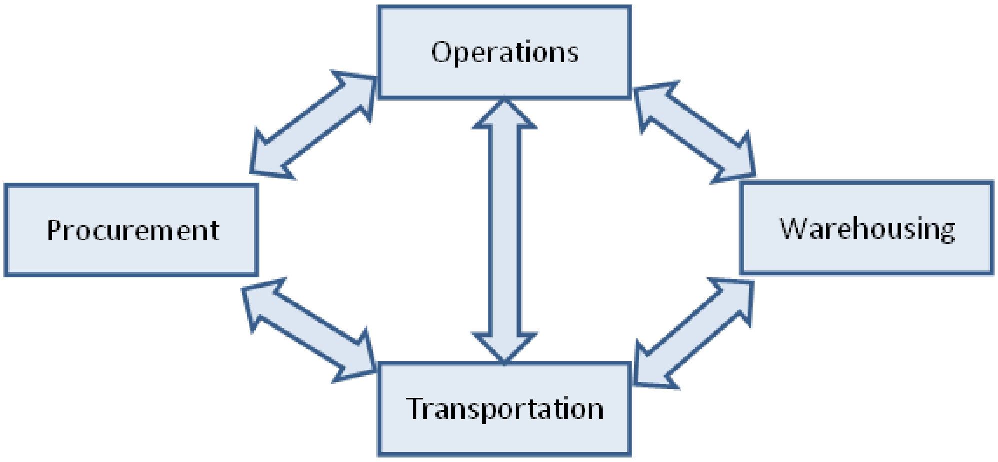

Figure 7.3. Cross functionality effect of suggested policy (own creation, 2011)

7.2. Further research

7.2.1 Suggestions to Thule Sweden AB

Thule's first priority should be to evaluate if there are more inventory locations for other products that can be considered unnecessary. This project has only investigated one high volume product in the company and the potential savings can be considered high if there are more similar situations. The same goes for the low volume products and the potential savings of allowing them to be made to order after the semi-finished inventory. All in all the potential savings in this department should be substantial.

The current system to measure the average inventory is based on the values of Fridays. For a better estimation on inventory levels (and give a better base for lean managerial decisions) all weekdays should be included as the shipping day has a great effect on the information available in the system.

Decreasing lead times are important for various reasons and this project has given several suggestions where focus needs to be laid to decrease lead times. There is also a need to investigate how Thule's transportation costs are changed if a higher degree of incomplete pallets are used or if the effect is negligible.

A system for determining order costs would help different departments to judge their decision based on the company as a whole instead of only focusing on their own department. Often is the order cost based on the interest rate and a lower interest rate suggests a larger order quantity. But the potential of a cross functional order cost would increase the integration level in Thule and work against sub optimization.

7.2.1 Suggestions to further research

The conflict of a low interest rate and lean is an interesting point and should be further studied academically. There should be more companies that use low interest rates and still aim for a lean production and the question is if these companies should continue to focus on lean.

A further study of how smaller batches, not fit for pallets, affect transportation costs for the products and to what degree would be very interesting. Third-part-logistical companies can usually pack different customers shipments together and the effect of this could be important to future batch size decisions.

7.3. Generalisation

The conclusions in this project should be valid on other similar products in Thule and in other companies with similar production. Therefore the generalisation should be considered high. The suggestions to focus on transportation lead times (when the operation cycle time is low) and on smaller batches (when there are bottlenecks in the production) is a valid conclusion that can most likely be generalised to a high number of producing companies. The removal of unnecessary inventories and the usage of a two stage inventory system is most likely a way to improve both efficiency and cross functionality to a broad category of companies.

7.4. Critic to own work

This project has not focused on the exact costs but has instead used estimation of costs (although based on real data) at certain production points and used that value to estimate total costs, safety stocks, reorder points and possible earnings. Most noticeable is the lack of using the cost for all items connected to the products investigate, instead the costs have been based on a single basic material and then increased slightly when deemed necessary. Although different costs should produce a different exact result, the general conclusion of possible earnings and batch sizes are still valid.

In the choice of model there is no theory describing the competitive models that can be used for optimization. This is because Berling and Marklund's (2011) model can, with simple assumptions, be modified with the use several known formulas. The basic model is thus only a frame that then can be modified to suit the modelers' situation. There are however parts where the model is rather complex and at these parts the theory on the model is lacking. The assumption is that the original complex calculations are not interesting to explain in full, but instead the importance is the function of the model as a whole.

Readers should notice that the empirical data could have been more extensive. This is most noticeable regarding cross functional aspects. The data available gives satisfying foundation to the conclusions and although more focus could have been laid on basic empirical data which would give a more detailed result of why Thule has the batch policy they have, the main conclusion would not change.

7.5. Authors ending words

We hope you have enjoyed reading our project degree and perhaps learned much. For us, this has been an interesting journey with many new experiences. We consider ourselves fortunate to have worked with Thule Sweden AB. The projects conclusion would not have had the same high quality if Thule had not provided dedicated personal during the projects process and have been extremely helpful. This shows the importance of the company's collaboration to produce valid suggestions for improvements in a master degree project.

Also, this project shows the effect of using outsiders, to give a fresh perspective on the processes. Using a contact in the company that is rather new in the company but has a similar background to the students also gives two advantages; (1) the contact needs to set themselves in the companies activities and during the process will most likely faster collect knowledge about the operations in the company and (2) there has never been any issues of compromising the academicals part needed for grades and so the conclusions gathered is consisted with academically criteria as well as grounded in logical thinking to produce valid suggestions to the company.

Perhaps the most interesting thing is, although Thule is a company of great competence there are always logistical elements that company should improve, such as low integration and the usage of several inventory locations which both works against any lean management. This does not suggest that Thule is doing something wrong, but instead show that these basic parts of inventory management should not be taken for granted and can be difficult to deal with.

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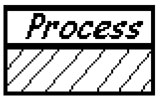
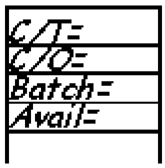
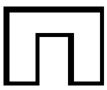
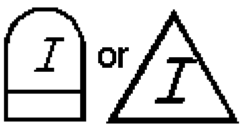
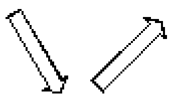
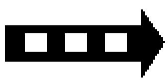
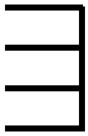
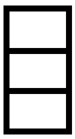
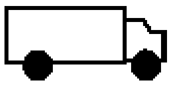
Appendix A. Value Stream Map Icons

VSM Process Symbols

 **Customer/Supplier**	This icon represents the Supplier when in the upper left, the usual starting point for material flow. The customer is represented when placed in the upper right, the usual end point for material flow.
 **Dedicated Process**	This icon is a process, operation, machine or department, through which material flows. Typically, to avoid unwieldy mapping of every single processing step, it represents one department with a continuous, internal fixed flow path.
 **Shared Process**	This is a process operation, department or workcenter that other value stream families share. Estimate the number of operators required for the Value Stream being mapped, not the number of operators required for processing all products.
 **Data Box**	This icon goes under other icons that have significant information/data required for analyzing and observing the system. Typical information placed in a Data Box underneath FACTORY icons is the frequency of shipping during any shift, material handling information, transfer batch size, demand quantity per period, etc.
 **Workcell**	This symbol indicates that multiple processes are integrated in a manufacturing workcell. such cells usually process a limited family of similar products or a single product. Product moves from process step to process step in small batches or single pieces.

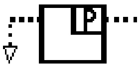
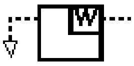
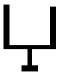
VSM Material Symbols

 **Inventory**	These icons show inventory between two processes. While mapping the current state, the amount of inventory can be approximated by a quick count, and that amount is noted beneath the triangle. If there is more than one inventory accumulation, use an icon for each. This icon also represents storage for raw materials and finished goods.
 **Shipments**	This icon represents movement of raw materials from suppliers to the Receiving dock/s of the factory. Or, the movement of finished goods from the Shipping dock/s of the factory to the customers
	This icon represents the "pushing" of material from one process to the next process. Push means that a process

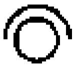
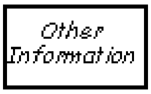
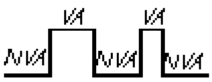
Push Arrow	produces something regardless of the immediate needs of the downstream process.
 **Supermarket**	This is an inventory “supermarket” (kanban stockpoint). Like a supermarket, a small inventory is available and one or more downstream customers come to the supermarket to pick out what they need. The upstream workcenter then replenishes stocks as required. When continuous flow is impractical, and the upstream process must operate in batch mode, a supermarket reduces overproduction and limits total inventory.
 **Material Pull**	Supermarkets connect to downstream processes with this "Pull" icon that indicates physical removal.
 **FIFO Lane**	First-In-First-Out inventory. Use this icon when processes are connected with a FIFO system that limits input. An accumulating roller conveyor is an example. Record the maximum possible inventory.
 **Safety Stock**	This icon represents an inventory “hedge” (or safety stock) against problems such as downtime, to protect the system against sudden fluctuations in customer orders or system failures. Notice that the icon is closed on all sides. It is intended as a temporary, not a permanent storage of stock; thus; there should be a clearly-stated management policy on when such inventory should be used.
 **External Shipment**	Shipments from suppliers or to customers using external transport.

VSM Information Symbols

 **Production Cont.**	This box represents a central production scheduling or control department, person or operation.
 **Manual Info**	A straight, thin arrow shows general flow of information from memos, reports, or conversation. Frequency and other notes may be relevant.

 **Electronic Info**	This wiggle arrow represents electronic flow such as electronic data interchange (EDI), the Internet, Intranets, LANs (local area network), WANs (wide area network). You may indicate the frequency of information/data interchange, the type of media used ex. fax, phone, etc. and the type of data exchanged.
 **Production Kanban**	This icon triggers production of a pre-defined number of parts. It signals a supplying process to provide parts to a downstream process.
 **Withdrawal Kanban**	This icon represents a card or device that instructs a material handler to transfer parts from a supermarket to the receiving process. The material handler (or operator) goes to the supermarket and withdraws the necessary items.
 **Signal Kanban**	This icon is used whenever the on-hand inventory levels in the supermarket between two processes drops to a trigger or minimum point. When a Triangle Kanban arrives at a supplying process, it signals a changeover and production of a predetermined batch size of the part noted on the Kanban. It is also referred as "one-per-batch" kanban.
 Kanban Post	A location where kanban signals reside for pickup. Often used with two-card systems to exchange withdrawal and production kanban.

VSM General Symbols

 **Operator**	This icon represents an operator. It shows the number of operators required to process the VSM family at a particular workstation.
 **Other**	Other useful or potentially useful information.
 **Timeline**	The timeline shows value added times (Cycle Times) and non-value added (wait) times. Use this to calculate Lead Time and Total Cycle Time.

Appendix B. Tabulated values

Table B1 Tabulated Values of $g(p_{l,n}, Q_{l,n}) \cdot 10^4$, i.e., if x is an entry in the table then $g(p_{l,n}, Q_{l,n}) = x \cdot 10^{-4}$

$Q_{l,n}$	$p_{l,n} = 1$	5	10	20	30	40	50	60	70	80	90	100	150	200	250
1	40.8	75.7	90.5	104	112	117	121	125	127	129	131	133	140	144	148
10	20.4	45.1	59.0	72.8	80.7	85.9	90.0	93.3	96.0	98.3	100	102	109	114	117
20	9.74	26.7	39.8	54.0	62.2	68.2	72.4	75.9	78.8	81.3	83.5	85.4	92.4	97.3	101
30	5.87	17.8	29.4	43.0	51.0	56.5	60.7	64.2	67.0	69.8	71.9	73.8	81.0	85.9	89.7
40	4.03	12.8	22.5	35.4	43.1	49.0	53.2	56.7	59.6	62.0	64.2	66.1	72.9	78.2	81.9
50	2.98	9.91	18.3	30.5	38.2	43.9	48.0	51.5	54.3	56.7	58.9	60.8	67.7	72.6	76.5
60	2.35	7.91	15.0	26.1	33.5	38.8	42.8	46.1	48.9	51.3	53.4	55.2	62.0	67.3	70.6
70	1.91	6.53	12.8	23.2	30.5	35.9	40.1	43.5	46.4	48.8	51.0	52.9	59.7	64.6	68.3
80	1.60	5.51	10.9	20.3	27.1	32.2	36.2	39.5	42.2	44.5	46.6	48.4	55.2	59.9	63.5
90	1.38	4.80	9.54	18.0	24.4	29.2	33.0	36.3	38.7	40.9	42.8	44.6	51.1	55.5	58.9
100	1.21	4.18	8.48	16.5	22.7	27.6	31.5	34.7	37.4	39.7	41.7	43.8	50.3	55.5	59.0
150	0.734	2.56	5.27	10.8	15.7	19.6	22.6	25.3	27.6	29.6	31.3	33.3	39.2	43.3	46.4
200	0.527	1.81	3.78	7.86	11.8	15.1	17.8	20.1	22.4	23.8	25.4	26.7	32.0	36.0	39.5
250	0.415	1.40	2.92	6.21	9.56	12.6	15.5	17.9	20.0	22.0	23.7	25.2	31.7	36.8	40.2
300	0.340	1.15	2.34	5.05	7.68	10.1	12.3	14.2	15.9	17.3	19.0	20.2	24.8	28.1	29.7
400	0.252	0.828	1.71	3.66	5.72	7.73	9.61	11.2	12.7	14.1	15.4	16.6	21.1	24.3	26.7
500	0.201	0.644	1.31	2.88	4.49	6.21	7.84	9.49	11.0	12.3	13.8	15.0	20.2	23.9	26.3

Table B2 Tabulated Values of $k(p_{l,n}, Q_{l,n})$

$Q_{l,n}$	$p_{l,n} = 1$	5	10	20	30	40	50	60	70	80	90	100	150	200	250
1	0.943	0.957	0.961	0.965	0.966	0.967	0.968	0.969	0.969	0.970	0.970	0.970	0.971	0.972	0.973
10	1.163	1.119	1.094	1.076	1.066	1.062	1.059	1.056	1.054	1.053	1.051	1.050	1.046	1.043	1.042
20	1.381	1.271	1.207	1.158	1.138	1.124	1.117	1.111	1.107	1.103	1.099	1.097	1.088	1.084	1.079
30	1.519	1.383	1.287	1.217	1.189	1.172	1.162	1.153	1.147	1.141	1.136	1.132	1.119	1.111	1.106
40	1.613	1.469	1.357	1.264	1.228	1.205	1.194	1.183	1.175	1.168	1.163	1.158	1.145	1.134	1.128
50	1.686	1.533	1.410	1.299	1.255	1.228	1.213	1.200	1.193	1.185	1.179	1.174	1.159	1.148	1.141
60	1.736	1.584	1.458	1.337	1.287	1.257	1.240	1.226	1.216	1.207	1.200	1.194	1.177	1.163	1.158
70	1.779	1.630	1.491	1.363	1.306	1.271	1.251	1.235	1.223	1.214	1.206	1.199	1.183	1.170	1.161
80	1.814	1.666	1.529	1.392	1.333	1.296	1.272	1.255	1.242	1.235	1.227	1.220	1.197	1.183	1.174
90	1.838	1.691	1.556	1.419	1.355	1.316	1.291	1.271	1.265	1.254	1.246	1.238	1.214	1.200	1.190
100	1.861	1.721	1.582	1.437	1.370	1.327	1.300	1.280	1.266	1.254	1.244	1.235	1.214	1.196	1.186
150	1.931	1.803	1.673	1.520	1.441	1.390	1.365	1.341	1.323	1.309	1.297	1.285	1.257	1.240	1.228
200	1.963	1.852	1.725	1.579	1.492	1.437	1.400	1.379	1.355	1.349	1.336	1.325	1.291	1.270	1.250
250	1.974	1.880	1.764	1.626	1.533	1.471	1.425	1.393	1.369	1.354	1.338	1.325	1.276	1.244	1.227
300	1.987	1.896	1.796	1.650	1.567	1.506	1.464	1.432	1.408	1.389	1.371	1.359	1.318	1.294	1.300
400	1.995	1.926	1.829	1.698	1.608	1.543	1.494	1.468	1.439	1.417	1.398	1.384	1.333	1.306	1.287
500	1.997	1.948	1.865	1.733	1.655	1.587	1.536	1.493	1.461	1.435	1.409	1.390	1.323	1.287	1.278