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Abstract

Production planning focuses on systems to control and plan production, while still fulfill customer demand with the lowest use of resources as possible. An important part of production planning is to determine the timing and quantities of which products to be produced. In this dissertation, the lot-sizing problem at Ringnes is solved with the aid of four lot-sizing techniques. The lot-sizing methods that are applied are the Silver Meal heuristics, Part Period Balancing, Least Unit cost and the Wagner Within algorithm. Three specific research questions are formulated for this study that addresses which lot-sizing method that provide the best results for Ringnes, how robust the solutions are and which factors that have an impact on the lot-sizing methods. A quantitative approach is used to solve the research question.

The main findings in this thesis are that of the heuristics that were applied, the Silver Meal heuristics provided the best result for Ringnes. With dynamic programming, the Wagner Within algorithm managed to reduce total cost by 2.2 % compared to the Silver Meal heuristic. When the solution from the lot-sizing methods were measured against demand, the solution resulted in high inventory levels and stock outs. By evaluation of the forecast, results showed that the forecast accuracy was low, which weakened performance of lot-sizing schemes substantiality.

Keywords: Lot-sizing, production planning, replenishment policies, forecasting.

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1.0 Introduction

1.1 Background for thesis

Managing production and inventory flows is an important activity within logistics and supply chain management. Silver et al (1998) state that the competitiveness of the Japanese manufactures has made the rest of the world realize the potential in successfully implementation of inventory management and production planning and scheduling systems. Production planning is defined as a forward-looking process that tries to meet future demand with minimal use of resources (Jacobs, et al. 2011). Silver, et al. (1998) have stated that decision-making in production planning and inventory management involves comprehending a diversity of external and internal factors, as forecasts, demand, inventories, capacity and materials. To succeed within these activities, it is important to have implemented systems that assist decision makers in processing key information to make the best possible decision.

In production planning and inventory management, there are three main issues; (1) how often the inventory status should be determined, (2) the time between placements of replenishment orders and (3) the size of the replenishment orders (Silver et al. 1998). The focus in this thesis is on replenishment policies at one of the largest breweries in Norway, respectively Ringnes. For Ringnes, the focus has been on the third main issue in production planning, to determine the size of replenishment orders. Therefore, emphasises in this thesis is on the lot-sizing problem at Ringnes. Lot-sizing decisions are made with respect to inventory levels, forecasts and setup costs. The lot-size may impact the overall performance. First, because the sizes and timing determine how well customer orders are satisfied. Second, larger lot-sizes aids to increase efficiency at the production lines.

To measure their performance, Ringnes operates with key performance indicators (KPI), where different department is responsible for their “own” set of KPI’s. The main measure for the production-planning department is the stock service level (SSL) KPI. This KPI measures order fulfilment rate of customer orders. If a customer of Ringnes place an order for a product that Ringnes does not have on stock, it alters the KPI. The amount that is not available for the customer order are backlogged, and will have a negative impact on the KPI. The main KPI for the forecasting department is the forecast accuracy KPI. This KPI measure the forecast accuracy for each stock keeping unit (SKU). The forecast is essential for planning along the whole supply chain, which makes this KPI equally important for the production-planning department. A range of KPI’s governs the production department, but the most important is the overall equipment efficiency (OEE) KPI. This KPI measure the productivity by mapping the amount of total available time that are spent on producing output. If the production line has stops due to maintenance or setup, this alters the OEE. There needs to be continuous output from the line for all available time to achieve an OEE of 100 %. This target is unrealistic, as there will always be changeovers or idle time at the production lines. Nevertheless, an important aid to increase the OEE is to produce larger series to reduce the downtime.

In some cases, there may be a conflict of interest between the production department and the planning department. Larger series where setup and idle times is reduced are favourable for the OEE. For the SSL, it may be favourable with smaller series that can be better adapted to the changes in demand. The final production plan that determines the production series are made on a weekly basis and the plan for the following week is determined one week in advance. Before the production plan is determined, there is a meeting between the planning department, the production department and the blending department (responsible for preparing liquid for production). Typical issues that are discussed during this meeting are scheduling, quantities and configuration of SKU's in the production plan. For example, the blending department may have issues related to the scheduling of products and quantities as there are constraints regarding the capacity and availability of the blending tanks. There exist minimum limits of how much the department must blend in each tank. However, the most important attainment is that the production plan is designed for the operation to be most efficient at an aggregated level.

1.2 Research focus

The research is focused on a sample of products from one production line at Ringnes, the production line and the sample of products will be presented in section 2.1. By the forecasts and specific parameters related to this sample, their replenishment policies and lot-sizing decision is studied from a conceptual point of view. Making the right replenishment decision in production planning will have an impact on a manufactures performance, efficiency and competitiveness (Karimi, et al. 2003). The optimal decision is recognized where setup, production and holding costs are minimized. Therefore, the accuracy of these parameters is very important in lot sizing calculations. Most lot sizing techniques balances the parameter of inventory cost with the parameter of setup cost. Browne, et al. (1996), argues that studies should focus on how to improve these factors instead of focusing on best solutions of calculating lot sizes. Further, it is questioned in Browne et al. (1996), p. 185, why we have lot-sizes, and its argued that if we could remove the cost of placing orders and the capacity that are lost during setups the lot-size would always be at one unit. They argue that instead of doing research regarding lot-sizing, researchers should focus on how to remove the costs that are “creating” the lot-sizing problem.

In this study, the focus in on the overall replenishment policy, where both calculation of lot-sizes and vulnerability in relation to uncertainty in these parameters will be addressed. This is because it is impossible to avoid or remove setup and inventory cost for operations at Ringnes. The production lines have many products and to remove both setup and inventory costs would require one specialized production line for each product with the ability to make quick adjustment to meet variations in demand. This is not considered as a realistic opportunity. Therefore, the potential for productivity improvements of replenishment policies will be considered and studied.

1.3 Cooperation with Ringnes

The reason why this thesis is written in cooperation with Ringnes is that in the summer of 2016, the author had an internship at the production-planning department at Ringnes. During the internship, both knowledge and interest in the operation at the company was obtained. At the end of the program, they offered this opportunity for collaboration.

1.4 Purpose and value of study

The purpose of this study is to provide Ringnes with a quantitative research that addresses their replenishment policy. The conceptual framework provided by the literature is used to analyse the policy that is currently used by Ringnes, and to compare current practice against policies presented in the literature. Hopefully, this research can assist in discussions regarding how these decisions are made today and sizes of production series. The goal is to investigate and identify which replenishment policy that are most advantageous for Ringnes. The approach to this research is to apply different conceptual frameworks on real life data from Ringnes. The empirical data includes forecast, production data, inventory parameters and changeover data from one production line at Ringnes. This data and the literature will be used to analyse current practice and provide recommendations for improvements.

The value of this study for Ringnes is the comparison of the theoretical framework for replenishment policies compared to the current policy. Current policies include an ERP system that suggest lot-sizes and production planners assess the proposal in regard to forecast, inventories and scheduling opportunities for the following period. The production proposal from the ERP system is rarely applied, it is mostly used as notifications to which products that need to be produced. The production planner state the quantities and detailed scheduling manually. For example, if the identified optimal lot-size in this study suggest a lot size remarkably higher than the quantities produced today, it creates an incentive for Ringnes to increase the series size of that product. In this matter, we study and investigate efficiency opportunities in this process at Ringnes.

1.5 Thesis outline

Chapter 2: In chapter two, the company (Ringnes), and the research questions and the objectives that govern this thesis is presented.

Chapter 3: Chapter three contain a description of the most relevant literature towards production planning, replenishment and lot-sizing.

Chapter 4: In chapter four, the methodology, assumptions and the general approach in this thesis is explained.

Chapter 5: The results from the analysis is presented in chapter five. The first part of the chapter present results from the lot-sizing calculations and the final part presents analysis regarding the results.

Chapter 6: In chapter six, the result and analysis is discussed in relation to the research questions and the literature.

Chapter 7: The conclusion and recommendations is presented in chapter seven.

2.0 Presentation of company and research objectives

2.1 About Ringnes

Ringnes is Norway's largest brewery company and supplies the Norwegian markets with beer, soda and water. Ringnes operated mainly within the B2B segment Their brands are well known, and the most famous brands includes Carlsberg, Solo, Imsdal and Farris among others. In addition to produce their own brands, Ringnes operates as a production provider for external brands. Primarily, Ringnes serve the Norwegian market, but additionally exports some products to the Swedish market. Ringnes is fully own by the Danish based company Carlsberg group.

Ringnes has four production plants, which approximately produce 400 million litres annually. The plants are respectively located in Trondheim (EC Dahls), Larvik (Farris), Imsdalen (Imsdal) and Oslo (Gjelleråsen). Divided by markets, Ringnes produce 141 million litres of beer, 185 million litres soda and 73 million litres of water (Ringnes.no, n.d.). The main production facility at Gjelleråsen has five production lines and is their largest plant with an annual production capacity of 180 million litres. The production line that is studied in this thesis is the production line 207. Line 207 produces a range of brands within the soft drink segment. The machinery at production line 207 is designed to produce 1.5 litres bottles.

The data collected from this line includes forecast data, production volumes, inventory costs and setup related data. The largest product in the portfolio at 207 has a total forecast of approximately 80 million litres over a two years' period, in comparison the smallest product has a total forecast of approximately 500 000 litres. The volatility of demand is ranging from a standard deviation of 1694 L on the most stable products, to a standard deviation of 170 694 L on the most volatile. In Table 1, the sample from the production line is presented where the unit of measurement is litres. Notice, that all products are anonymized due to restrictions for Ringnes as an external production provider. The products have been given letters in alphabetical order.

Material	Total forcast over two years	Average per week	Min per week	Max per week	Standard deviation
A	4 682 895,50	47 301,97	22 846,70	71 035,80	8 610,54
B	681 079,60	6 879,59	2 301,00	27 054,40	4 974,86
C	5 779 988,40	58 383,72	40 401,50	105 816,60	9 327,89
D	80 400 811,30	812 129,41	449 135,80	1 433 622,30	170 685,54
E	7 757 239,00	78 355,95	23 909,10	1 144 947,30	137 875,05
F	3 734 319,90	37 720,40	25 251,70	76 691,80	8 648,93
G	8 294 204,70	83 779,85	0,00	760 355,80	132 278,95
H	38 991 536,40	393 853,90	227 092,60	749 798,10	70 618,01
I	5 339 731,30	53 936,68	33 849,70	93 353,00	11 879,24
J	11 152 765,30	112 654,19	68 565,80	475 562,80	47 224,83
K	5 460 710,10	55 158,69	34 750,40	87 295,90	10 532,64
L	1 398 384,80	14 125,10	8 543,20	33 910,50	3 672,29
M	521 895,00	5 271,67	2 934,30	14 340,30	1 694,86
N	1 864 412,20	18 832,45	10 071,80	50 936,80	5 147,22
O	1 106 082,10	11 172,55	4 714,30	40 565,70	6 667,18
P	4 656 994,80	47 040,35	27 866,00	101 835,40	11 708,72
Q	1 455 882,60	14 705,88	829,00	31 167,30	4 593,45
R	5 323 895,80	53 776,73	31 593,50	122 808,80	11 907,34
S	502 342,50	5 074,17	0,00	10 222,10	1 941,71
T	612 359,50	6 185,45	0,00	21 887,90	3 130,73

Table 1. Presentation of the sample from production line 207.

2.2 Replenishment policies at Ringnes

The main managerial tasks of the production-planning department at Ringnes is to provide a production schedule that ensures that the demand for the following period is satisfied. Ringnes operates with several planning horizons depending on the objective of the planning. For example, aggregated capacity planning has a planning horizon of one year. Because the production plans are made on week to week basis, the planning horizon that is relevant in this thesis are the planning horizon that is characterized as medium-term.

At Ringnes, the inventory replenishment policy can be viewed as an iterative process in deciding which product to produce when and to what quantity. A considerable amount of work is devoted to decide which product and quantity to produce for each planning horizon. Ringnes' products are defined as fast moving consumer goods (FMCG), which means that the products are perishable and have a best before date. Because of this, the concentration of inventory is different compared to other industries. Inventories in FMCG companies may have a risk of a total loss of value if they exceed their best before date. This is most relevant in the food and beverage industries, but is also relevant for products that may be outdated because of technology development. Ringnes operates in a make to stock (MTS) environment, which includes having inventory of products in anticipation of demand. The products they have on inventory are finished product ready to be distributed to retailers. The combination of FMCG in an MTS environment requires an inventory and replenishment policy that are well functioning. If the policies are inaccurate, the company may experience significant losses because of waste of inventories and loss of sales.

Current lot-sizing practice at Ringnes includes a framework in the ERP system SAP APO. The SAP system provides an overall assessment of constraints regarding inventory, blending, and production capacity. The lot-sizes are suggested in regards to these constraint, however, there are no mathematical model that govern the calculation. The lot-size suggestion from the system are determined by merging following days of forecast values. The final decisions regarding production lot-sizes is made in companionship between the production planning and the production department. The decision is governed by personal judgement by assessing the proposals from the SAP system and days of supply and production capacity. Days of supply provides an indication of how many days the current inventory level will satisfy the forecasted demand.

To assess and compare the lot-sizes provided from this system against the conceptual approach from the literature, data of production quantities for the same products and planning horizon was retrieved. This data is presented in Table 2. Description of how the parameters of setup costs and inventory costs are measured is presented in methodology chapter. The number of setups is how many times the respective product has been produced during the planning horizon and the average lot-size is the average volume that has been produced. From the total inventory column, we see that some of the values are negative. The following formula for determining inventory in period T is used: Inventory T = inventory T-1 + lot-size T – forecast T. Where inventory T-1 is previous period inventory value, and lot-size T is included in the periods where production has occurred. The negative values are explained by higher forecast values than production lot-sizes. For those products where this is prevailing, the total cost is misleading.

The current replenishment policy presented in Table 2, is used as comparison for the replenishment polices from the conceptual framework. However, as the total costs in the

Table 2 gives a poor foundation for comparison, emphasis is made towards average lot-sizes and number of setups during the planning horizon.

Ringnes						
Material	Number of setups	Setup cost	Total inventory	Holding cost	Total cost	Average lot size
A	42	kr 1 298,14	-19 714 903,00	kr 0,03	-kr 469 018,28	96 533,1
B	20	kr 1 104,21	-3 264 150,20	kr 0,03	-kr 64 597,14	31 046,4
C	58	kr 1 913,58	-53 263 692,40	kr 0,03	-kr 1 303 459,40	81 446,7
D	96	kr 3 423,95	-352 820 446,20	kr 0,03	-kr 9 040 644,18	807 903,0
E	53	kr 3 403,04	15 271 868,20	kr 0,03	kr 585 914,28	155 003,8
F	64	kr 1 719,65	7 173 553,00	kr 0,03	kr 300 555,07	59 607,0
G	62	kr 3 368,37	289 653 476,80	kr 0,03	kr 7 900 747,82	201 400,3
H	93	kr 3 209,11	35 901 640,20	kr 0,03	kr 1 251 835,45	417 866,3
I	59	kr 1 733,05	-31 027 249,30	kr 0,03	-kr 721 695,62	76 344,4
J	65	kr 1 539,12	-43 490 499,30	kr 0,03	-kr 1 054 871,38	159 171,0
K	49	kr 2 541,10	-24 207 552,00	kr 0,03	-kr 518 331,23	98 505,6
L	28	kr 1 694,30	-9 965 872,00	kr 0,03	-kr 217 208,77	41 995,7
M	18	kr 1 500,37	-380 881,50	kr 0,03	kr 16 892,17	28 160,0
N	32	kr 1 647,98	-9 174 125,50	kr 0,03	-kr 190 888,73	50 838,0
O	30	kr 1 454,05	-5 404 888,80	kr 0,03	-kr 99 908,46	34 329,6
P	47	kr 1 653,83	-18 110 592,50	kr 0,03	-kr 403 206,63	87 926,0
Q	34	kr 1 459,90	-4 237 014,70	kr 0,03	-kr 62 879,59	42 302,1
R	44	kr 2 222,72	-30 621 273,40	kr 0,03	-kr 715 365,36	104 896,1
S	23	kr 2 028,79	4 843 745,00	kr 0,03	kr 175 290,41	27 122,1
T	21	kr 2 347,17	1 458 398,80	kr 0,03	kr 88 019,06	31 433,1

Table 2. Historical data of replenishment at Ringnes (in litre).

2.3 Overall research objective

The overall research objective is to address the replenishment policy for a sample of products at the production line 207 at Ringnes, and compare current practices with theoretical optimality. Three research questions are formulated which underlies and comply the overall research aim. The research questions are presented below.

2.4 Research questions and objectives

1. *Which replenishment policies for solving the lot-sizing problem are applicable and who provides the optimal solution for production planning at Ringnes?*

The objectives of research question one is to identify how known replenishment polices can aid the production planning at Ringnes. To help understand the degree of which it would be possible to apply such a policy and explore how the different lot-sizing method impact costs. In addition; identify which technique from the conceptual framework that provides the optimal solution of the lot-sizing problem. The objective is to explore if there exists an incentive to increase or decrease the size of the production series.

2. *How robust are the solutions from the conceptual framework to uncertainty in demand?*

The objective of research question two is to study how well the replenishment policies perform when changes in the demand occur. Production planning at Ringnes is made with respect to forecasts that involves uncertainty and it is interesting to test how lot-sizing methods perform regarding the uncertainty.

3. *Which factors have impact on replenishment policies at Ringnes?*

The objectives of research question three is to provide an assessment of different factors that have an impact on the replenishment policies at Ringnes. Specifically, assess and understand the effect and impact of forecasting, setup and inventory cost on replenishment policies.

3.0 Literature review

The purpose of the literature review is to present relevant literature that can be used as a framework to address the research questions. Included is an introduction to production planning in general, and different characteristics of this process, followed by a short classification of production planning strategies. The specific literature to research question (RQ) one is presented in chapters 3.2 – 3.4. Chapter 3.5 and 3.6 addresses research question two and chapters 3.7 and 3.9 cover research question three. In Table 3, the content of the literature review is presented.

3.0 Literature review		
3.1 Introduction		
RQ1	RQ2	RQ3
3.2 Lot-sizing problem *3.3 Lot-sizing methods* *3.4 Applicability of replenishment policy*	*3.5 Inventory management* *3.6 Forecasting*	*3.7 Performance measurement* *3.8 Setup and scheduling effects in a production setting* *3.9 Sensitivity analysis*

Table 3. Content of literature review

3.1 Introduction

A management policy is a set of principles and guidelines with an objective to direct the organization to achieve their goals (BusinessDictionary.com, n.d.). A replenishment policy contains principles related to inventory decisions to resolve the fundamental purpose of a replenishment system, respectively; how often the inventory status should be determined, when a replenishment order shall be placed and the size of the order. In a manufacturing company like Ringnes, mainly the production planning department controls these decisions. Therefore, the introduction emphasises on decisions making in production planning. Later, literature related to specific decisions made in respect to replenishment policies will be presented.

3.1.1 Production planning. *"Production planning and scheduling focuses on systems for controlling and planning production*" (Silver et al. 1998, p. 23). A system for planning and production control includes procedures that may be in form of an ERP system, traditional practices or personal experience, which aids the decision of when to produce and the size of replenishment orders. The aim of production planning is to provide a production schedule to fulfil the future demand. This schedule is in a make to stock environment based on the forecasted sales and inventory levels of each product. Accordingly, the production planning is dependent on information regarding forecasts and inventory levels, as well as availability of raw materials. The production schedule provided by the production planning department has both direct and indirect impact on the other operations in a company. The distribution department makes plans for future deliveries based upon the availability of products defined by the production plan. Therefore, linkages exist between distribution and production planning. Storage or inventory facilities need to know which raw materials that are demanded for the period, as well as the need for available capacity for finished products. In other words, the production planning serve an important role within the supply chain. Figure 1 from Beamon (1998), p. 283 defines the position of production planning in the supply chain. Links exist between the production planning, manufacturing facility and the inventory facility. However, Figure 1 misses some important links as the linkage between planning and sales/forecasting department. As mentioned above, some of the most important information used in production planning is obtained from the sales/forecasting department.

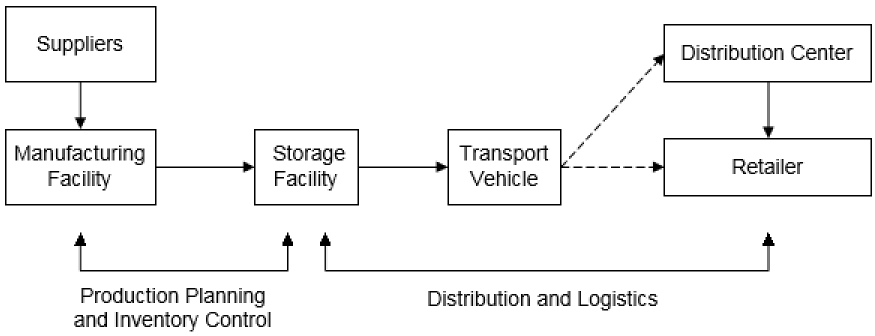

Figure 1. Defining the position of production planning in a supply chain.

Figure 2 below is retrieved from Nahmias' (2009), p.128 and presents a hierarchy of production decisions. In Figure 2, the steps and information flows to prepare a detailed production schedule is illustrated. The input data to a production plan is the forecast for future demand. The forecast defines which quantities of each product that will affect the inventory levels. The objective of the production plan is to schedule which products that needs to be produced to obtain the desired inventory levels for the following period. This enhances the importance of the forecast accuracy, and its impact on the performance of the whole supply chain. If the forecast accuracy is low, the following operations in the supply chain will be conducted with greater uncertainty. As we see from Figure 2, the forecast is carried out prior to the production plan on an aggregated level, and the production plan makes the basis for the master production schedule and the material requirements plan. The material requirement planning includes the required raw materials for production of the products in the master production schedule.

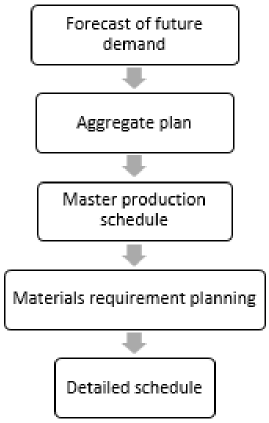

Figure 2. Hierarchy of decision in production planning, from Nahmias (2009).

3.1.2 Planning horizons. Karimi et al (2003) distinguishes between three planning horizons for decisions in production planning, hereby long-term, medium-term, and short-term decision-making. This can be defined as strategic, tactical, and operational planning. Strategic production planning has a planning horizon that range from two to five years. Tactical production planning has a horizon of one year and operational planning has a planning horizon that range from day to day or weeks/month depending on the type of manufacturing company. In long-term strategic decision-making, a manufacturer makes decisions regarding equipment, processes, facilities and capacity planning. For medium-term tactical planning, the production quantities, material requirements and optimization approaches are planned. Short-term planning includes sequences of jobs and decisions related to daily operations (Karimi et al. 2003, p. 365).

The basic issue in production planning is to schedule the amount of resources that should be applied in each period to achieve production goals. Production goals relates to product availability and efficiency of operations. Resources includes production equipment, capacity, human resources, raw materials and inventory levels (Jacobs et al. 2011). The key in production planning is to find the right balance between supply and demand. If demand exceeds supply, there are a lack of product availability and the service level towards the customer decrease. To encounter this, typical cost related to overtime production and distribution will increase, as well as the quality could suffer because of rush to deliver products (Jacobs et al. 2011). If supply exceeds demand, inventory levels increases, inefficiencies may occur resulting from unbalance between production capacity and demand. If discounts are initiated to increase demand, this could reduce the performance, as profit margins is reduced. Therefore, production planning departments desires to avoid the cost related to unbalance between supply and demand.

3.1.3 Views of production processes. Chopra & Meindl (2013), differentiate between two views of supply chain processes. These views are push and pull processes. Push and pull processes related to when production is initiated to response to customer demand. In a push process, execution of production is initiated based on anticipation of customer demand. The anticipation of demand is estimated with forecasts, and it is a speculative process as the production is based on forecasted demand and not actual demand. In a pull process, production is initiated based on customer orders, and the production of a product is specific to a customer order. The push and pull view is useful and important when we consider supply chain decisions related to replenishment polices manufacturing and procurement.

3.1.4 Production strategies. A production strategy defines the way a company disposes their production capacity to meet customer demands. There are three extreme approaches to production strategies in a supply chain; the level, chase, or flexible strategy. A forth strategy is a hybrid/tailored strategy which combines some aspects from the other approaches. In practice, a hybrid strategy is most commonly applied. Following, are the three distinct production strategies presented.

A level production strategy involves a constant rate of output where inventory builds up in periods with low demand and depletes in periods with high demand (Jacobs et al. 2011). This strategy enables a stable workforce and production capacity. The disadvantages are that the production is not synchronized with demand, and in periods with high demand, there are risk of delays and backlogs (Chopra & Meindl, 2013). A chase production strategy enhances a synchronization of the output rate with the demand. The production capacity is adjusted to meet demand, which in low demand periods may include laying off employees and reducing machine capacity. The disadvantages with this production strategy is that the adjustments of workforce and production capacity may be expensive and difficult to apply. The advantage is that the inventory cost is low, therefore this strategy may be profitable when the cost of carrying inventory is high (Chopra & Meindl, 2013). A flexible strategy is applicable in settings where there is excess production capacity, and the production planner has the ability to adjust the workforce and production capacity regarding the demand. This does not include hiring or firing of the workforce, because the planner can demand the workforce to work overtime or shorter days to compensate for variations in the demand (Chopra & Meindl, 2013).

3.2 Lot-sizing problem

The lot-size is defined as the number of units in one production batch (Malakooti, 2013). In the logistics literature, the lot-sizing problem is well known, and there is conducted a lot of research concerning this problem (Glock et al, 2014). Although there are several distinctions regarding the problem, the basics or foundation in the problem is coherent. The basic issue of the lot-sizing problem is when and how much to produce to satisfy the demand. Below are some definitions that express the concerns in the lot-sizing problem presented.

"The problem related to the extent of how many units in one batch will minimize the total holding and setup cost over the planning horizon" (Nahmias, 2009, p. 376).
"*The process of identifying how many parts should be produced (before changing the setup for another part) is called the lot-sizing problem*" (Malakooti, 2013, p. 272).

"*The manufacturing lot-size problem is basically one of converting requirements into a series of replenishment orders*" (Vollmann et al. 2005, p. 479).

"*Lot-sizing decisions give rise to the problem of identifying when and how much of a product to produce such that setup, production and holding cost are minimized"* (Karimi et al. 2003, p. 365).

The concerns or objective of the lot-sizing problem of minimizing total cost of inventory and setup cost is mathematically formulated as:

$$\min \sum_{j=1}^{J} \sum_{t=1}^{T} (s_j x_{jt} + h_j I_{jt}) \text{ (Haase, 1994)}$$

Where;

j	item/product
T	period
s_j	setup cost coefficient
x_{jt}	binary value indicating if setup occur (1 or 0)
h_j	inventory cost coefficient
I_{jt}	inventory of item j
q_{jt}	lot-size for item j in period t
d_{jt}	demand for item j in period t

This objective may be governed by several constraints that extend the scope of the problem. The extensions of the lot-sizing problem vary with respect to the type of demand, how the capacity is managed and the type of product that are produced. In Table 4 the different distinctions and dimensions is presented.

Distinction:	Dimensions:	
Level	Single	Multi
Demand	Deterministic	Probabilistic
Demand variation	Static	Dynamic
Capacity	Limited	Unlimited
Time horizon	Finite	Infinite

Table 4. Extensions of the lot-sizing problem.

First, there are either a single-item or a multi-item problem. This relates to the setup structure of the production plant. A single item problem consists of one item where setups and scheduling is independent of the other items, this is classified as a simple setup structure (Karimi et al. 2003). A multi-item problem consists of two or more dependent products, where the setup cost and time occurs and are affected by the order the items are produced. This is classified as a complex setup structure. The multi-item problem is naturally more complicated than the single item problem.

Second, an important factor to the lot-sizing problem is the characterization of demand. The demand is an input to solve the lot-sizing problem. The first concern is whether the demand is deterministic or probabilistic. Deterministic demand is known in advance and will not change over time. Probabilistic demand is not known, but is predicted to occur with some degree of probability (Karimi et al. 2003). Further, it is differentiated between static and stochastic demand. If the demand is static, it means that the rate of the demand is stationary and that it does not vary over time. Stochastic or dynamic demand varies over time. It is less complicated to solve the lot-sizing problem where the demand is characterized as deterministic and static compared to probabilistic and stochastic demand.

Third, a distinction between an uncapacitated problem and a capacitated problem. An uncapacitated problem indicate that there is no limitation of the production or inventory capacity and there are no constraints on the lot-sizes. If the problem is capacitated it indicate specific constraints regarding either production or inventory capacity. This means that the lot-sizes are constraint to certain sizes where the capacity is not exceeded.

The last distinction is related to time horizon of the problem that are solved. If the time horizon is finite it means that the time horizon is limited and typically for a specific number of periods. If the time horizon is infinite, there are no limitations for the time-periods.

3.3 Lot-sizing methods

The first framework to solve the lot-sizing problem where introduced in 1913 when Harris first presented the economic order model (Harris, 1913). Since 1913, there have been a lot of research regarding lot-sizing, and a numerous of lot-sizing framework and methods have been introduced (Glock et al, 2014). The simplest of the methods are the lot for lot method, which includes producing exactly the requirements for each period. The solution by the lot for lot strategy will rarely produce an optimal solution (Nahmias, 2009). The aim of lot-sizing methods are to calculate the trade-off between inventory cost and setup cost and identify the appropriate balance.

Malakooti (2013), differentiate between static and dynamic lot-sizing methods. Static lot-sizing is when the lot-sizes are equal for all the periods, which may be applicable where the demand are stable over the planning horizon. Dynamic lot-sizing adjust the lot-sizes in accordance to fluctuations in demand. These lot-sizing methods are used when the demand is characterized as stochastic demand. Most lot-sizing techniques are developed for discrete demand cases, where the demand is time-phased and stated from period to period (Vollmann, et al. 2005). To solve the lot-sizing problem by these techniques, we need some parameters to be measured and known. First, we need to know the demand or the requirement for the planning horizon. As previously mentioned, this may both be deterministic or probabilistic, and make the basis for the lot-sizing calculations. Secondly, we need to know the cost of having the products on inventory and the costs for setup to production of the product. Finally, each individual method may have some own assumptions that govern that method, as some methods take the cost of production into account. Figure 3 from the article of Glock et al (2014) illustrates the distinctions between stationary and dynamic lot-sizing models.

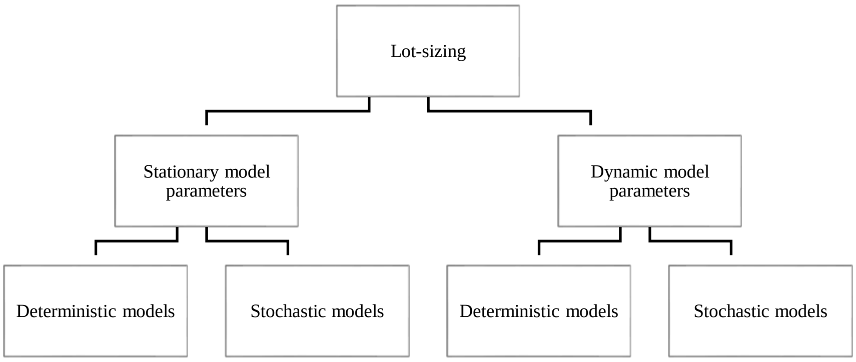

Figure 3. Structure of lot-sizing problem. Retrieved from Glock et al (2014), p. 42.

In the next subsections, four techniques for solving the lot-sizing problem are presented. Each technique has its own approach to solve the problem. The methods characteristics, formulas for calculating and inputs that are necessary will be discussed. In the result section, the computational result from application of these techniques will be presented, based on the data from Ringnes. The five techniques that which are included to solve the lot-sizing problem in this thesis are the Silver-Meal heuristic, least unit cost, past period balancing and the Wagner Within algorithm. Some other lot-sizing techniques which are not included is the mentioned Economic Order Quantity (EOQ) method, Groffs' method (Baciarello et al. 2013), McLarens' order moment (MOM) (Bregman, 1991), Least period cost (Bregman, 1991) and Least total cost (LTC) (Baciarello et al. 2013).

3.3.1 Silver-Meal Heuristics. The Silver-Meal (SM) heuristic calculates lot-sizes based on average holding and setup costs per period and the method was first developed by Edward A. Silver and H.C Meal in 1973 (Silver & Meal, 1973). The approach of the methods is that requirements from two periods are merged to one lot-size if the total cost decrease by merging the two periods. This process continues until merging the past period with the following does not reduce average holding and setup cost (Nahmias, 2009). If including demand for one more period in the lot-size increase the average cost, the lot-size is equal to a quantity that satisfy the previous periods demand. If the average cost decreases, the lot-size increases (Malakooti, 2013).

The inputs of the Silver Meal heuristic are as follows:

C_p	setup cost
C_h	holding cost
r_i	net requirement for given period
T	last period for lot-size iteration
C_T	average cost per period
i	period counter

Formula for calculating the Silver Meal average cost per period: $C_T = \frac{C_p + \sum_{i=1}^{T}(i-1)r_i C_h}{T}$

3.3.2 Least Unit Cost. The least unit cost (LUC) heuristics has the same principle as the Silver-Meal heuristic, but instead of minimizing the average cost per period, the LUC method minimizes average cost per number of units. In the formula for the Silver Meal above, the denominator is *T*, which is the number of periods that are included in the lot-size. In the formula for the LUC heuristics below, we see that the denominator is the sum of the units that are included in the lot-size. This number gives the average cost of holding and setup per unit that are included in the lot-size. If average cost increases by including units for one more period, we stop. The next formulation begins from the following period.

The inputs to the Least Unit Cost heuristic are as follows:

C_p	setup cost
C_h	holding cost
r_i	net requirement for given period
T	last period for lot-size iteration
C_T	average cost per unit
i	period counter

Formula for calculating the average cost per units: $C_T = \frac{C_p + \sum_{i=1}^{T}(i-1)r_t C_h}{\sum_{i=1}^{T} r_i}$

3.3.3 Part Period Balancing. The part period balancing (PPB) approach is to balance the setup and inventory cost by merging the lot-sizes until the period where the inventory cost is as close as possible to the setup cost (Jacobs, et al., 2011). The principle of the PPB method is equal to the economic order quantity method. However, the PPB method balance the setup and inventory cost when the demand rate is fluctuating (Malakooti, 2013). The method provides dynamic lot-sizes that adjust in accordance to demand. The inventory and setup cost are balanced for each period. For example, if the setup cost is fixed at 200 in the first period, the demand for the following periods are included in the lot-size up to the point where the inventory cost equal 200. The inventory cost exceeds as the demand for period two needs to be held on inventory for one period, the demand for period three needs to be held on inventory for two periods, etc.

The inputs for the PPB heuristic are as follows:

r_i Net requirement for given period

C_p Setup cost

C_h Holding cost

Formula for determining balanced inventory cost: $\sum_{i=1}^{T}(i-1)r_t C_h$

3.3.4 Wagner-Within Algorithm. The Wagner Within (WW) algorithm is a dynamic version of the economic order quantity method and was first presented by Wagner and Within in 1958 (Wagner & Whitin, 1958). The algorithm is an extension of the EOQ by allowing the demand to be dynamic, compared with the EOQ which solve the problem for static demand. The algorithm was developed as a dynamic programming algorithm to solve the limited time horizon lot-sizing problem to optimality (van Eikenhorst, 2015, p. 19). Dynamic programming is based on the principle of optimality (Nahmias, 2009, p. 414). By dynamic programming, the original problem is divided into small portions where the optimal solution of the portion of the problem is identified. The portion of the problem is gradually enlarged until the original problem is solved entirely (Hillier & Lieberman, 2010, p. 425). A dynamic programming approach facilitates to save considerable computational time, because the possible combination of the solution is reduced by solving the smaller portion of the problem.

The original algorithm from 1958 is based on forward dynamic programming (Wagner & Whitin, 1958). The approach in Nahmias (2009), presents a backward recursion approach. It is stated that the backward recursion approach is natural and more intuitive.

Inputs to the WW algorithm includes;

t	period
d_t	amount demanded in t period
i_t	inventory cost
s_t	setup cost
x_t	amount ordered or lot-size

The functional equation to minimize cost is;

$$f_t(I) = \min[i_{t-1}I + \delta(x_t)s_t + f_{t+1}(I + x_t - d_t)]$$

Where

$\delta(x_t) = 0$ if $x_t = 0$ and 1 if $x_t > 0$.

3.4 Applicability of replenishment policy

In this section, possible practical challenges for applying lot-sizing procedures into production planning will be discussed. The application of a new procedure in an already functioning system is challenging. Decisions in a production system may already be governed by tested personalized approaches, accepted industrial practices or traditional approaches that are embedded in the organization (Silver et al 1998).

A lot-sizing method can be viewed as a decision system, where the method assist a decision-maker in deciding appropriate lot-sizes. It is stated in Silver, Pyke and Peterson (1998) p. 29, that "*decision systems and rules must be designed to help expand the bounds put upon that individual ability to rationalize*". This is related to the bounded rationality of human being, which means that humans do not have the capacity to identify all possible solutions of a complex problem and therefore may fail to choose the optimal solution. A decision system should assist the decision maker by presenting solutions in a way that make it possible to act rational.

Another important characteristic of the method is that the complexity should not outweigh the cost saving (Vollmann, et al. 2005). The method cannot be too complex and time consuming to use. The most prominent use of a lot-sizing method will be as a supplement to the ERP system. Both to assess the optimality of the lot-size and to assess the cost of production of the lot-size.

3.5 Inventory management

If managed correctly, inventories can be a strategic competitive weapon (Silver, Pyke and Peterson, 1998, p. 9). *"Inventory management encompasses decisions regarding purchasing, distribution and logistics, and specifically addresses when and how much to order"* (Silver, Pyke, Peterson, 1998, p. 23.). An important part of inventory management is the replenishment policy. The replenishment policy defines the approach a company should have to manage and control how inventories are managed and how inventory manage uncertainty. Chopra & Meindl (2013) presents two types of replenishment policies, the continuous review and periodic review. A continuous review replenishment policy includes a fixed order quantity, which are ordered each time the inventory levels drops below the reorder point. A period-review replenishment policy includes a scheduled time where the inventory levels are reviewed. If the inventory levels are too low, an order is placed with a quantity that will satisfy the desired inventory level. The size of this order may vary in accordance to the demand for each period.

3.5.1 Inventory environments. One factor determines the inventory environment of a company; this is the customer order decoupling point (CODP). This is the point in the supply chain where inventories are allocated to a specific customer, and demand shift from independent to dependent. Independent demands are not directed to one specific customer, whereas dependent demand is specific to one customer. This point is important because the company is responsible for the order quantity and timing to this point, beyond the CODP the order quantities and timing are determined by the customer. Further discussion of this point will be as we look at the different inventory environments. We have four basic inventory environments, these are make to stock (MTS), make to order (MTO), assemble to order (ATO) and engineer to order (ETO) (Vollmann, et al. 2005). The position of the CODP in each inventory environment is illustrated in Figure 4 below. Companies may operate with several and different configurations of these environments. For the purpose of this thesis, only the MTS environment is presented further.

Inventory location	Suppliers	Raw materials	Work in process (WIP)	Finished goods
CODP	Δ	Δ	Δ	Δ
Environment	ETO	MTO	ATO	MTS

Figure 4. Customer order decoupling point (CODP) in inventory environment. Reproduced from Vollman, et al. 2005, p. 21.

In a make to stock (MTS) environment, the CODP is located at the finished goods inventory. This means that the company has the control and responsibility of inventory levels in the whole supply chain, including finished goods inventory. An MTS environment entails a procedure for production and inventory where products are made in anticipation of demand. The production is initiated by inventory levels, which means that none of the products is produced for dependent demand. In this environment, the customer service is determined by the availability of products on stock, therefore it is essential to balance the inventory levels and the desired level of customer service. This would not have been a problem if the company had unlimited inventory capacity, but that is not the case. Therefore, a key aspect of this environment is to manage the finished goods inventory, and decide inventory levels and replenishment policies (Vollmann, et al. 2005, p. 21).

3.5.2 Function of inventories. Cachon & Terwiesch (2009), state five reasons for holding inventories. Respectively, processing time of products, seasonal demand, economies of scale, separation of steps in a process, and stochastic demand. In accordance to Sox et al (1999), the inventory in a production setting may serve three distinct roles. This includes assisting the production system to reduce the number of setups, as the demand are satisfied by the inventory in periods where the specific product is not produced. In addition, the inventory level creates a buffer for periods where the demand is volatile, and thereby protect against stock outs. Finally, Sox et al (1999), state that the inventory investment made for one product may be advantageous for other products. Because, as inventory is high of a product there is no need to produce this item. This creates flexibility regarding production of other products, and that the planner can schedule the production with minimal use of setups. In this way, the advantage of inventory of one product is shared among the other products.

3.5.3 Types of inventory. In the logistics literature, it is distinguished between different types of inventory. First, inventories may be categorized regarding where the items are in the production process, from raw material to finished product. Secondly, inventories may be categorized by which purpose they serve. Further, the differentiations made between cycle stock, safety stock, anticipation stock, congestion stock, pipeline stock and decoupling stock will be discussed with emphasis on the relevant types.

Cycle stocks is the most common type of inventories. This type exists in all organization that order or produce their products in batches. The time-period between a purchase or production order determines the size of the cycle stock. Silver et al (1998) have listed three reasons to why companies purchase/produces in batches: economies of scale, discounts, or technological restrictions. Economies of scale is achieved where setup or order cost are high, and the cost per unit is decreasing as the order size increase. Discounts gives purchasers an incentive to order larger batches, which will reduce the purchase cost per unit. A technological restriction that may be a reason to produce in batches could be minimum capacity. For example, a beer production line that have brewed a large tank of beer need to produce a batch to empty the tank. If they do not, large amount of beer is wasted.

Congestion stocks are products that compete for the same limited production capacity, and therefore need to wait for equipment to be available (Silver et al 1998).

Anticipation stocks are inventories produced/purchased in anticipation of demand (Silver et al 1998). The inventory is typically accumulated in periods with spare capacity. Normally, anticipated stock is kept for peak periods where the capacity is fully utilized.
Other reasons to accumulate anticipation stock might be in cases where it may occur events that disrupts the supply, for example maintenance. By using anticipation stocks, the production line can plan to keep a smooth production capacity, and not add and subtract capacity, which may be costly (Cachon & Terwiesch, 2009).

Safety stocks are inventory that shall protect against uncertainty in supply and demand. Arnold et al (2012) differentiate between quantity and timing related uncertainty. Quantity uncertainty occurs when sales is unanticipated high or low and causes differences in supply and demand. Timing uncertainty occurs when lead times of supply or demand is unanticipated high or low. Safety stocks are kept to protect against quantity uncertainty. Silver et al (1998) define p. 234 the safety stock defined as "*the average level of the net stock just before a replenishment arrives"*. If the demand after a replenishment order is placed is higher than expected, the size of the safety stock is the buffer that can ensure the deliverability of the company. The size of the safety stock is determined by the desired service level and forecast accuracy. A simple formula for calculation the safety stock is retrieved from Silver et al (1998) and is as follows;

$$Safety\ stock = k\sigma_L$$

Where

k safety factor

σ_L standard deviation of forecast error

The safety factor is determined by the desired service level. A service level of 99.99 % require a safety factor of 4.00, and a service level of 50 % require a safety factor of 0.00. The safety factor determines the number of standard deviation of the forecast error that shall be kept at safety stock, as the safety factor is multiplied with the safety factor (Arnold et al, 2012). We see that the safety stock is directly related to the forecast estimation. If a company desire to obtain a high service and their forecast contain large errors, the cost of holding the safety stock may be high.

Pipeline inventories are goods or products that are transported within a company and relates to the flow time in a process, and the only way to reduce pipeline inventory is to reduce flow time. Pipeline inventories can also be classified as goods in transit or work in progress (Silver, Pyke & Peterson, 1998; Cachon & Terwiesch, 2009).

Decoupling or buffer stock is inventories that are held at workstations in a production process to address uncertainty in processing time. This stock is used to absorb variations in flow rates in a process and thereby enable continuous processing eliminating stops (Cachon & Terwiesch, 2009).

3.6 Forecasting

Forecasting is the key in demand management. A well-developed system for demand management within the firm creates significant benefits. *"Demand management includes* *activities that range from estimating the demand from customers, through converting specific customer orders into promised deliveries, to helping balancing supply and demand"* (Vollmann, et al., 2005, p. 17). If we imagine that a company could eliminate uncertainty for the demand rate for the next twelve months, capacity and supply could be planned accordingly. Recall the hierarchy of production decisions that were presented in Figure 2, all decisions made in production are made on basis on forecast information. Forecasting has an important role in the operation planning in a manufacturing company (Nahmias, 2009)

A forecast is an estimate of the demand for the respective product (Vollmann, et. al., 2005). There are a lot of information that can be used to provide this estimate. Important data that is used to calculate a forecast is previous demand, trends, variation in sales and seasonality. It is also important to map factors that may have an impact of the sales. The impact sources for a forecast is divided into internal and external factors. The internal factors are measures that the company have control over, for example measures of marketing initiatives, promotions and characteristics of the product. External factors are data of competing products and/or competitors' sales incentives. Arnold et al 2012, p. 170, presents four principles of forecasting; (1) forecast are usually wrong, (2) forecast should include an estimate of error, (3) forecast are more accurate for family groups and (4) forecast are more accurate for nearer time periods.

3.6.1 Forecasting methods. There are two approaches to formulate a forecast, a quantitative approach and/or a qualitative approach. Nahmias (2009), define these as objective or subjective methods. A subjective approach to forecasting does not use historical data, but estimate the forecast based on human judgement (Nahmias, 2009). An objective approach, are forecasting methods that estimates the forecast by analysing quantitative historical sales data. Further distinctions of objective approaches are made between time series and causal methods (Malakooti, 2013; Nahmias, 2009). Time series methods determine the forecast on basis on historical data of the specific product of which the forecast is made. In time series, we can often identify different patterns of the demand, depending of the type of product and its characteristics. The different patterns we can identify is a trend, seasonality patterns, cycles, or randomness (Nahmias, 2009). The forecasting methods will not be further discussed in this section. The importance of forecast in replenishment policies are the accuracy of the forecast. In the following, forecast evaluation methods will be emphasized.

3.6.2 Forecasts evaluation. To evaluate the accuracy of a forecast, we calculate the forecast error. In the literature, there are presented several approaches that assess the forecast error. The methods that are used to measure the forecast errors in this thesis are the mean error, mean absolute deviation (MAD), mean absolute percentage error (MAPE) and mean squared error (MSE).

$$\text{Mean error} = \frac{\sum_{i=1}^{n}(\,forecast\ demand_i - actual\ demand_i\,)}{n}$$

The mean error measures the average deviation between the forecasted demand and the actual demand over the planning horizon. The mean error provides indication of the direction of the forecast error, as the error is measured either by a positive or negative number. However, when measuring the average mean error, where both negative and positive errors are observed, the mean error levels out and might be misguiding. A forecast evaluation that does not level out errors is the mean absolute deviation.

$$\text{MAD} = \frac{\sum_{i=1}^{n} |actual\ demand_i - forecast\ demand_i|}{n}$$

The MAD forecast evaluation gives an absolute measure of the forecast error. This indicates that the measure includes all errors. The MAD measure provides a better forecast evaluation than the forecast error. The MAD ignores the direction of the forecast error, as the absolute value of the error is measured (Arnold et al 2012).

$$\text{MAPE} = \frac{100}{n} \sum_{t=1}^{n} \left| \frac{actual\ demand - forecast\ demand}{actual\ demand} \right|$$

MAPE measures the absolute percentage error between the forecast and the actual demand. Equally, to the MAD measure this method ignores the direction of the error (Silver et al 1998).

$$\text{MSE} = \frac{1}{n} \sum_{i-1}^{n} (actual\ demand - forecast\ demand)^2$$

MSE measures the square root of the forecast error. The MSE measure along with the MAD measure is dependent on the magnitude of the values (Nahmias, 2009). Larger deviations are indicated where the values of the forecast and demand is large. If we have a forecast of 10 and demand of 8, the forecast error is 2 or 20 %. If we have a forecast of 1000 and a demand of 800, the error is still 20 %, however the MAD and MSE increase with the magnitude of the values resulting in a MAD of 200.

3.7 Performance measurement

This section has the objective to create a framework to analyse the current replenishment policies with the policies that are previously presented. Beamon (1998), state two objectives of a set of performance measurements. The first is to measure the efficiency or effectiveness of an existing system. The second is to compare a current system effectiveness against competing systems. The objective in this research is to compare current system performance or efficiency against competing systems.

Beamon (1998), differentiate between two categories of performance measurements. Respectively, qualitative and quantitative. Qualitative performance measurements do not have numerical measurement indicators and performance is measured by feedback and observations. Some of the qualitative performance measures that Beamon (1998) has presented is customer satisfaction or service, flexibility, information and material flow integration, risk management, and supplier performance.

Quantitative performance measurement are those indicators that have numerical measures. Beamon (1998) divides the quantitative measures further into two categories. First, those measures that are related to cost or profits, and second, those who relates to customer responsiveness. Performance measures related to cost or profit includes cost minimization, sales/profit maximization, inventory investment minimization or return on investment maximization (Beamon, 1998). Performance measures related to customer responsiveness includes fill rate maximization, product lateness minimization, customer response time minimization, lead-time minimization, and function duplication minimization (Beamon, 1998).

The most evident measure to compare the policies against is the cost measure of their performance. The total cost of a replenishment policy includes the cost of inventory and setup cost. Another measure to compare the policies are the customer responsiveness, this measure how well the policies can adapt to variations in the demand. If stock-outs occur, the performance of the policy will be altered. The lot-sizes in the replenishment policy is a measure that is important for the efficiency of the production lines. There are better facilitated to increase the efficiency at the production line with larger lot-sizes. By small lot-sizes, the setups will occur more frequent, which will alter the efficiency.

3.8 Setup and scheduling effects in production settings

To address one of the root causes to why we have lot-sizes we will consider setup cost and if there exist opportunities to reduce the setup costs. Cachon & Terwiesch, (2009) differentiate between internal and external setup tasks. Internal setups are those setup tasks that can only be performed during stops at the machineries. External setups are those tasks that can be performed while the machineries are operating. Converting internal setups to external setup may be a cost-efficient way to make the production more effective.

Antunes et al (2016), p. 74, presents a method that addresses setup costs. This is the Single Minute Exchange of Die (SMED) method. The basics of this method is to not threat setups as stipulated constraints, but identify root causes of the setup and address these causes to reduce waste in the setup time. SMED originates from the automobile industry where they wanted to address and reduce the setup time used to change dies in the production. A die is a device that is used to cut metal parts into their preferred shapes. This method includes seven steps, (1) observe and measure current methodology, (2) separate internal and external tasks, (3) transform internal task into external task, (4) improve remaining internal tasks, (5) make external tasks more efficient, (6) standardize new procedure and (7) repeat method.

Antunes et al. (2016), divides a process changeover or a setup into three “ups”. These are clean up, setup and start up. The clean-up phase includes removing all equipment, products, components or residuals from the product that were previously produced. The time used for this phase varies according to the difference from the previous product to the next. The setup phase is the activities that are required to prepare the production line to run a new process. During this period, there are no outputs from the production line and no value is created. Which means that all the time spent in the setup phase are waste, in other word; utterly unproductive (Antunes, 2016, p 72). The start-up phase is the time from beginning the processing of a new product to the process have reached its full speed or its steady state. This phase includes fine-tuning of the equipment and it is normal that products jams and the production line has several small stops during this period (Antunes, 2016). Figure 5 below, represent the whole process related to a changeover at a production line. From the axis origin to the first stippled vertical line is the cleaning phase, where output from the production line decrease from steady state to zero in output. The setup time is illustrated between the two first stippled lines, in this period there is no output, hence no value creation. From the second to the third stippled line is the start-up phase, here production of a new product begins and the output increases from zero to the steady state during this period.

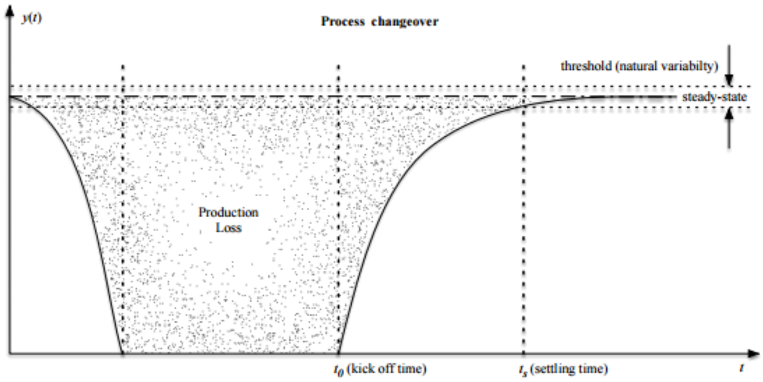

Figure 5. Phases in a process setup. (Retrieved from Antunes et al. 2016)

3.9 Sensitivity analysis

An important factor of the calculations made in this thesis is that they are made on estimations of future conditions. The inventory cost parameters and setup cost parameters are estimation of the reality. Therefore, it is important to investigate and understand how the optimal solution is dependent of the input data (Sarker & Newton, 2008). An approach to this is to perform a sensitivity analysis, to determine which parameters that have the most significant impact on the solution.

"An optimal solution is optimal only with respect to the specific model being used to represent the real problem, and such solution becomes a reliable guide for action only after it has been verified as preforming well for other reasonable representations of the problem" (Hillier & Lieberman, 2010, p. 218).

It is further stated in Hillier & Lieberman (2010), p. 218, that one of the main purposes of the sensitivity analysis is to identify the sensitivity parameters. These parameters cannot be changed without changing the optimal solution. The range for the coefficient of which the optimal remain unchanged is the allowable range for that coefficient.

For the purpose of this study, the sensitivity analysis is used to measure how the total cost of a replenishment policy is impacted by changes in the setup and inventory cost parameters. It will also be used to measure the allowable range of the parameters without influencing the setup structure of the optimal solution.

4. Methodology / Research approach

In this chapter, the methodical approach to solve the research questions is presented. The overall approach in the study is defined in section 4.1. The research method is presented in section 4.2. The specific data collection method is presented in section 4.3. The approach to the analysis and interpretation of the result is presented in section 4.4, followed by a description of the reliability and verifiability of the study. The focus in this chapter is to provide a description of the approach and assumptions that governs the results. Some methodologic theory is presented, however the emphasis is on the approach that are made in this thesis.

4.1 Research approach

Creswell (2014) distinguishes between three approaches to research; qualitative, quantitative, or a mixed methods approach. A qualitative research design has a goal to explore and understand social problems, by either individuals or groups. A quantitative research has a goal "*to test objective theories by examining the relationship between variables",* by analysing numbered data (Creswell, 2014). A mixed method approach is a combination between the two. In this study, a mixed methods approach is applied. The method approach is adapted in accordance to the research objectives stated in section 2.3.

To investigate the applicability of lot-sizing methods from research question one, a quantitative approach is used to apply the replenishment policies on the data from Ringnes, followed by a qualitative approach to identify implications that may be present for applying the policy in their production planning. The implications are identified and assessed by secondary literature and own experiences. For research question three, which concerns the robustness of the solution to the lot-sizing problem, a quantitative approach is used to measure the performance of the policies. For research question three, concerning factors that have impact on replenishment policies, both approaches are used. To measure the relationship between setup cost, inventory cost and replenishment policy a quantitative approach is used. For the relevant factors that do not have numerical data to measure, a qualitative approach is applied. By this approach, relevant literature is used to discuss the relationship of the specific factor and the replenishment policy.

4.2 Research method

The purpose of this study is to provide Ringnes with a research that addresses the production quantities and measures the performance of the production quantities that are enforced today.

The performance is measured by comparing the production quantities against theoretical optimal quantities. The approach to this is to examine what other research that are conducted in a similar setting. This research will be used to identify possible replenishment policies, which may be applicable at Ringnes and the characteristics and required inputs of each method. Each replenishment policy will be calculated on basis of specific data from Ringnes. The result from the calculations will make basis for the comparison and analysis.

The specific research method in this thesis is a case study method. A case study method facilitates research of empirical investigation of a real-life problem in context using multiple sources (Saunders et al. 2009, p. 145). The most important features of the research method are not the theory related to the specific method, it is the way the method enables you to answer the particular research questions and the objectives in your thesis (Saunders et al. 2009).

A case study method enables a research that has an explanatory nature and investigates a specific problem in a real-world setting. In this thesis, the real-world setting is the operation of Ringnes, and the specific problems are related to the production planning and replenishment policies. By using a case study approach, the scope of the research addresses replenishment polices and the factors that have impact on replenishment. As the focus is on specific operations at Ringnes, the research method is a single case study.

4.3 Data collection

The data is collected from two main sources. The first source for primary data is from the cooperating company, in this case Ringnes. The second source of data is secondary data collected from textbooks, journal articles or other recognized literature. There exist several techniques for collection of data. Some of the techniques presented in the methodical literature are interviews, observations and questionnaires (Saunders et al. 2009). The technique that is used to collect data in this thesis is by email correspondence with Ringnes and a contact person at the production planning department. The data that have been collected by this approach includes specific data concerning forecasts, production volumes, setup times and related costs. This data is classified as the primary data of the research. The secondary data is collected through searches in databases and library.

This approach is selected to use the conceptual framework found in the literature in a practical setting at Ringnes. The objective of the thesis is to identify if there exist a potential for improvement at Ringnes. Relevant approaches from the literature will be used to identify if such potential exists.

4.3.1 Primary data. The primary data is collected by the mentioned correspondence with Ringnes. The data is collected through the contact persons in the respective departments. The forecast data is collected through a contact person in the forecasting department, production volumes is collected through the production planning department and specific cost related to production is collected through contact person in the production department.

For the sample of products presented in section 2.1, the data that is retrieved includes; (1) forecast for a two-year period, (2) production volumes for the same period (3) mapped setup times for products, (3) time cost at production line to calculate setup cost, and (4) inventory and depreciation cost.

4.3.2 Secondary data. The basis for the secondary data is textbooks and journal articles. The textbooks used in this thesis is related to production, inventory management, and supply chain management. The journal articles are collected through search in library databases. The search words that are used to retrieve the articles are; replenishment polices, production planning, lot-sizing, lot-sizing methods, etc.

4.4 Framework for data analysis

The framework for the data analysis will define what we are going to do with the data that have been collected (Biggam, 2008). In this section, we will present preparation of the data, inputs, lot-sizing calculation and interpretation of the results.

4.4.1 Preparing the data. The first step to analyse the collected data was to prepare and fit the data to the problem setting. In the Excel spreadsheets that was received from Ringnes, some forecast values were negative which probably indicates estimated scrapping of products that have exceeded their best before date. The spreadsheet was prepared by removing the negative values from the spreadsheet.

The second preparation that had to be made was that in the beginning of 2015, Ringnes was in a transition phase where the standard hard recyclable bottles were replaced by the soft one-way bottle types we have today. The difference between the standard and one-way bottles is that the standard bottles were shipped back to the brewery, washed and reused, where the one-way bottles are only used one time and then melted to a new bottle. In the forecasts, this is represented by different SKU's number for each bottle type. For the first eight weeks of 2015, most one-way bottle SKU's does not have any forecast values, as they are not yet introduced to the market. However, some one-way bottle SKU's have forecast from the first week in

2015 as they were introduced to the market. The standard bottles SKU's of the correlated brands only have forecast values for the first eight weeks. However, as the forecasted values for the same product in both SKU's where similar and correlated, the two forecasts have been merged of the same brands. This is done to create a basis as equal as possible for the whole sample.

The third preparation of the dataset was that all the numbers from Ringnes was presented in hectolitres (HL), where one hectolitre equals 100 litres (L). Therefore, all forecast values and production volumes from Ringnes was multiplied with 100. The analysis and calculation that were made in this paper is made in litres. The two major parameters in lot-sizing is the setup cost and the inventory cost. Following, how the setup cost and inventory cost where identified and measured will be presented.

4.4.2 Analysis of setup costs at production line 207. Ringnes provided an Excel spreadsheet where all activities related to changeovers were mapped. The data was registered in accordance to how many minutes each task or activity of the changeover process would require. The setup costs for each product is in a large degree determined by the schedule of the production and the preceding product. If the product that is scheduled before is in the same taste but in different package, the setup is less time consuming, because there is only necessary to do a changeover on the package line that is positioned after the bottling production. However, if the preceding product is in a different taste, package and bottle type than the following, the setup is more time consuming. As previously mentioned, in addition to produce their own product, Ringnes serve as a production provider for external brands. In production setups, this may be governed by specific rules related to cleaning and preparation of the production line for the external product. In this case, the setup cost will be higher.

To estimate the setup cost for each product, all the setups that are performed during 2016 have been mapped. The setup times concerning the type of soda and the type of package is also separated. To measure the setup cost under normal conditions, setup observations under abnormal conditions, for example, where the setups are conducted on shift with small workforce, under training or with specific tests have been excluded. For each product, the setup cost is therefore twofold. The first part of the setup cost contains an average of all observations which are related to setup of the specific type of soda. For a Pepsi product, this includes that all changeover to Pepsi is mapped and an average time is calculated based on these observations. The second part of the setup cost includes the time that are spent to change the type of packaging. An average is found with the same approach as presented above. In Figure 6 an illustrative example of how the calculation is made. A more detailed presentation of the setup cost divided by each product is found in appendix A.

As we can see from Figure 6, the setups have been mapped according to minutes that have been used on each task. To convert the total time in minutes to an actual cost per setup, a cost per minute at the production line has been collected. The data includes cost per hour of each shift at the production line, and an average cost per hour is calculated, this is further divided into an average cost per minute. We can measure the total cost of each setup, where the setup time is multiplied with cost per minute. As mentioned above, see appendix for detailed mapping of setup cost for all products.

Description	Setup				Overall result	Average
Type of soda	A5 C - D	A2 H - D	A5 M - D	A5 B - D		
(time min)	145	68	90	131	434	94

Description	Setup				Overall result	Average
Type of package	6pck > 4pck	6pck > 4pck	8 pck til 4pck	Single > 4pck		
Time (min)	33	11	24	30	97	21

Average setup (min)			Cost per setup
D setup	pack setup	Total (min)	Total cost
94	21	115	kr 3 423,95

Product		
Average cost per hour shift	min/hour	Minute cost
kr 1 779,39	60	kr 29,66

Figure 6. Example of setup cost analysis.

4.4.3 Inventory cost parameter. Ringnes has specified the parameter for inventory cost and they include two parameters in this inventory cost. Respectively, the capital cost and the inventory cost. This is presented in Table 5 below. The capital cost is stated at 0.009 NOK per litre per month. The specific inventory cost is stated at 56 NOK per pallet per month. A pallet produced at production line 207 equals 576 L per pallet. To allocate this to litre per month, the cost per pallet (56 NOK) is divided on the number of litre per pallet (576). This gives a total combined inventory cost at 0.097 NOK per litre per month.

Capital and inventory cost		
Capital	Inventory	Total
	56 NOK/month	
0.009	0.097	0.106

Table 5. Presenting capital and inventory cost.

4.4.4 Planning horizon and sample. In the literature review, planning horizons were divided into short-term, medium-term, and long term. The data provided by Ringnes includes forecast data for the years of 2015 and 2016, where the data is divided according to weeks and there are 99 weeks in the observations. As the replenishment polices are calculated on a week-to-week basis, the planning horizon is classified as short-term. However, the replenishment policies are calculated and compared over the entire planning horizon over two years.

The replenishment policies are calculated for 20 SKUs' from Ringnes portfolio. In total on the datasheet for production line 207, there are 49 SKU's. The products that have been excluded is related to seasonal SKU's as Christmas soda, and products that have been removed from production during the planning horizon.

4.4.3 Calculating of lot-sizes. The lot-sizes are calculated on basis of the forecast data, inventory costs and setup cost provided from Ringnes. The literature is used to identify and assess which methods to apply to the dataset. Each method that are used in this thesis are presented in the literature review. To apply and calculate the lot-sizes, Excel is used. The model for each lot-sizing method is formulated on basis of the approaches in the literature. Especially, Nahmias (2009) textbook has been an important source for construction of each method. In Figure 7, a screenshot is presented as an example of the excel sheet of one method. As the model for each method has been constructed in Excel, the same approach is applied for all the SKU's in the sample. The total cost for each SKU for each method is measured and compared to identify the best performing method. The total cost is calculated with the following formula: total cost = number of setup * setup cost + total inventory * inventory cost. After obtaining the total costs for all lot-sizing methods, we can identify the best performing method.

Holding cost	Ch	kr 0,11	per L / month									
Holding cost	Ch	kr 0,03	per L / week									
Setup cost	Cp	kr 1 913,58	per setup									
	T		L / per week									
	CT		L									
1 HL		100	L									
			1	2	3	4	5	6	7	8	9	10
Material	Calendar year / week		01.2015	02.2015	03.2015	04.2015	05.2015	06.2015	07.2015	08.2015	09.2015	10.2015
D	**Net requirements for period (ri)**		50 793	59 005	43 068	53 003	63 245	63 253	73 342	65 035	59 060	57 855
	Lot size		109 798		96 071		126 498		73 342	124 095		115 612
	Last periode for lot size iteration			X		X		X	x		x	
			0,038	**0,032**	0,038	0,049					0,032	0,030
				0,032	0,030	0,038	0,050					0,033
					0,044	**0,035**	0,042	0,053				
						0,036	0,031	0,039	0,051			
							0,030	**0,028**	0,037	0,048		

Figure 7. An example Excel sheet of lot-sizing calculations.

4.4.5 Interpretation and analysis of result. It is stated in Hillier & Lieberman (2010) that in operation research a lot of work remains after identifying the optimal solution of a model. The optimal solution in this thesis is defined as the method that presented the lowest total cost over the planning horizon. After identifying the best method, the results from the best performing method is analysed in a sensitivity analysis. Here, we measure the sensitivity to the solutions related to the setup and inventory cost. Note, that the parameters that are used in the lot-sizing calculation are estimates of reality and can change. The lot-sizing solutions that are identified is dependent on the accuracy of the inventory cost and setup costs parameters. Therefore, it is necessary to measure the dependence of the solutions in regards to these parameters. First, the impact of the setup and inventory cost on the total cost is analysed. Secondly, the structural change concerning the number of setups of the solution is measured against changes in both setup cost and inventory cost. This analysis is conducted by adjusting the parameters by one additional percentage until the number of setups in the solution is changing.

To measure how robust of the lot-sizing solutions are to changes in demand, the lot-sizes which are calculated on basis of forecasts are applied towards estimation of real demand. The real demand is estimated based on historical production lots that was applied by Ringnes. If we assume that the production volumes of Ringnes are equal to the preceding period demand, we can estimate the demand by dividing the real lot-size on the number of periods between the production lots. Thereby; estimated demand is equal lot-size divided by periods since last production. For example, if Ringnes has production lots in week 4 and 7 in 2015, and the lot-size in week 7 (2015) is 1200. The estimated demand for the periods; 5, 6 and 7 is equal 400 (1200/3). From Figure 8, the highlighted lot-size is divided on the preceding periods from the last production lot.

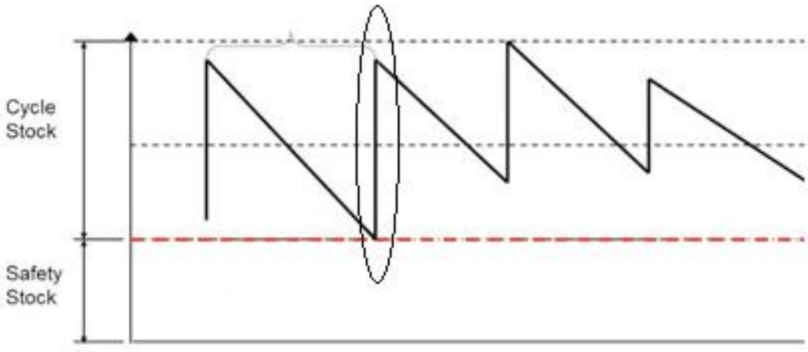

Figure 8. Illustrating assumptions concerning demand estimation.

The estimated real demand is used to measure how the replenishment policies would perform if their production schedules where followed. Especially, the number of stock outs that would occur by following the replenishment policy is emphasized. The stock outs are measured by the SUMIF function in Excel. If the inventory level is below zero, the negative volume is included in the stock out value.

4.5 Verification and reliability

All methods have been calculated on the basis of the same inputs to the models. The data concerning setup cost and forecast data is specific to each SKU. The WW algorithm was in the literature argued as a method that provided an optimal solution (Nahmias, 2009).

However, these kinds of estimations are highly dependent on the accuracy of the parameters that are used to provide an optimal solution. The inventory cost parameter was provided by Ringnes, which ensures the credibility of this parameter. The setups cost is estimated on the basis of the data which were provided by Ringnes with the approach that are explained above. Thus, there are precautions that the setup cost may differentiate from practice. The most important precaution is that each product has been assigned their own setup cost, where they may rarely be produced by them self. Ringnes reduces setup costs by combining production of familiar products.

5. Analysis / Presentation of results

In this chapter, the results from the application of the lot-sizing techniques based on the data from Ringnes will be presented. The section is built up as follows; first the lot-sizing problem at Ringnes will be specified. Followed by the calculation of lot-sizes with the aid of the different heuristic lot-sizing techniques. The approach to solve the lot-sizing problem to optimality is presented in section 5.4. There is a brief presentation of a sensitivity analysis that address different factors that may have impact on the replenishment policies. In section 5.6 and 5.7 forecast will be evaluated and a new solution based on estimated demand will be presented.

5.1 Lot-sizing problem at Ringnes

The lot-sizing problem that are studied at Ringnes is a single-level uncapacitated lot-sizing problem with probabilistic and stochastic demand. In practice, as several products are produced at the same production line, there makes this a multi-level problem. However, because of the complexity related to the multi-level, the problem is addressed as the single item problem. As previously stated, the basis for determination of production quantities is forecasts that are made with a probability to occur. The demand of the products is stochastic, which indicate uncertainty in demand.

Concerning capacity at the production line, because the amount of resources available at the production line is not considered as a constraint when we solve this problem for one of the products of the portfolio. The largest product in the portfolio is product D, this product has an average forecast of approximately 800 000 L per week, and the highest observed forecast in a week at 1 430 000 L. For the capacity on the production line, the average volume that are produced at production line 207 for the years 2015 and 2016 is approximately 2 200 000 L per week. The highest observed produced volume for one week at production line 207 is 3 700 000 L. Because the problem is solved as a single item problem and the assumption that the capacity constraint is 3 700 000 L per week at the production line, the capacity is not considered a constraint.

The heuristics methods that are applied to solve the single item uncapacitated lot-sizing problem at Ringnes are the Silver Meal (SM) heuristic, least unit cost (LUC) and part period balancing (PPB). The method that is used to solve the problem to optimality is the Wagner Within (WW) algorithm. Essentially, these methods are chosen based on their adaptability to variations in demand. As stated in the introduction, the products studied in this thesis have a large variation in demand, and the forecast are uncertain. Because all production planning at Ringnes is made on the basis of forecast, a similar approach is made in this thesis. However, because of the uncertainty related to the forecast, it is interesting to study the performance of the optimal solution compared with the heuristics in hindsight of the forecast uncertainty. The main reason for choosing and adapting these methods is to first, compare their solutions made on the basis of the forecast, and thereby study how this performance may change when we know how the accuracy of the forecast.

The calculation that are presented in section 5.2, until 5.5 is solely based on the forecast provided by Ringnes. In section 5.6 the forecast based solution is compared against the estimated real demand. Further, in section 5.7 the optimal solution based on the forecast is compared against a new optimal solution which are based on the estimated real demand.

5.2 Replenishment policies by heuristics

The lots that were proposed by each heuristic vary in regard to size and frequency of production as the methods has their own approach to balance the setup cost against the inventory cost. Each method is calculated on the same inputs for each product, concerning the setup cost, inventory cost and the forecasted demand. This facilitates for comparing the heuristics impact on the performance for Ringnes. In the following, an extract of the calculation for one product (M) is presented to illustrate the lot-sizes and frequency of production for each heuristic, the y axis represent volume and the x axis represent periods.

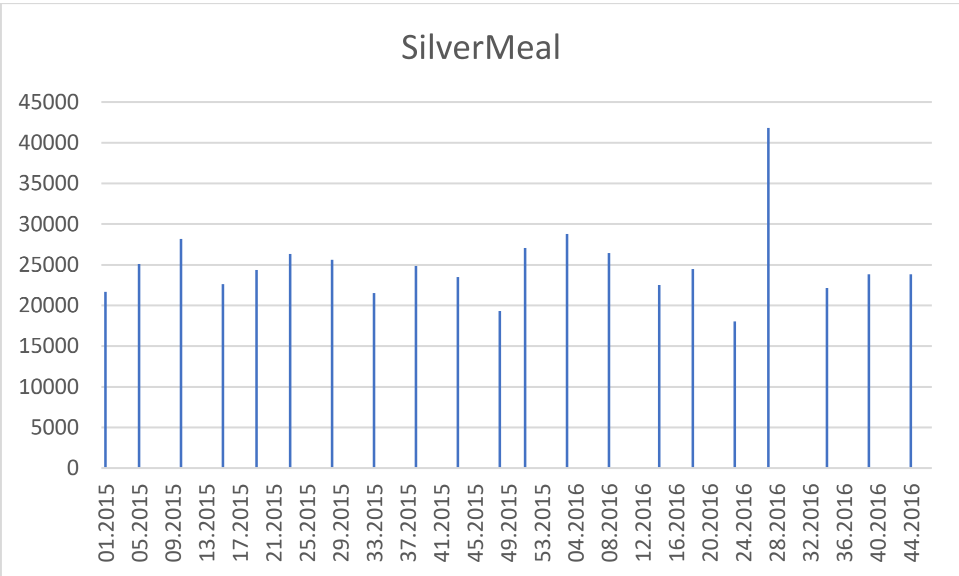

Figure 9. Presentation of lot-sizes and frequency of Silver Meal heuristic for SKU M.

In Figure 9, the production scheme from the SM heuristic is presented. As we can see from the Figure, the SM heuristic proposed 21 setups during the two years' period. The average lot-size were 24852 L, resulting in a total inventory level of 955 467 L. Total cost (setup and holding costs) by this method resulted in 56 880.8 NOK. See Appendix B, 8.2.1 for calculation of the SM for all products in the sample.

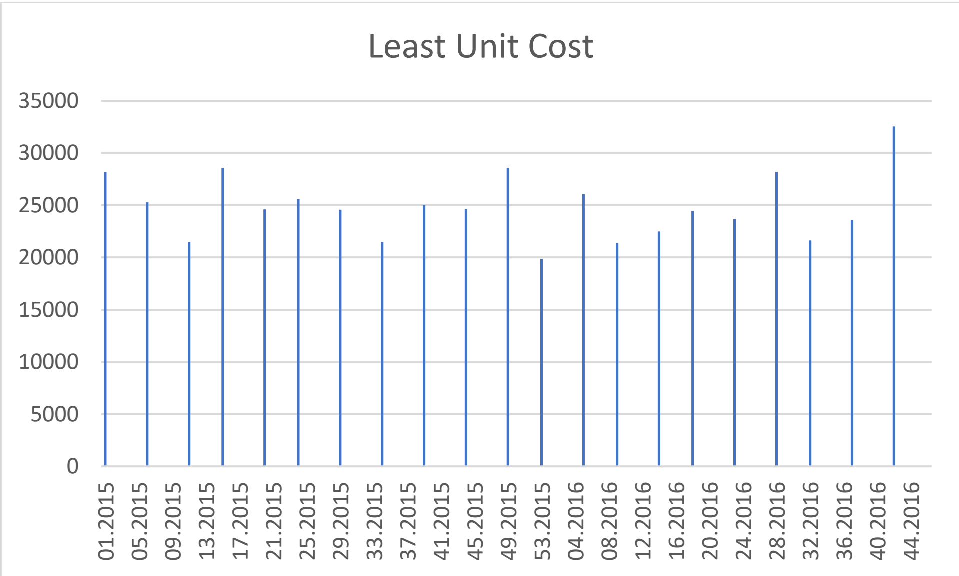

Figure 10. Presentation of lot-sizes and frequency of Least Unit cost method for SKU M.

From Figure 10, we see that the LUC method proposed 21 setups during the two-year period. The average lot-size were 24 852 L. The total inventory with least unit cost were 968 337 L. The LUC method resulted in a total cost of 57 222.5 NOK for this SKU. See Appendix B, 8.2.3 for calculation of the LUC method for all products in the sample.

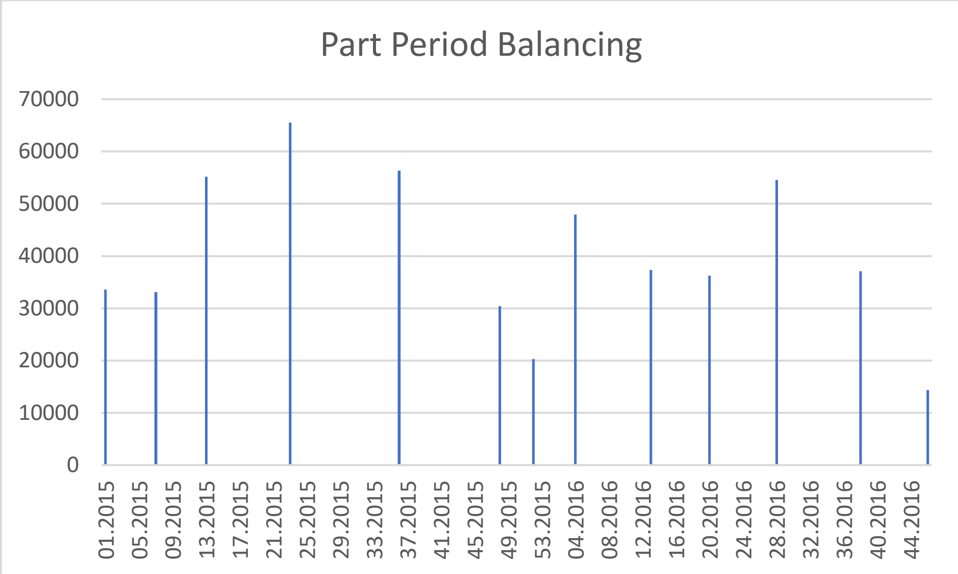

Figure 11. Presentation of lot-sizes and frequency of Part Period Balancing for SKU M.

In Figure 11, the production scheme for the PPB is presented. As we can see, this method proposes 13 setups during the two-year period. This result in an average lot-size of 40 145 L. By following this production scheme, the total inventory would be 2 008 008 L over the two years. The total cost of the PPB method resulted in 72 828.6 NOK. See Appendix B, 8.2.2 for calculation of the PPB method for all products in the sample.

5.3 Comparing heuristics

The most evident measure to compare the heuristics are the total cost. Total costs are again referred to as total setup cost and total inventory cost during the planning horizon over two years. In Table 6, the total cost for each SKU according to methods and the percentage deviation from the best solution is presented.

	Silver Meal		PPB		LUC	
Material ID	Total cost	% deviation from best solution	Total cost	% deviation from best solution	Total cost	% deviation from best solution
A	kr 124 037,41	0,01 %	kr 128 024,89	3,2 %	kr 124 027,65	-
B	kr 50 146,07	-	kr 64 472,07	28,6 %	kr 55 264,87	10,2 %
C	kr 171 034,12	-	kr 174 676,49	2,1 %	kr 172 216,19	0,7 %
D	kr 338 970,62	-	kr 338 970,62	-	kr 338 970,62	-
E	kr 245 595,26	-	kr 271 395,34	10,5 %	kr 248 646,03	1,2 %
F	kr 135 289,26	0,40 %	kr 149 610,69	11,0 %	kr 134 748,71	-
G	kr 201 022,56	-	kr 231 138,65	15,0 %	kr 250 321,41	24,5 %
H	kr 317 702,12	-	kr 317 702,12	-	kr 317 702,12	-
I	kr 154 868,63	-	kr 159 452,67	3,0 %	kr 156 473,18	1,0 %
J	kr 152 373,16	-	kr 194 258,05	27,5 %	kr 152 373,16	-
K	kr 200 170,53	0,53 %	kr 218 431,20	9,7 %	kr 199 115,90	-
L	kr 92 698,54	0,32 %	kr 110 882,75	20,0 %	kr 92 398,74	-
M	kr 56 880,78	-	kr 72 828,62	28,0 %	kr 57 222,54	0,6 %
N	kr 104 377,37	-	kr 115 892,58	11,0 %	kr 104 619,29	0,2 %
O	kr 74 210,94	-	kr 87 420,70	17,8 %	kr 78 240,30	5,4 %
P	kr 143 102,60	-	kr 151 859,40	6,1 %	kr 143 330,21	0,2 %
Q	kr 85 446,92	-	kr 99 930,58	17,0 %	kr 87 024,90	1,8 %
R	kr 180 527,20	0,59 %	kr 200 793,69	11,9 %	kr 179 473,37	-
S	kr 65 713,10	0,64 %	kr 87 524,30	34,0 %	kr 65 296,07	-
T	kr 74 657,33	-	kr 89 714,19	20,2 %	kr 77 496,57	3,8 %
Total cost	kr 2 968 824,53	-	kr 3 264 979,59	10,0 %	kr 3 034 961,84	2,2 %

Table 6. Total cost for heuristics over two-year period.

The lowest performing heuristics was the PPB method. As we see from Table 5, of the twenty SKU's that were compared, the PPB found the best solution for two of the SKU's, respectively material D and H. However, the two other methods also identified this solution for these products. As the products D and H has very high demand, it makes it almost impossible to exclude production for one week, because of the high costs related to inventories of the following periods demand. The reason to why the PPB method performed poorly was because of the number of setups, for all the SKU's the PPB method included the fewest number of setups. In Table 7, the total number of setups is presented and the method that proposed the lowest number of setups is marked in green. We can see that the PPB have the lowest number of setups for all SKU's. The overall total cost for replenishment by the PPB method is 3 054 511.0 NOK, which is 10 % higher than the best performing method.

Number of setups		
Silver meal	PPB	LUC
72	**49**	72
26	**17**	28
50	**49**	51
99	**99**	**99**
46	**32**	49
49	**36**	51
33	**31**	41
99	**99**	**99**
56	**46**	55
99	**58**	99
49	**36**	50
32	**19**	34
21	**13**	21
35	**24**	34
30	**19**	30
54	**43**	53
35	**23**	34
49	**38**	50
19	**10**	18
18	**14**	18

Table 7. Number of setups for each SKU for two-year period.

The best performing heuristic that were identified is the SM method. This method identified the best solution for fourteen of the twenty SKU's in the sample. The overall total cost for replenishment by the SM method is 2 758 355.9 NOK for the planning horizon. This is 2.2 % better than the second-best heuristics, respectively the LUC method.

5.4 Solving to optimality

It is stated in Nahmias (2009), that the lot-sizing techniques of PPB, LUC and SM are easy to apply and give a near optimal result. However, they do not necessary provide a true optimal result. An optimal result is defined by a technique that minimize the holding and setup cost over the planning horizon. In the following, the approach to estimate the optimal replenishment policy for Ringnes will be presented. Note that this optimal solution is dependent of the accuracy of the inventory cost, setup cost and forecasts parameters. The optimal solution is only valid if the parameters used in the calculation is accurate. This solution is based on forecasts, and the solution is mutually dependent of the forecast to be accurate.

The number of possible solutions of a problem with n periods is 2^{n-1} (Nahmias, 2009). As previously mentioned, the planning horizon in our sample is 99 periods (weeks). This gives the number of possible solution to this problem 2^{99-1}, which equals 6.33825 E+29 possibilities. This is both unnecessary and unpractical to calculate and we can use dynamic programming by the WW algorithm as an approach to solve this problem for optimality.

In chapter 3.3.4, there where distinguished between two approaches to dynamic programming, respectively forward or backward induction. To solve the problem, the WW algorithm with a backward induction approach were used. In Figure 12 below, the replenishment policy by the WW algorithm is presented for product M. This replenishment policy suggested 21 setups, with an average lot-size of 24 852 L, which is the same amount as both the SM and LUC suggested. However, the total inventory is reduced to a total of 927 163 L over the planning horizon. This is a reduction of total inventories from the SM by approximately 28 000 L over two years and resulting in a total cost over the planning horizon of 56 129.13 NOK. This is a reduction of 1.3 % compared to the solution found by the SM heuristic. See Appendix B, 8.2.4 for calculation of the WW algorithm for all products in the sample.

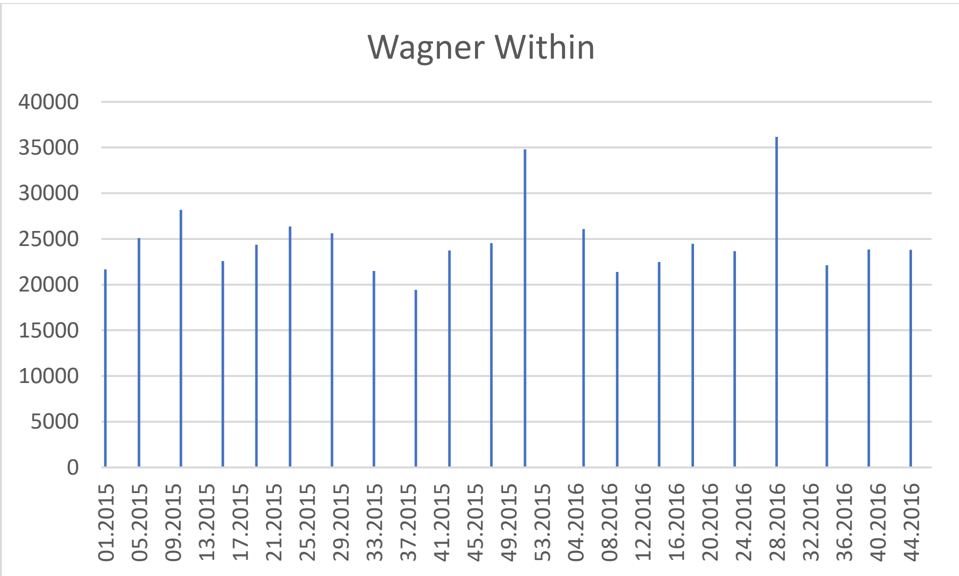

Figure 12. Presentation of lot-sizes and frequency of Wagner Within algorithm for SKU M.

In Table 8, the number of setups, total cost and improvement for the whole sample is presented. In the first column of the table, we can see the performance of the best heuristics and in the second column, the performance of the WW algorithm is presented. The WW suggest a replenishment policy that reduced the total costs for almost all products in the sample. The exception where on the largest products concerning volume in the sample. On those products, the heuristics had also been able to identify the optimal solution, which included 99 setups respectively in each period. The largest SKU's concerning volume in the sample are SKU's D, H and J.

Material	Best heuristic	Number of setups	Cost		Wagner Within	Number of setups	Cost		WW deviation from best heuristics
A	LUC	72	kr	124 027,6	WW	73	kr	122 994,1	-0,8 %
B	SM	26	kr	50 146,1	WW	26	kr	49 668,1	-1,0 %
C	SM	50	kr	171 034,1	WW	53	kr	169 690,1	-0,8 %
D	ALL	99	kr	338 970,6	WW	99	kr	338 970,6	0,0 %
E	SM	46	kr	245 595,3	WW	46	kr	237 205,8	-3,4 %
F	LUC	51	kr	134 748,7	WW	50	kr	134 301,7	-0,3 %
G	SM	33	kr	201 022,6	WW	36	kr	185 875,2	-7,5 %
H	ALL	99	kr	317 702,1	WW	99	kr	317 702,1	0,0 %
I	SM	56	kr	154 868,6	WW	57	kr	153 835,1	-0,7 %
J	SM & LUC	99	kr	152 373,2	WW	99	kr	152 373,2	0,0 %
K	LUC	50	kr	199 115,9	WW	49	kr	197 035,4	-1,0 %
L	LUC	34	kr	92 398,7	WW	32	kr	91 573,2	-0,9 %
M	SM	21	kr	56 880,8	WW	21	kr	56 129,1	-1,3 %
N	SM	35	kr	104 377,4	WW	37	kr	101 335,6	-2,9 %
O	SM	30	kr	74 210,9	WW	30	kr	72 854,1	-1,8 %
P	SM	54	kr	143 102,6	WW	54	kr	142 038,0	-0,7 %
Q	SM	35	kr	85 446,9	WW	34	kr	83 960,6	-1,7 %
R	LUC	50	kr	179 473,4	WW	51	kr	178 923,6	-0,3 %
S	LUC	18	kr	65 296,1	WW	18	kr	63 516,2	-2,7 %
T	SM	18	kr	74 657,3	WW	17	kr	73 489,3	-1,6 %
Total			kr	2 965 448,9			kr	2 923 471,2	-1,4 %

Table 8. Comparison of the best performing heuristics with the Wagner Within algorithm.

The largest improvement in the sample was made on product G, where the WW algorithm presented a replenishment policy that reduced the total cost with 15 147.37 NOK. From the best heuristics (SM), WW increased the number of setups from 33 to 36. This resulted in a reduction of the average lot-size from 251 340 L to 230 395 L.

5.5 Sensitivity analysis

The sensitivity analysis is performed to study how sensitive the optimal solution is to changes in the parameters of the calculations. The sensitivity parameters that are studied are the setup cost and the inventory cost. These parameters are estimations of reality, and may in practice change. For example, the setup cost parameter is likely to vary, because the schedule that products have, will influence the setup time. Therefore, the sensitivity of the optimal solution concerning especially to the setup cost parameters are relevant.

Sensitivity report		- 2 %	- 1 %	Original value	+ 1 %	+ 2 %
ID: M	Parameter	1470,4	1485,4	1500,4	1515,4	1530,4
- 2 %	0,0260			kr 55 636,70		
- 1 %	0,0263			kr 55 882,92		
Original value	0,0266	kr 55 498,97	kr 55 814,05	kr 56 129,13	kr 56 444,21	kr 56 759,29
+ 1 %	0,0268			kr 56 375,34		
+ 2 %	0,0271			kr 56 621,56		

Table 9. Sensitivity report of product M where result is presented in total cost.

Sensitivity report		- 2 %	- 1 %	Original value	+ 1 %	+ 2 %
ID: M	Parameter	1470,4	1485,4	1500,4	1515,4	1530,4
- 2 %	0,0260			-0,88 %		
- 1 %	0,0263			-0,44 %		
Original value	0,0266	-1,12 %	-0,56 %	0,00 %	0,56 %	1,12 %
+ 1 %	0,0268			0,44 %		
+ 2 %	0,0271			0,88 %		

Table 10. Sensitivity report of product M where result is presented in percentage change.

In Table 9 above, the sensitivity report for product M is presented. The inventory cost parameter is listed vertical in the table, with range from – 2 % to + 2 % and the original value of 0.266 in the middle. The setup cost parameter is listed horizontal and have the same range as the inventory cost. For each change that is made concerning the parameters, the adjusted total cost is calculated and presented in the table. In Table 9, the results are presented by the adjusted total cost. In Table 10, the total cost has been estimated to percentage change from the original optimal solution, in this case 56 129.13 NOK.

The identified sensitivity between the optimal solutions and the parameters of inventory cost was equal to 0.44 % for the product M. For one percentage change in the inventory cost the optimal solution increases or reduces respectively with 0.44 percentage. If the inventory cost change with two percentages, the optimal solution changes respectively by 0.88 percent. The identified sensitivity between the optimal solution and the setup cost parameter was equal to 0.56 % for a one percentages change and 1.12 % for a two percentages change.

In Table 11, a sensitivity report is presented concerning structural changes in the initial solution. We examine how substantial the changes in the parameters related to inventory cost and setup cost needs to be to change the number of setups in the solution. From the initial solution, the WW solution for the product M included 21 setups. To reduce the number of setups with one setup, the setup cost need to increase by 14 %. To increase the number of setups, the setup cost need to be increased by 4 %. For the inventory cost parameter, a 9 % reduction of the cost would reduce the solution with one setup. To increase the number of setups, the inventory cost needs to increase by 7 %. If we interpret these results, we see that the initial solution is more sensitive to reduction compared to increasing the setup cost.

Sensitivity report		- 4 %	- 2 %	Original value	+ 8 %	+ 14 %
ID: M	Parameter	1440,4	1470,4	1500,4	1620,4	1710,4
- 9 %	0,0242			20		
- 5 %	0,0252			21		
Original value	0,0266	22	21	21	21	20
+ 5 %	0,0279			21		
+ 7 %	0,0284			22		

Table 11. Sensitivity report of structural change in solution.

5.6 Comparing optimal replenishment with estimated demand

Remembering Arnold et al (2012) first and fourth principle for a forecast, that it is usually wrong and that a forecast is more accurate for short time periods. The forecast of stochastic demand includes a degree of uncertainty concerning the real demand. There is a high degree of uncertainty related to the forecasted values as the planning horizon is over a two-year period.

The calculations in the previous part of this chapter has been as mentioned solely based on forecasted demand. In this part, the previous identified optimal solution will be compared against estimation made of real demand. The real demand is estimated on the basis of the true production volumes from Ringnes (detailed description of this estimation assumption in chapter four). Notice that this is rough estimates, and the forecast evaluations is affected by this.

5.6.1 Forecast evaluation. To evaluate the forecast, the estimated demand has been compared against the forecast values and the mean error, MAD, and MAPE have been calculated. Mean error is the only forecast evaluation that provide an indication of the direction of the forecasted error. From Table 12, we can see that the mean error for the forecast of product M is 533.48 L, this indicates that the forecast is higher than the actual demand and for product G is minus 42 794 L, which indicate that the forecast is less than the demand. However, as the forecast error sums all the errors during the period, the forecast error is levelled out over the period and does not provide an accurate measure of the error.

The MAD evaluation method finds an absolute value of all the errors in the forecast, which enables the measure to account for all errors. By the MAD none of the errors in the sample are levelled out from the calculation. The MAD measure indicates that over the two years period the absolute error is 2355.17 L per week for product M, which indicate significant deviation from the forecast. According to the MAPE, there is a 64.02 % deviation from the forecast per week. The forecast evaluation results will be further discussed in Chapter 6. The MSE evaluation is not calculated in this forecast evaluation. Because the MSE provides a comparison of two forecast, it is not found appropriate for this evaluation.

Material	Total forecast	Estimated demand	Mean Error	MAD	MAPE
A	4 682 886,50	4 074 552,00	6 144,79	17 708,02	56,99
B	681 079,60	663 126,86	181,34	3 049,05	43,78
C	5 779 988,40	4 723 908,00	10 667,48	18 091,08	56,41
D	80 400 811,30	77 558 688,00	28 708,32	255 554,97	51,88
E	7 757 239,00	7 440 180,00	3 202,62	40 035,27	55,53
F	3 734 319,90	3 776 736,00	-428,45	12 797,79	41,46
G	8 294 204,70	12 530 880,00	-42 794,70	92 994,42	79,45
H	38 991 536,40	38 861 568,00	1 312,81	143 613,42	53,33
I	5 339 731,30	4 504 320,00	8 438,50	19 264,40	52,19
J	11 152 765,30	10 346 112,00	8 148,01	44 462,01	63,09
K	5 460 710,10	4 826 772,00	6 403,42	21 378,56	65,27
L	1 398 384,80	1 196 637,60	2 037,85	6 142,00	63,37
M	**521 895,00**	**469 080,00**	**533,48**	**2 355,17**	**64,02**
N	1 864 412,20	1 626 816,00	2 399,96	7 706,09	65,71
O	1 106 082,10	1 042 214,40	645,13	4 863,92	53,87
P	4 656 994,80	3 951 399,18	7 127,23	16 710,28	70,46
Q	1 455 882,60	1 454 032,00	18,69	5 853,86	55,89
R	5 323 895,80	4 598 896,80	7 323,22	15 801,32	54,29
S	502 342,50	1 373 392,00	-8 798,48	9 121,62	57,18
T	612 359,50	1 373 392,00	-7 687,20	8 389,21	54,20
Average	9 485 876,09	9 319 635,14	1 679,20	37 294,62	57,92

Table 12. Forecast evaluation of sample (excluding MAPE, all number in litres).

Table 12 illustrates that the forecast evaluations indicates substantial differences in the forecast and estimated demand. The MAD measures is as mentioned in the literature review, dependent on the magnitude of the values, which in this case gives large differences. However, it is naturally to indicate large deviation over a two-year period, but it alters the performance of the optimal solution as both the inventory level increases and the capability to deliver may be weakened.

5.6.2 Inventory levels with estimated real demand. If we account for the direction of the forecast error given by the mean error and the magnitude of the forecast error indicated by the MAD error, using the WW replenishment policy would result in an increasing number of products on inventory. In Figure 13, the inventory level development over the planning horizon is presented for product M. Excluding the first's couple of weeks and the period from approximately period 29 to 37, the inventory level is increasing over the whole horizon. In addition, the mismatch is demonstrated by stock outs in the period 3 and 4.

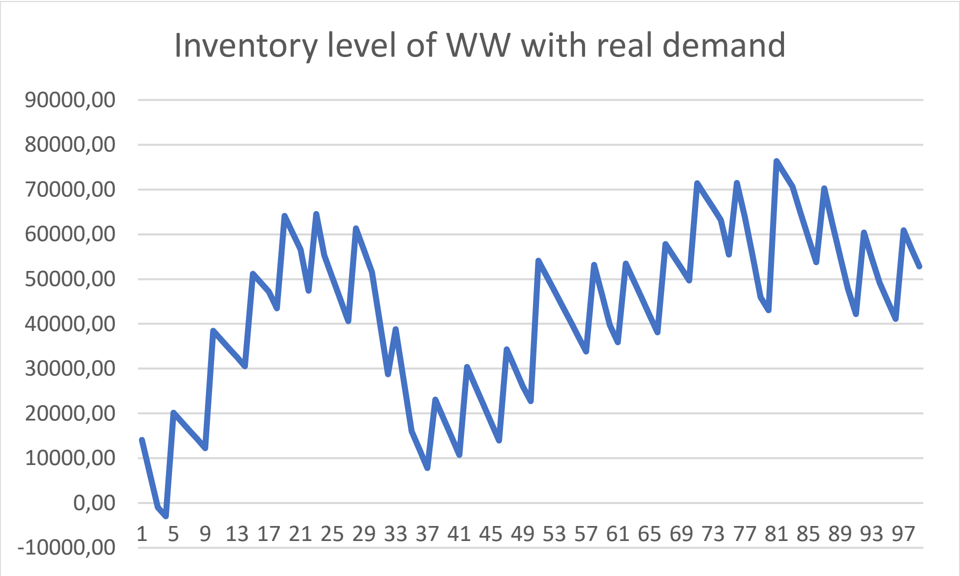

Figure 13. Inventory level of the WW based on forecast with estimated real demand.

As we see can from Figure 13 and 14, the inventory level increases during the period. From Figure 14, we can see how the lot-sizes extend the inventory level, and in this instance work against its purpose.

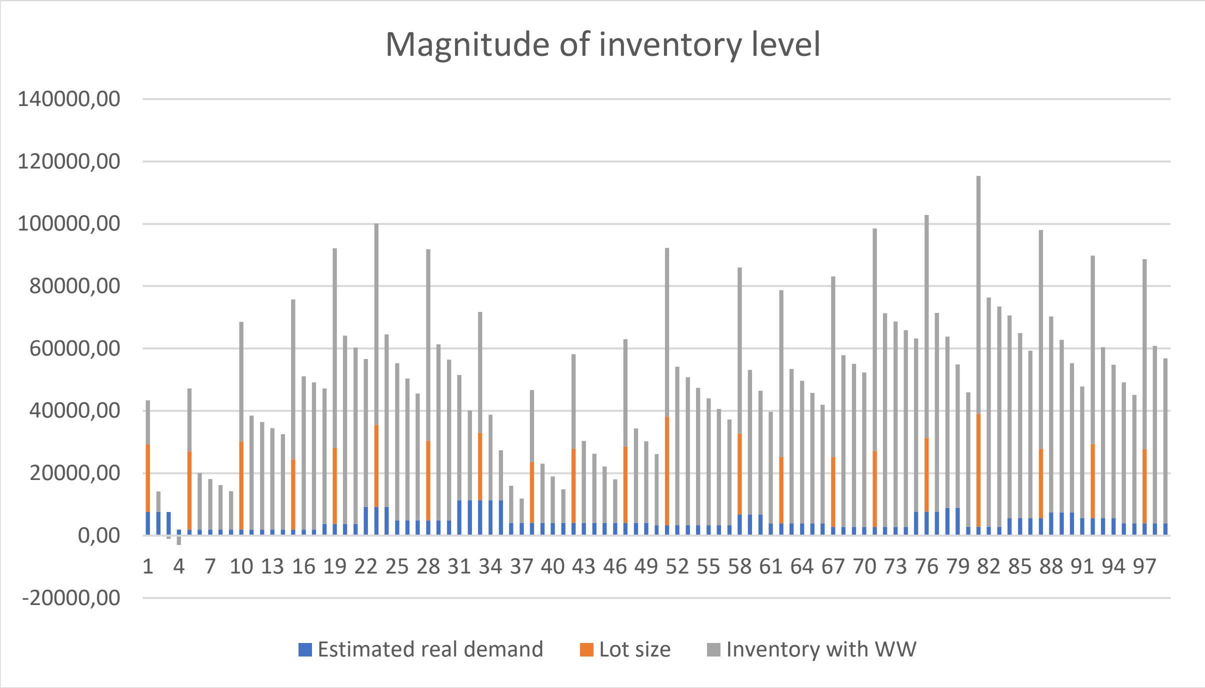

Figure 14. Magnitude of inventory level by following WW method.

The lack of forecast accuracy alters the original solution and result in mismatch between supply and demand. For some products, the inventory level increases during the planning horizon as illustrated by the example above, and for some other product the lot-sizes are not capable of supplying the demand and result in large negative inventory levels. This is illustrated in the calculations presented in Appendix C.

5.6.3 Measuring forecast solution robustness. In this section, the initial forecast solutions suggested by the WW, SM, LUC and PPP methods is applied to real estimated demand. The robustness is measured by that the lots identified with the methods are simulated produced in an environment where the estimated demand occurs. In Table 13, the measured robustness for all methods for product M is presented. The robustness is measured by the degree of stock outs by application off the methods.

For product M, stock outs would have occurred for the methods SM and WW. The stock out volume would have been the same with 2972 L for both methods. By application of the LUC and the PPB methods there would not occurred any stock outs during the planning horizon.

	Product	Number of setups	Setup cost	Total inventory	Holding cost	Total cost	Stock outs
SM	M	21	kr 1 500,4	4 518 357	0,03	kr 151 495,27	-2 972
PPB	M	13	kr 1 500,4	5 287 517	0,03	kr 159 917,77	0
LUC	M	21	kr 1 500,4	4 247 845	0,03	kr 144 311,70	0
WW	M	22	kr 1 500,4	4 435 439	0,03	kr 150 793,73	-2 972

Table 13. Measuring robustness of initial solutions presented by the lot-sizing methods.

If we compare the performance, the WW algorithm still performs best when we compare total costs. However, if we compare their robustness against stock outs, the LUC and PPB method are the two methods that do not have any stock outs. Of the two, the LUC method provides the solution that result in the lowest total cost. If we look at the total of stock outs with adjusted demand in the entire sample, the PPB is the method that result in the lowest amount of stock outs. The total stock outs during the planning horizon for all products is presented in the Table 14 below. The calculation for each lot-sizing method is presented in Appendix C.

	SM	LUC	PPB	WW
Total demand	186 392 702,84	186 392 702,84	186 392 702,84	186 392 702,84
Total Stock Outs	-9 549 087,86	-9 540 630,40	-9 409 800,15	-9 569 993,03
SSL	94,88 %	94,88 %	94,95 %	94,87 %

Table 14. Total amount of stock outs for all product divided by the methods.

At Ringnes, stock outs hurt the performance indicator stock service level (SSL). A stock out is defined where a product is ordered by a customer, but is not available at stock. For each litre that is ordered and not available the SSL is altered. For the production line 207, the target value of the SSL is 98.5 %. From Table 14, we see that the SSL target is not reached with any of the lot-sizing methods.

5.7 Calculating new optimal solution based on adjusted demand

To investigate how the solution will change to the estimated demand, a new solution is calculated on basis of the estimated demand. The optimal solution for product M by forecast was identified by the WW and resulted in a total cost of 56 129 NOK. The solution suggested 21 setups during the planning horizon.

If we calculate a new solution on basis of the estimated demand that was measured to be below the original forecast, the new solution suggests 18 setups during the planning horizon. The total cost with this solution was 51 349.60 NOK, which is a reduction of 9 % from the original solution. The average lot-size increased from 24 852 L to 26 060 L. The new solution is presented in Figure 15 below.

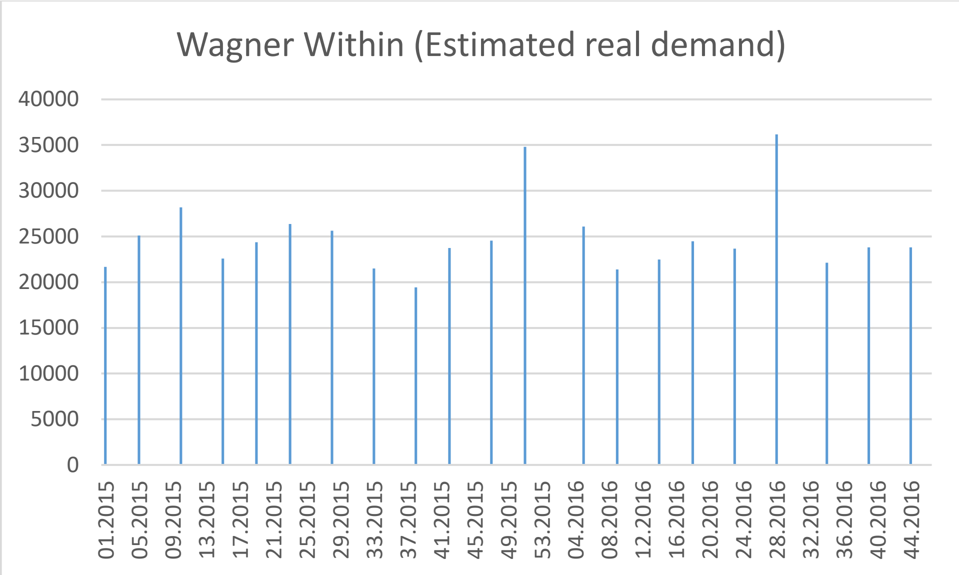

Figure 15. Illustrating new solution for WW with adjusted demand.

If we assume that we knew what the demand would have been, this solution is the true optimal solution for the lot-sizing problem at Ringnes. If we calculate this solution for the whole sample, we can study how the lot-sizing methods have performed compared by the true optimal solution. In Appendix D, the true optimal solution is presented in the first column and the methods total cost and percentage deviation from the true optimal solution. In Table 15, a summary of the total costs for all products is presented. We see that the WW forecast solution suggested a replenishment policy closest to the true optimal solution, with a deviation of 1.02 %.

	Total cost	% deviation from optimal
True optimal	kr 2 893 728,47	
WW - forecast	kr 2 923 471,19	1,02 %
SM - forecast	kr 2 968 824,53	2,53 %
PPB - forecast	kr 3 264 979,59	11,37 %
LUC - forecast	kr 3 034 961,84	4,65 %

Table 15. Comparing lot-sizing method against true optimal solution.

6. Discussion

In this section, the results that were presented in the previous chapter will be discussed against the literature that were presented in chapter three.

6.2 Discussion RQ 1

The objectives of research question one, was to identify how lot-sizing methods could aid production planning at Ringnes, the applicability of the method, which method that performed best and if there was an incentive for Ringnes to increase or decrease the current lot-sizes.

A replenishment policy is as previously mentioned a key to inventory management and governs a company's approach to maintain a desired inventory level. In the previous section, several lot-sizing techniques has been presented and applied to a sample of products from Ringnes portfolio. The specific techniques that were applied includes the Silver Meal heuristics, part period balancing, least unit cost, and the Wagner Within algorithm.

To apply these techniques for replenishment at Ringnes, their approach was followed and calculated on basis of relevant forecast, setup costs and inventory cost. Of the heuristics that were applied, the SM heuristic suggested the best solution according to the performance measure of cost minimization. Compared to the other heuristics the SM suggested the best solution for 14 of the 20 SKUs'. For the remaining 6 SKUs', SM did not deviate more than 1 % from the best solution. The second-best heuristics was the LUC method. Over the two years planning horizon for all SKUs' in the sample, LUC resulted in an increase in total costs of 2.2 %. The deviation between the SM and the LUC is not substantial when they are compared over a two-year period.

The approach of the SM is to calculate an average cost per period, by including one setup cost and the inventory cost for stocking the following periods demand. The LUC method calculates an average cost on basis of the production quantity, where the setup cost and following inventory cost are divided on the quantity that is produced. The approach to divide the summed cost of either quantity or number of periods proved to be a better approach compared to the PPB method. The approach of the PPB method is to produce a lot-size in the period where the inventory cost of stocking the following periods demand is as close as possible to the setup cost. The PBB approach did rarely suggested two consecutive periods of production. Therefore, the PPB method suggested the fewest number of setups during the planning horizons. This resulted in higher level of inventories over the planning horizon and thus resulted in highest total cost compared to the other methods.

To solve the lot-sizing problem to optimality, the WW algorithm was applied. The input was the same as with the heuristics to provide a basis for comparison of the heuristics and the WW algorithm. The results in this research indicated that the WW algorithm achieved an optimal replenishment policy compared to the heuristics. As the WW algorithm presented a solution that found the best result for all the products. Total cost minimization by application of the WW algorithm compared to the best heuristics was NOK 41 997.8, in percentage a reduction of 1.4 (see Table 7 in result section).

In the literature review, it was mentioned that a lot-sizing method can be viewed as a decision system that increases the rationality of the decision maker. The approach of the WW algorithm does indeed increase the rationality of the decision maker, because the algorithm calculates all possible solutions for the replenishment policy of a finite problem. The heuristic methods are myopic, and calculate the problem from period to period, without assessing the entire planning horizon. Because of the condition for the WW algorithm, it is a prerequisite that the data is both available and known for the whole planning horizon. This is not the case for Ringnes, as the demand are variable and can easily change for the periods. Lot-size decisions are made by assessing forecast for a short time ahead. Normally, with a time horizon that range from one week to one month. Because of this criterion, the myopic heuristic can be favourable for application to production planning at Ringnes.

To study the lot-sizing methods against current practice by the performance measure cost minimization is not appropriate because the lot-sizes that are used by Ringnes deviates from the forecast. The current replenishment policy was presented in Table 2, at page 14. The inventory levels in the Table is misguiding from the reality. The inventory level is calculated by subtracting the forecast from the production quantities. The production quantities follow the demand, and as the forecast is higher than the demand, the inventory levels increase. This makes total cost of current practice misguiding and the basis for comparison is small. However, we can study the average lot-sizes and number of setup from the true optimal solution found in Chapter 5.7 with current practice.

Material	Current Ringnes		True optimal		Ringens vs true optimal	
	Number of setups	Average lot size	Number of setups	Average lot size	Number of setups	Average lot size
A	42	96 533	62	65 719	20	-30 815
B	20	31 046	26	25 505	6	-5 542
C	58	81 447	51	92 626	-7	11 179
D	96	807 903	98	791 415	2	-16 488
E	53	155 004	43	173 027	-10	18 024
F	64	59 607	50	75 535	-14	15 928
G	62	201 400	53	236 432	-9	35 031
H	93	417 866	97	400 635	4	-17 232
I	59	76 344	54	83 413	-5	7 069
J	65	159 171	84	123 168	19	-36 003
K	49	98 506	47	102 697	-2	4 192
L	28	41 996	28	42 737	0	741
M	18	28 160	18	26 060	0	-2 100
N	32	50 838	32	50 838	0	0
O	30	34 330	29	35 938	-1	1 609
P	47	87 926	50	79 028	3	-8 898
Q	34	42 302	35	41 544	1	-758
R	44	104 896	48	95 810	4	-9 086
S	23	27 122	27	50 866	4	23 744
T	21	31 433	24	57 225	3	25 792

Table 16. Comparing current practice at Ringnes with true optimal.

In Table 16, the number of setups and average lot-size from the true optimal solution is compared against the same for current practice at Ringnes. Naturally, the average lot-sizes are correlated to the number of setups, and as the for fewer setups over the planning horizon the average lot-size is larger. For some product, the true optimal solution indicates that Ringnes should increase the number of setups and reduce lot-sizes over the planning horizon. Especially, for products A and J the optimal solution indicate that Ringnes should reduce the average lot-size and increase number of setups over the planning horizon. For products E, F and G, the true optimal solution indicates that Ringnes should reduce number of setups, and increase the lot-sizes. It is interesting to see product N, where current practice at Ringnes is identical with the optimal solution.

6.3 Discussion RQ 2

The objectives of research question two was to study how robust the replenishment polices is to uncertainty in demand. The robustness of the replenishment policies is in this thesis measured by how the lot-sizes calculated on the basis of the forecast performed with estimated demand. The demand was estimated by the approach described in section 4.4.5. Although the estimation may be slightly imprecise, the forecast errors were decisive for the performance of the lot-sizing method.

The forecasts were evaluated by the measures of mean error, MAD and MAPE. The results of the forecast evaluation (Table 12), showed large deviation between the forecasts and the demand. Because the data is over a two-year period it is natural that there is deviation. As stated in the literature, forecasts are more accurate for nearer periods. The average MAD error of 37 294 L, shows that the deviation is large, and impacts production planning. However, due to the variety of SKU's there are some SKU's that create large impact on the forecast estimate. Especially, the volumes related to SKU's D and H are significant higher compared to the other in the sample. To eliminate the impact from the volume of the SKU's, the MAPE error presents an average percentage deviation between the forecast and the demand. The average MAPE for the whole sample was 57.92 %. That indicates that the forecast deviates above 50 percentage from the actual demand each week over the horizon. In Figure 16, a graph that illustrated the relationship between the forecast and the estimated demand is presented. The graph is collected from the product that had the highest observed MAPE, respectively product G. As we see from the Figure 16, to some extent, the forecast follows the curve of the demand. However, some deviations result in large impact on the forecast evaluation.

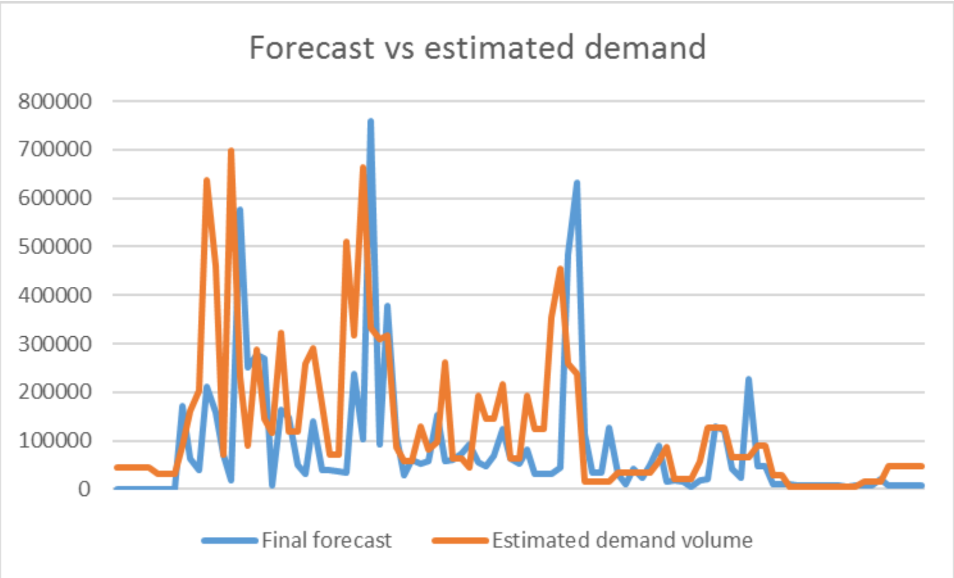

Figure 16. Forecast vs estimated demand for product G.

First, a stock out occurs when the inventory is not capable of fulfilling a customer order or request. Ringnes customers are mostly retailers. For each request from a retailer that Ringnes does not have on stock, the SSL KPI are altered. The target for the SSL for production line 207 is 98.5 %. That includes, that for all requested volume, Ringnes shall have the available stock to fulfil 98.5 % of the volume. In Table 14, the SSL achieved from each lot-sizing method was presented. None of the method was able to achieve a SSL close to the target at 98.5 %.

By stock out the overall performance of Ringnes is altered. Stock out reduce the reliability of Ringnes over the customers, and reduce the service towards the customer. Stock outs also hurt profitability for Ringnes as sales are lost. The replenishment policy should assist the company to avoid stock outs, and to maintain a high service level.

As presented in the Chapter 5, mismatch between the supply and demand resulted in increasing inventory levels. Because the lot-sizing methods suggested lot-sizes in exact quantities following the input to the calculation (forecast), the forecast error altered the initial solution. The computational results indicate that the lot-sizing methods that performed best in the initial solution, had the largest amount of stock outs when the lot-sizes was used for the estimated demand, respectively the SM and WW. Although all the methods had large number of stock outs, the method that had the lowest amount of stock outs was the PPB method. Because the PPB method suggest the lowest number of setups and thus had the largest inventory level during the planning horizon, the method was best suited to cope with changes in demand. However, the PPB method was the most expensive, and presented the poorest solution to the lot-sizing problem.

The approach of every lot-sizing methods is to satisfy the input demand without any inventories at the end of the planning horizon, where the lot-sizes are adapted to the precise input. For Ringnes to maintain a service level of 98.5 %, we need to study the which functions the inventory serve. From Chapter 3.5.3, we remember the cycle and safety stocks. The lot-sizes maintains the cycle inventory and the safety stock is used as a buffer when the demand exceeds the supply. For the replenishment policy at Ringnes to maintain a high service level towards the customer, a safety stock need to be kept to protect against forecast error and other unanticipated events that may alter the service level.

6.4 Discussion RQ 3

The objectives of research question three was to provide an assessment of the factors that have an impact on the replenishment policies, where the factors related to forecasting, setup and inventory cost were emphasized.

The sensitivity analysis provided basis to discuss the factor that have the largest impact on the replenishment policy. The result from the analysis indicates that the setup cost has the most significant impact on the total cost of the solution from the replenishment policy. By increasing or reducing the setup cost of 2 %, the total cost of the solution changed with 1.12 %. By increasing or reducing the inventory cost by 2 % the total cost of the solution changed with 0.88 %.

The setup cost for the different products was in this thesis measured by mapping the setup average time for the respective type of soda and the type of packaging. Total setup time was calculated by merging the two parts for each product. In practice, these costs are sequence dependent. This includes that the time used for the setup is dependent on the product that were prior produced. For example, in a sequence where two products have the same packaging, the setup of packaging would not occur. This change in setup cost dependent of the preceding product has influence on the setup cost, and further on the replenishment policy.

As the setup cost parameter has the largest impact on the performance of the replenishment policy, Ringnes may take initiatives to reduce the setup cost. As mentioned, the setup costs are sequence dependent, and a measure to reduce the cost may be to convert internal setups to external setups. This is an approach from the SMED method that was presented in the literature review. To convert internal setups to external setups, the total setup time could be reduced, which will aid cost minimization for Ringnes.

As previously mentioned, the forecast accuracy was decisive for the performance of the replenishment policies. The forecast accuracy was discussed in section for RQ 2. The optimal solution that was identified by the WW algorithm was altered when we tested the solution against estimated real demand, as the WW solution resulted in large stock outs (see Table 14). The lot-sizing methods are therefore completely dependent on accurate input parameters, which includes demand data, inventory cost and setup cost. If the data is imprecise as were tested with the estimated demand, the total cost of the solution increases and the service level decreases.

The importance of the accurate replenishment policy is governed by the industry that Ringnes operate in. In the FMCG industry the products are perishable and by increasing the level of inventory that resulted from the lack of forecast accuracy hurt the performance. Since the product on inventory does not have any value if their best before date is passed. The inventory that pass their best before date, is scrapped. Because of this, the inventory levels in Ringnes need to be adjusted in regard to the changing demand. This adjustment are managed by production quantities that account for changes in demand.

7. Conclusion and recommendations

7.1 Conclusion of research questions

1. ***Which replenishment policies for solving the lot-sizing problem are applicable and who provides the optimal solution for production planning at Ringnes?***

The results from this research showed that for the planning horizons where we know the input for the whole planning horizon, the WW algorithm provides an optimal solution for the problem. The WW increases the rationality of a decision maker, by assessing all possible solution for the lot-sizing problem for all periods. However, for shorter planning horizon as in operational planning at Ringnes, myopic heuristics as the SM and LUC may be favourable. Because the prerequisite of the WW algorithm to know the data for the whole planning horizon it may not be applicable.

To study current practice at Ringnes, the true optimal solution to the lot-sizing problem with estimated demand was estimated. The results did not indicate a clear coherence for Ringnes to increase or reduce the lot-sizes. However, for some product, respectively products A and J, the result showed that Ringnes should reduce the average lot-sizes. For product E, F, and G, the result indicated that Ringnes should increase the lot-sizes.

2. ***How robust are the solutions from the conceptual framework to uncertainty in demand?***

The lot-sizing methods is in its self not robust when it comes to uncertainty in demand, because they suggest lot-sizes exactly to satisfy the input demand. By measuring their respective SSL performance measure, none of the lot-sizing methods met the target value of 98.5 %. Stock outs hurt performance and we thrive to avoid stock outs. The high target value of Ringnes indicates a focus of keeping service towards the customers high.

The robustness of a replenishment policy is achieved by reducing forecast errors, which enable production lots to be closer to actual demand or using the safety stock as buffer. The safety stock is held to account for uncertainty in demand and unanticipated events, which may alter the service level.

3. ***Which factors have impact on replenishment policies at Ringnes?***

The most important factor that have impact on the performance of the replenishment policy is the accuracy of the forecast. Because the lot-sizing methods use this forecast as input to the calculation, and the lot-sizes is determined by following the forecast value in production. Forecasts is the key in production planning, and if we could remove the uncertainty related to the demand, we could optimize the lot-sizing problem with no risk of stock outs or increased inventory levels. If we with certainty could determine the demand, the optimal solution is mutually dependent of the accuracy of the inventory and setup cost parameter.

From the sensitivity analysis, the setup cost parameter showed the largest impact on cost minimization. An approach that might aid cost minimization for the setup cost is the SMED method. By converting internal setups to external setups, setup cost is reduced.

7.2 Recommendations

To recommend a lot-sizing method for application, the WW algorithm provides optimal solution for finite planning horizon where all data is known. For shorter horizon, the SM heuristic provided the best solution of the myopic heuristics. For production planning at Ringnes, SM may be an aid to balance the setup and inventory cost when deciding production quantities.

This study showed that forecast accuracy has large impact on performance of lot-sizing methods. The forecast evaluation indicated large deviation between the forecast values and the actual demand. Therefore, evaluation of forecasting techniques is recommended. By decreasing the forecast error, planning may be performed with less uncertainty and in larger degree optimized.

Another factor that had impact on replenishment policies was setup cost. To reduce cost of setups, the SMED method can be useful by converting internal setups to external setups. By converting internal setups to external, will enable higher productivity at the production line and higher profitability.

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8. Appendices

Appendix A: Mapping of setup costs

Material	Soda setup (min)	Package setup (min)	Total (min)	Cost per setup
	Soda setup	Pack setup		
A	23,41	20,37	43,77	kr 1 298,14
	Soda setup	Pack setup		
B	23,41	13,83	37,23	kr 1 104,21
	Soda setup	Pack setup		
C	44,16	20,37	64,52	kr 1 913,58
	Soda setup	Pack setup		
D	94,39	21,06	115,45	kr 3 423,95
	Soda setup	Pack setup		
E	94,38	20,37	114,75	kr 3 403,04
	Soda setup	Pack setup		
F	44,16	13,83	57,99	kr 1 719,65
	Soda setup	Pack setup		
G	94,38	19,20	113,58	kr 3 368,37
	Soda setup	Pack setup		
H	94,38	13,83	108,21	kr 3 209,11
	Soda setup	Pack setup		
I	38,07	20,37	58,44	kr 1 733,05
	Soda setup	Pack setup		
J	38,07	13,83	51,90	kr 1 539,12
	Soda setup	Pack setup		
K	65,32	20,37	85,68	kr 2 541,10
	Soda setup	Pack setup		
L	36,76	20,37	57,13	kr 1 694,30
	Soda setup	Pack setup		
M	36,76	13,83	50,59	kr 1 500,37
	Soda setup	Pack setup		
N	35,20	20,37	55,57	kr 1 647,98
	Soda setup	Pack setup		
O	35,20	13,83	49,03	kr 1 454,05
	Soda setup	Pack setup		
P	35,40	20,37	55,77	kr 1 653,83
	Soda setup	Pack setup		
Q	35,40	13,83	49,23	kr 1 459,90
	Soda setup	Pack setup		
R	54,58	20,37	74,95	kr 2 222,72
	Soda setup	Pack setup		
S	54,58	13,83	68,41	kr 2 028,79
	Soda setup	Pack setup		
T	65,32	13,83	79,14	kr 2 347,17

Appendix B: Replenishment policies

8.2.1 Silver Meal

SilverMeal						
Material	**Number of setups**	**Setup cost**	**Total inventory**	**Holding cost**	**Total cost**	**Average lot size**
A	72	kr 1 298,14	1 151 219	0,027	kr 124 037,41	65 040
B	26	kr 1 104,21	807 237	0,027	kr 50 146,07	26 195
C	50	kr 1 913,58	2 837 644	0,027	kr 171 034,12	115 600
D	99	kr 3 423,95	0	0,027	kr 338 970,62	812 129
E	46	kr 3 403,04	3 353 544	0,027	kr 245 595,26	168 636
F	49	kr 1 719,65	1 921 503	0,027	kr 135 289,26	76 211
G	33	kr 3 368,37	3 384 091	0,027	kr 201 022,56	251 340
H	99	kr 3 209,11	0	0,027	kr 317 702,12	393 854
I	56	kr 1 733,05	2 177 231	0,027	kr 154 868,63	95 352
J	99	kr 1 539,12	0	0,027	kr 152 373,16	112 654
K	49	kr 2 541,10	2 849 000	0,027	kr 200 170,53	111 443
L	32	kr 1 694,30	1 449 069	0,027	kr 92 698,54	43 700
M	21	kr 1 500,37	955 468	0,027	kr 56 880,78	24 852
N	35	kr 1 647,98	1 758 508	0,027	kr 104 377,37	53 269
O	30	kr 1 454,05	1 151 909	0,027	kr 74 210,94	36 869
P	54	kr 1 653,83	2 025 774	0,027	kr 143 102,60	86 241
Q	35	kr 1 459,90	1 293 527	0,027	kr 85 446,92	41 597
R	49	kr 2 222,72	2 696 763	0,027	kr 180 527,20	108 651
S	19	kr 2 028,79	1 022 994	0,027	kr 65 713,10	26 439
T	18	kr 2 347,17	1 220 398	0,027	kr 74 657,33	34 020

8.2.2 Part Period Balancing

Part Period Balancing						
Material ID	Number of setups	Setup cost	Total inventory	Holding cost	Total cost	Average lot size
A	49	kr 1 298,14	2 425 706	0,027	kr 128 024,89	95 569
B	17	kr 1 104,21	1 720 940	0,027	kr 64 472,07	40 064
C	49	kr 1 913,58	3 046 863	0,027	kr 174 676,49	117 959
D	99	kr 3 423,95	0	0,027	kr 338 970,62	812 129
E	32	kr 3 403,04	6 119 169	0,027	kr 271 395,34	242 414
F	36	kr 1 719,65	3 302 639	0,027	kr 149 610,69	103 731
G	31	kr 3 368,37	4 771 854	0,027	kr 231 138,65	267 555
H	99	kr 3 209,11	0	0,027	kr 317 702,12	393 854
I	46	kr 1 733,05	3 002 466	0,027	kr 159 452,67	116 081
J	58	kr 1 539,12	3 953 558	0,027	kr 194 258,05	192 289
K	36	kr 2 541,10	4 780 608	0,027	kr 218 431,20	151 686
L	19	kr 1 694,30	2 963 259	0,027	kr 110 882,75	73 599
M	13	kr 1 500,37	2 008 009	0,027	kr 72 828,62	40 146
N	24	kr 1 647,98	2 874 771	0,027	kr 115 892,58	77 684
O	19	kr 1 454,05	2 251 651	0,027	kr 87 420,70	58 215
P	43	kr 1 653,83	3 040 589	0,027	kr 151 859,40	108 302
Q	23	kr 1 459,90	2 498 642	0,027	kr 99 930,58	63 299
R	38	kr 2 222,72	4 380 644	0,027	kr 200 793,69	140 103
S	10	kr 2 028,79	2 531 916	0,027	kr 87 524,30	50 234
T	14	kr 2 347,17	2 140 941	0,027	kr 89 714,19	43 740

8.2.3 Least Unit Cost

Least Unit Cost						
Material ID	Number of setups	Setup cost	Total inventory	Holding cost	Total cost	Average lot size
A	72	kr 1 298,14	1 150 851	0,027	kr 124 027,65	65 040
B	28	kr 1 104,21	916 833	0,027	kr 55 264,87	24 324
C	51	kr 1 913,58	2 810 097	0,027	kr 172 216,19	113 333
D	99	kr 3 423,95	0	0,027	kr 338 970,62	812 129
E	49	kr 3 403,04	3 083 983	0,027	kr 248 646,03	158 311
F	51	kr 1 719,65	1 771 634	0,027	kr 134 748,71	73 222
G	41	kr 3 368,37	4 225 794	0,027	kr 250 321,41	202 298
H	99	kr 3 209,11	0	0,027	kr 317 702,12	393 854
I	55	kr 1 733,05	2 302 915	0,027	kr 156 473,18	97 086
J	99	kr 1 539,12	0	0,027	kr 152 373,16	112 654
K	50	kr 2 541,10	2 713 596	0,027	kr 199 115,90	109 214
L	34	kr 1 694,30	1 310 175	0,027	kr 92 398,74	41 129
M	21	kr 1 500,37	968 337	0,027	kr 57 222,54	24 852
N	34	kr 1 647,98	1 829 676	0,027	kr 104 619,29	54 836
O	30	kr 1 454,05	1 303 642	0,027	kr 78 240,30	36 869
P	53	kr 1 653,83	2 096 623	0,027	kr 143 330,21	87 868
Q	34	kr 1 459,90	1 407 924	0,027	kr 87 024,90	42 820
R	50	kr 2 222,72	2 573 379	0,027	kr 179 473,37	106 478
S	18	kr 2 028,79	1 083 688	0,027	kr 65 296,07	27 908
T	18	kr 2 347,17	1 327 315	0,027	kr 77 496,57	34 020

8.2.4 Wagner Within

Wagner Within						
Material ID	Number of setups	Setup cost	Total inventory	Holding cost	Total cost	Average lot size
A	73	kr 1 298,14	1 063 046	0,027	kr 122 994,06	64 149
B	26	kr 1 104,21	789 238	0,027	kr 49 668,10	26 195
C	53	kr 1 913,58	2 570 855	0,027	kr 169 690,14	109 056
D	99	kr 3 423,95	0	0,027	kr 338 970,62	812 129
E	46	kr 3 403,04	3 037 624	0,027	kr 237 205,82	168 636
F	50	kr 1 719,65	1 819 559	0,027	kr 134 301,74	74 686
G	36	kr 3 368,37	2 433 161	0,027	kr 185 875,19	230 395
H	99	kr 3 209,11	0	0,027	kr 317 702,12	393 854
I	57	kr 1 733,05	2 073 051	0,027	kr 153 835,12	93 679
J	99	kr 1 539,12	0	0,027	kr 152 373,16	112 654
K	49	kr 2 541,10	2 730 941	0,027	kr 197 035,41	111 443
L	32	kr 1 694,30	1 406 693	0,027	kr 91 573,22	43 700
M	21	kr 1 500,37	927 163	0,027	kr 56 129,13	24 852
N	37	kr 1 647,98	1 519 849	0,027	kr 101 335,59	50 390
O	30	kr 1 454,05	1 100 815	0,027	kr 72 854,12	36 869
P	54	kr 1 653,83	1 985 683	0,027	kr 142 037,97	86 241
Q	34	kr 1 459,90	1 292 530	0,027	kr 83 960,55	42 820
R	51	kr 2 222,72	2 468 974	0,027	kr 178 923,56	104 390
S	18	kr 2 028,79	1 016 665	0,027	kr 63 516,23	27 908
T	17	kr 2 347,17	1 264 802	0,027	kr 73 489,33	36 021

Appendix C. Performance of replenishment polices to estimated demand

8.3.1 Silver Meal

Performance of SM with estimated real demand	Number of setups	Setup cost	Total inventory	Holding cost	Total cost	Stock outs
A	72	kr 1 298,14	34 541 457,70	0,03	kr 1 010 733,75	-157 715
B	26	kr 1 104,21	8 227 703,29	0,03	kr 247 200,67	-66 747
C	50	kr 1 913,58	57 810 282,90	0,03	kr 1 630 863,10	0
D	99	kr 3 423,95	344 558 038,50	0,03	kr 9 488 900,75	-65 134
E	46	kr 3 403,04	49 922 328,10	0,03	kr 1 482 255,19	-776 502
F	49	kr 1 719,65	6 689 470,50	0,03	kr 261 905,29	-100 591
G	33	kr 3 368,37	33 579 560,30	0,03	kr 1 002 880,03	-4 667 718
H	99	kr 3 209,11	70 085 262,50	0,03	kr 2 178 855,21	-1 461 746
I	56	kr 1 733,05	36 605 235,20	0,03	kr 1 069 123,41	0
J	99	kr 1 539,12	72 245 676,20	0,03	kr 2 070 897,23	-259 954
K	49	kr 2 541,10	45 153 974,50	0,03	kr 1 323 602,64	-166 573
L	32	kr 1 694,30	13 669 080,90	0,03	kr 417 207,74	-38 526
M	21	kr 1 500,37	4 518 356,53	0,03	kr 151 495,27	-2 972
N	35	kr 1 647,98	15 145 690,20	0,03	kr 459 881,42	-41 692
O	30	kr 1 454,05	8 160 616,78	0,03	kr 260 331,08	-27 070
P	54	kr 1 653,83	39 448 402,15	0,03	kr 1 136 881,30	0
Q	35	kr 1 459,90	7 421 605,50	0,03	kr 248 181,45	-11 752
R	49	kr 2 222,72	42 685 023,60	0,03	kr 1 242 437,67	-72 314
S	19	kr 2 028,79	- 403 430,70	0,03	kr 27 833,60	-871 050
T	18	kr 2 347,17	- 59 911,00	0,03	kr 40 658,01	-761 033

8.3.2 Part Period Balancing

Performance of PPB with estimated real demand	Number of setups	Setup cost	Total inventory	Holding cost	Total cost	Stock outs
A	49	kr 1 298,14	37 423 385,00	0,03	kr 1 057 407,69	-175 598
B	17	kr 1 104,21	9 114 879,79	0,03	kr 260 822,25	-66 747
C	49	kr 1 913,58	58 019 502,40	0,03	kr 1 634 505,46	0
D	99	kr 3 423,95	344 558 038,50	0,03	kr 9 488 900,75	-65 134
E	32	kr 3 403,04	48 240 046,70	0,03	kr 1 389 938,65	-725 871
F	36	kr 1 719,65	8 119 674,50	0,03	kr 277 529,75	-100 591
G	31	kr 3 368,37	34 669 863,90	0,03	kr 1 025 096,91	-4 667 718
H	99	kr 3 209,11	70 085 262,50	0,03	kr 2 178 855,21	-1 461 746
I	46	kr 1 733,05	37 430 470,60	0,03	kr 1 073 707,45	0
J	58	kr 1 539,12	72 750 772,50	0,03	kr 2 021 206,31	-224 554
K	36	kr 2 541,10	42 891 657,50	0,03	kr 1 230 491,29	-122 372
L	19	kr 1 694,30	14 247 158,20	0,03	kr 410 532,96	-29 313
M	13	kr 1 500,37	5 287 516,60	0,03	kr 159 917,77	0
N	24	kr 1 647,98	15 077 630,30	0,03	kr 439 946,30	-29 807
O	19	kr 1 454,05	9 386 265,67	0,03	kr 276 884,37	-28 933
P	43	kr 1 653,83	40 463 217,15	0,03	kr 1 145 638,09	0
Q	23	kr 1 459,90	8 605 503,70	0,03	kr 262 101,69	-7 020
R	38	kr 2 222,72	44 341 481,50	0,03	kr 1 261 975,94	-72 314
S	10	kr 2 028,79	- 195 175,80	0,03	kr 15 104,86	-871 050
T	14	kr 2 347,17	301 160,50	0,03	kr 40 857,80	-761 033

8.3.3 Least unit cost

Performance of LUC with estimated real demand	Number of setups	Setup cost	Total inventory	Holding cost	Total cost	Stock outs
A	72	kr 1 298,14	34 541 090,10	0,03	kr 1 010 723,99	-157 715
B	28	kr 1 104,21	7 625 550,89	0,03	kr 233 418,60	-59 689
C	51	kr 1 913,58	57 782 736,50	0,03	kr 1 632 045,16	0
D	99	kr 3 423,95	344 558 038,50	0,03	kr 9 488 900,75	-65 134
E	49	kr 3 403,04	49 482 992,60	0,03	kr 1 480 797,52	-776 502
F	51	kr 1 719,65	6 746 577,00	0,03	kr 266 861,08	-101 427
G	41	kr 3 368,37	31 367 291,70	0,03	kr 971 078,95	-4 667 718
H	99	kr 3 209,11	70 085 262,50	0,03	kr 2 178 855,21	-1 461 746
I	55	kr 1 733,05	36 730 918,80	0,03	kr 1 070 727,96	0
J	99	kr 1 539,12	72 245 676,20	0,03	kr 2 070 897,23	-259 954
K	50	kr 2 541,10	45 018 570,80	0,03	kr 1 322 548,02	-166 573
L	34	kr 1 694,30	13 619 947,70	0,03	kr 419 291,59	-39 263
M	21	kr 1 500,37	4 247 845,30	0,03	kr 144 311,70	0
N	34	kr 1 647,98	15 216 857,80	0,03	kr 460 123,34	-41 692
O	30	kr 1 454,05	8 312 349,98	0,03	kr 264 360,44	-27 070
P	53	kr 1 653,83	39 519 251,35	0,03	kr 1 137 108,90	0
Q	34	kr 1 459,90	7 536 002,60	0,03	kr 249 759,43	-11 752
R	50	kr 2 222,72	42 561 638,90	0,03	kr 1 241 383,84	-72 314
S	18	kr 2 028,79	- 569 157,60	0,03	kr 21 403,85	-871 050
T	18	kr 2 347,17	- 118 269,90	0,03	kr 39 108,25	-761 033

8.3.4 Wagner Within

Performance of WW with estimated real demand	Number of setups	Setup cost	Total inventory	Holding cost	Total cost	Stock outs
A	73	kr 1 298,14	36 129 066,80	0,03	kr 1 054 191,74	-175 598
B	26	kr 1 104,21	8 209 704,29	0,03	kr 246 722,70	-66 747
C	53	kr 1 913,58	57 543 494,40	0,03	kr 1 629 519,11	0
D	99	kr 3 423,95	344 558 038,50	0,03	kr 9 488 900,75	-65 134
E	46	kr 3 403,04	49 560 360,40	0,03	kr 1 472 642,93	-776 502
F	50	kr 1 719,65	6 587 527,00	0,03	kr 260 917,77	-100 591
G	36	kr 3 368,37	32 764 766,30	0,03	kr 991 347,82	-4 667 718
H	99	kr 3 209,11	70 085 262,50	0,03	kr 2 178 855,21	-1 461 746
I	57	kr 1 733,05	36 501 054,90	0,03	kr 1 068 089,90	0
J	99	kr 1 539,12	72 245 676,20	0,03	kr 2 070 897,23	-259 954
K	49	kr 2 541,10	45 035 915,90	0,03	kr 1 320 467,53	-166 573
L	32	kr 1 694,30	13 716 465,40	0,03	kr 418 466,07	-39 263
M	22	kr 1 500,37	4 435 439,23	0,03	kr 150 793,73	-2 972
N	37	kr 1 647,98	14 907 031,00	0,03	kr 456 839,65	-41 692
O	30	kr 1 454,05	8 103 919,52	0,03	kr 258 825,45	-27 004
P	54	kr 1 653,83	39 408 311,25	0,03	kr 1 135 816,66	0
Q	34	kr 1 459,90	7 455 868,50	0,03	kr 247 631,42	-14 103
R	51	kr 2 222,72	42 457 234,20	0,03	kr 1 240 834,03	-72 314
S	18	kr 2 028,79	- 390 487,40	0,03	kr 26 148,53	-871 050
T	17	kr 2 347,17	- 7 844,50	0,03	kr 39 693,50	-761 033

Appendix D. Comparing lot-sizing methods to true optimal solution

Material	True optimal	WW - forecast	% deviation	SM - forecast	% deviation	PPB - forecast	% deviation	LUC - forecast	% deviation
A	kr 110 500,6	kr 122 994,1	10 %	kr 124 037,4	11 %	kr 128 024,9	14 %	kr 124 027,6	11 %
B	kr 51 540,2	kr 49 668,1	-4 %	kr 50 146,1	-3 %	kr 64 472,1	20 %	kr 55 264,9	7 %
C	kr 151 218,6	kr 169 690,1	11 %	kr 171 034,1	12 %	kr 174 676,5	13 %	kr 172 216,2	12 %
D	kr 337 672,8	kr 338 970,6	0 %	kr 338 970,6	0 %	kr 338 970,6	0 %	kr 338 970,6	0 %
E	kr 222 371,6	kr 237 205,8	6 %	kr 245 595,3	9 %	kr 271 395,3	18 %	kr 248 646,0	11 %
F	kr 130 548,5	kr 134 301,7	3 %	kr 135 289,3	4 %	kr 149 610,7	13 %	kr 134 748,7	3 %
G	kr 244 390,6	kr 185 875,2	-31 %	kr 201 022,6	-22 %	kr 231 138,6	-6 %	kr 250 321,4	2 %
H	kr 315 230,3	kr 317 702,1	1 %	kr 317 702,1	1 %	kr 317 702,1	1 %	kr 317 702,1	1 %
I	kr 137 853,4	kr 153 835,1	10 %	kr 154 868,6	11 %	kr 159 452,7	14 %	kr 156 473,2	12 %
J	kr 147 063,3	kr 152 373,2	3 %	kr 152 373,2	3 %	kr 194 258,0	24 %	kr 152 373,2	3 %
K	kr 180 361,5	kr 197 035,4	8 %	kr 200 170,5	10 %	kr 218 431,2	17 %	kr 199 115,9	9 %
L	kr 81 478,6	kr 91 573,2	11 %	kr 92 698,5	12 %	kr 110 882,8	27 %	kr 92 398,7	12 %
M	kr 51 349,6	kr 56 129,1	9 %	kr 56 880,8	10 %	kr 72 828,6	29 %	kr 57 222,5	10 %
N	kr 91 366,2	kr 101 335,6	10 %	kr 104 377,4	12 %	kr 115 892,6	21 %	kr 104 619,3	13 %
O	kr 72 258,9	kr 72 854,1	1 %	kr 74 210,9	3 %	kr 87 420,7	17 %	kr 78 240,3	8 %
P	kr 126 976,4	kr 142 038,0	11 %	kr 143 102,6	11 %	kr 151 859,4	16 %	kr 143 330,2	11 %
Q	kr 82 458,1	kr 83 960,6	2 %	kr 85 446,9	3 %	kr 99 930,6	17 %	kr 87 024,9	5 %
R	kr 163 752,6	kr 178 923,6	8 %	kr 180 527,2	9 %	kr 200 793,7	18 %	kr 179 473,4	9 %
S	kr 93 457,0	kr 63 516,2	-47 %	kr 65 713,1	-42 %	kr 87 524,3	-7 %	kr 65 296,1	-43 %
T	kr 101 879,6	kr 73 489,3	-39 %	kr 74 657,3	-36 %	kr 89 714,2	-14 %	kr 77 496,6	-31 %
Total	kr 2 893 728,5	kr 2 923 471,2	1,02 %	kr 2 968 824,5	3 %	kr 3 264 979,6	11 %	kr 3 034 961,8	5 %